Analysis of investment policies for the Port of Lisbon with a System Dynamics model

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Abstract
A System Dynamics model is developed in order to study management policies that could lead to an increase in throughput in Port of Lisbon. Additional objectives include assessing port profits and investments associated with each management policy, as well as their implications to the regional economy. The impact of the port activity on regional employment, trade and GDP is used to measure the beneficial effects associated with each policy. A check of whether the results obtained from the System Dynamics model might be improved by using econometric techniques ruled against the latter.

Keywords: System Dynamics, port activity, management policies, regional economy, econometric techniques

1. Introduction

1.1. Background
The Port of Lisbon is the leader maritime port in Portugal in terms of container throughput, and ranks third in terms of total cargo throughput, behind ports of Sines and Leixões.

The influence of Port of Lisbon is primarily felt in the region of Lisbon, where the origin and destination of some 70% of its cargo is located. However, the Port of Lisbon extends its influence to outside the region of Lisbon, moving cargo to or from regions such as Azores.

A noticeable decrease in throughput growth rate in Port of Lisbon was observed in the years between 1995 and 2010 (see figure 1). Between 2005 and 2006, port throughput decreased and afterwards began to oscillate around a mean value of about 12 250 tons.
1.2. Study objectives and research questions

The objective of this study is to assess management policies that could lead to an increase in Port of Lisbon’s throughput and profit. The research questions are:

*Why has throughput growth rate decreased in Port of Lisbon over the years between 1995 and 2010, and particularly since 2005?*

*What are the most effective and efficient management policies to increase Port of Lisbon’s throughput and its profitability?*

1.3. System Dynamics and port economics

System Dynamics methodology constitutes an effective approach for studying the impact of port management policies because it allows the direct testing of several alternatives, it allows the incorporation of experts opinion in the model itself, and a System Dynamics model is easily modified in order to account for changes in the socioeconomic environment (e.g., an unexpected change in GDP, employment, etc).

For these reasons, System Dynamics appears to be an appropriate tool to answer the research questions posed in the previous section.

The System Dynamics approach has been used by several authors to study maritime transport industry and to identify management policies affecting port throughput and profitability, namely Castillo et al. (2004), Park et al. (2010), Carlucci et al. (2009), and Feng et al. (2008).
1.4. Methodology

The approach followed in the course of this work is a combination of the Systems Thinking (ST) and System Dynamics (SD) approaches. A special emphasis was put on identifying the structure of port competitiveness through the use of archetypes (ST), which was required to build a simulation model, with its respective stocks and flows (SD). The approach followed can be presented as:

1. Defining the problem in terms of dynamic behaviours, representing relevant variables as graphs over time;
2. Identify the structure responsible for those behaviours (generally with the use of archetypes);
3. Mapping independent stocks or accumulations (levels) in the system's structure and their inflows and outflows (rates);
4. Formulating a behavioural model capable of reproducing, by itself, the dynamic problem of concern (computer simulation);
5. Deriving understandings and applicable policy insights from the resulting model;

The translation of the Systems archetypes causal loop diagrams (ST) into the corresponding stock and flow diagrams (SD) followed the approach proposed by Bourguet-Diaz and Pérez-Salazar (2003).

1.5. Scope

Containerized and dry bulk are considered strategic cargoes for Port of Lisbon (CONSULMAR, 2007). Liquid bulk is not considered to be a strategic cargo for Port of Lisbon’s port authority. As such, it was used in the model as an external input. Break bulk cargo is also not a strategic cargo for that port, but due to its deep interrelation with containerized cargo, it was treated as an endogenous variable.

Table 1 - Model boundary.

<table>
<thead>
<tr>
<th>Endogenous</th>
<th>Exogenous</th>
</tr>
</thead>
<tbody>
<tr>
<td>○ Port capacity</td>
<td>○ Physical limits to port expansion</td>
</tr>
<tr>
<td>○ Containerized cargo throughput</td>
<td>○ Liquid bulk cargo throughput</td>
</tr>
<tr>
<td>○ Dry bulk cargo throughput</td>
<td></td>
</tr>
<tr>
<td>○ Break bulk cargo throughput</td>
<td></td>
</tr>
<tr>
<td>○ Port investments</td>
<td></td>
</tr>
<tr>
<td>○ Port prices</td>
<td></td>
</tr>
<tr>
<td>○ Regional GDP</td>
<td></td>
</tr>
<tr>
<td>○ Regional Trade</td>
<td></td>
</tr>
<tr>
<td>○ Service quality standards</td>
<td></td>
</tr>
</tbody>
</table>
Table 1 presents the model boundary. Physical limits to port expansion were considered as an exogenous parameter.

The time horizon for the model simulation spans from 1995 to 2010. The main criterion adopted for the choice of the time horizon was whether or not that same time horizon was sufficient for the dynamical behaviour of the variables under study to become clear. In other words, for the key variables to exhibit some behaviour typically associated with certain system archetypes. Also, it was not possible to obtain data prior to 1995 for the relevant variables.

2. Model construction

In this section, an example of the application of the proposed methodology is presented. Figure 2 shows the container throughput in Port of Lisbon as a graph over time. This allows the definition of the problem in terms of dynamic behavior, which constitutes the first step of the proposed methodology.

Figure 2 shows that the volume of containerized goods moving through the port of Lisbon had been steadily increasing since, at least, 1995. However, in 2004, the number of containers loaded and unloaded stopped increasing, even decreased slightly. Afterwards, annual container throughput began to oscillate around a mean value of slightly more than 500 thousand TEUs.

![Figure 2 - Container throughput at the Port of Lisbon [1000 TEUs] [source: APL (2012)].](image)

The decrease in container movement coincided with the decision of Mediterranean Shipping Company (MSC) to move the operation of its regular container line from port of Lisbon to port of Sines (APL, 2006). The general perception among port stakeholders
was that the installed capacity at the port of Lisbon was no longer able to satisfy the needs of that transportation agent because, as usage increased, port service quality began to degrade.

The behaviour over time of the container throughput seems to match the description of the growth and underinvestment archetype. In the growth and underinvestment archetype, growth reaches a limit that could be avoided or postponed if capacity investments were made (Senge, 1990). Instead, as a result of policies or delays in the system, demand (or performance) degrades, limiting further growth. This leads to further withholding of investments or even reductions in capacity, causing even worse performance.

This appears to be the case when it comes to investments in container terminals capacity at the port of Lisbon. Both the behaviour over time graph and data collected through informal interviews with some of the port actors seem to support this judgement.

![Figure 3 - Growth and underinvestment archetype for the container terminals at Port of Lisbon.](image)

Recently, the terminal previously used by MSC made efforts to increase its capacity. But the legal permission to start the necessary works has, to date, not yet been given, which is another typical feature of the growth and underinvestment archetype - the delay in building extra capacity. Figure 3 illustrates the growth and underinvestment archetype for a container terminal.
According to the proposed methodology, after the identification of the structure responsible for the observed behavior has been carried out with the use of archetypes, this structure must be translated into a System Dynamics format (i.e., a stock and flow diagram) in order to make it possible to run a simulation. The translation of the *growth and underinvestment* archetype for the container terminals causal loop diagram into a stock and flow formulation is presented in figure 4.

After the model is completed, simulation results were compared with historical data, in order to verify if the behavioural model is capable of reproducing, by itself, the dynamic problem of concern. Such comparison is made in figure 5.

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**Figure 4** - Stock and flow diagram for Port of Lisbon's container terminals ship-to-apron transfer capacity *growth and underinvestment* archetype.

**Figure 5** - Comparison between model results and historical data for containerized cargo port throughput.
3. Checking the System Dynamics model using econometric techniques

A check was made in order to determine if model results might be improved by using econometric techniques.

The dynamic hypothesis formulated by the System Dynamics model states that its structure of relationships is responsible for the behaviour observable in the data. This structure includes the feedback relationship between trade and port throughput. If this relationship is not present, including regional trade as an external input will allegedly improve the model's results.

The System Dynamics model was modified by introducing regional trade as an external variable (with values obtained from the econometric model) and dropping the feedback relation between port throughput and regional trade. The other model equations remained unchanged.

Figure 6 presents the historical data, the results obtained from the original System Dynamics model and the results obtained from the model modified with econometric techniques.

![Figure 6 - Comparison between historical data, System Dynamics model results and the results for the model modified with econometric techniques.](image)

4. Management policies analysis

The ability of a port to attract cargo depends essentially on two factors: port costs and the quality of the service provided. This section contains a review of management policies that could lead to an increase in cargo throughput, by changing port prices and
service quality (appreciated as functions of resource availability). In addition, the effect of deepening the access channels and berths will be assessed (changing depths of access channels and berths is also a way of changing port costs through economies of scale). Management variables will be changed one at a time by a 10% increase or decrease (depending on the variable) and its impact evaluated in terms of cargo throughput, port investments, port profits and regional employment. Evaluation consists of comparing model results to those obtained without introducing any management policy change (this scenario with no management policy changes is referred to as baseline).

The tested policies were:
1. Change in resources availability, through a decrease in the standard terminals capacity utilization;
2. Change in port prices;
3. Deepening port access channel and berths.

5. Results

Table 2 shows the impact of a 10% increase in resources availability for container, break bulk and dry bulk terminals.

<table>
<thead>
<tr>
<th>Impact on port throughput</th>
<th>Container terminals</th>
<th>Break bulk terminals</th>
<th>Dry bulk terminals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average difference to baseline scenario for the simulation period (1995-2010) [%]</td>
<td>3.27%</td>
<td>0.01%</td>
<td>0.08%</td>
</tr>
<tr>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>4.90%</td>
<td>0.03%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact on port profits</th>
<th>Container terminals</th>
<th>Break bulk terminals</th>
<th>Dry bulk terminals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average difference to baseline scenario for the simulation period (1995-2010) [%]</td>
<td>3.12%</td>
<td>0.04%</td>
<td>0.03%</td>
</tr>
<tr>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>5.53%</td>
<td>0.15%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact on port investments</th>
<th>Container terminals</th>
<th>Break bulk terminals</th>
<th>Dry bulk terminals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average difference to baseline scenario for the simulation period (1995-2010) [%]</td>
<td>35.99%</td>
<td>0.18%</td>
<td>0.38%</td>
</tr>
<tr>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>37.40%</td>
<td>0.00%</td>
<td>0.02%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact on regional employment</th>
<th>Container terminals</th>
<th>Break bulk terminals</th>
<th>Dry bulk terminals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average difference to baseline scenario for the simulation period (1995-2010) [%]</td>
<td>0.57%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>1.51%</td>
<td>0.01%</td>
<td>0.04%</td>
</tr>
</tbody>
</table>
Table 3 - Impact on port throughput of a 10% reduction in port prices

<table>
<thead>
<tr>
<th>Cargo Type</th>
<th>Storage Price Impact (%)</th>
<th>Port Authority Price Impact (%)</th>
<th>Average difference in port throughput to baseline scenario for the simulation period (1995-2010) [%]</th>
<th>Relative difference in port throughput to baseline scenario at the end of 2010 [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry bulk cargo</td>
<td>0.83%</td>
<td>1.75%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.74%</td>
<td>1.56%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Break bulk cargo</td>
<td>0.06%</td>
<td>0.15%</td>
<td>0.11%</td>
<td>0.20%</td>
</tr>
<tr>
<td></td>
<td>0.03%</td>
<td>0.05%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Containerized cargo</td>
<td>1.54%</td>
<td>3.14%</td>
<td>-0.33%</td>
<td>-0.51%</td>
</tr>
<tr>
<td></td>
<td>-0.19%</td>
<td>-0.30%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4 shows the impact of a 10% increase in access channel and berths depth.

Table 4 - Impact of a 10% increase in access channel and berths depth

<table>
<thead>
<tr>
<th>Impact on port throughput</th>
<th>Average difference to baseline scenario for the simulation period (1995-2010) [%]</th>
<th>3.21%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>6.46%</td>
</tr>
<tr>
<td>Impact on port profits</td>
<td>Average difference to baseline scenario for the simulation period (1995-2010) [%]</td>
<td>-0.40%</td>
</tr>
<tr>
<td></td>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>5.04%</td>
</tr>
<tr>
<td>Impact on port investments</td>
<td>Average difference to baseline scenario for the simulation period (1995-2010) [%]</td>
<td>16.45%</td>
</tr>
<tr>
<td></td>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>6.98%</td>
</tr>
<tr>
<td>Impact on regional employment</td>
<td>Average difference to baseline scenario for the simulation period (1995-2010) [%]</td>
<td>0.51%</td>
</tr>
<tr>
<td></td>
<td>Difference to baseline scenario at the end of 2010 [%]</td>
<td>1.45%</td>
</tr>
</tbody>
</table>

Model results suggest that the two management options that lead to a higher increase in port throughput, profits and regional employment are the options of deepening the access channel and increasing the container terminals resources availability.
6. Conclusions

A System Dynamics model was built in order to study management policies that could lead to an increase in port throughput and port profits in Port of Lisbon. Beneficial effects on the regional economy, in terms of regional GDP and regional employment, associated with each policy were also assessed.

The model results suggest that investing in container terminals capacity (i.e., building capacity in anticipation of future demand rather than reactively) is the most effective policy decision when the objective is to increase port throughput, port profits and regional employment. This was shown to be particularly evident in the case of container terminals, where a small change in standard capacity utilization levels (which dictates what is perceived as a need to invest in capacity) caused port throughput to increase in a very noticeable manner. However, such a policy implies an increase in investment levels (about 35% higher investment level for a 10% reduction in container terminals standard capacity utilization levels). Moreover, the beneficial effects of this type of decisions often take a relatively long time to be felt (regional employment increases 1.51% at the end of 15 years). The high levels of investment needed and the fact that some of the beneficial effects of such policy are felt only on the long run could cause decision makers to avoid it.

Model results also suggest that the impact of deepening the access channel and berths is almost the same, in terms of port profits and regional employment, as that of increasing container terminals resources availability. But while the option of increasing resources availability implies a continued high level of investments, the dredging option implies initial investments to be extremely high, but ensuing investments are much lower. The fact that the total investments for each of these two policies is almost the same together with the extremely high initial investments for deepening the access channel may favour the option of increasing resources availability at the container terminals, since this allows a much more smooth distribution of investments throughout the years.

The model results also indicate that port demand is relatively insensitive to port prices. The exception is the container terminals storage price, since this is directly related to capacity.
The model’s behaviour, either when comparing its results with historical data or when submitting it to policy changes, seems to indicate that some of the more important causal relations present in the port system were properly captured.

Model results also indicate that while there is no real advantage in making use of econometric techniques to modify System Dynamics models, there are even some disadvantages to this approach. Using econometric techniques in System Dynamics model causes the model to become less clear in terms of structural relations between variables. Moreover, econometric models assume that the user will not want to change its results, namely, for policy testing, and policy testing is precisely one of the main strengths of System Dynamics.

7. References


