# Dynamising Economic Impact Studies: The Case of the Port of Seville

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## RESUMEN

El objetivo de este artículo es, entre otros, proporcionar una herramienta para dinamizar los estudios de impacto económico sobre infraestructuras portuarias, a través de un modelo de simulación dinámica. En concreto, nos centramos en el impacto del puerto de Sevilla sobre la economía de la provincia en el año 2000. Además, el modelo explica el funcionamiento del Puerto de Sevilla, simulando la decisión de un buque de atracar en el Puerto de Sevilla o en otros puertos competidores. En esta decisión, se considera la influencia de las inversiones públicas en el Puerto de Sevilla que, al mejorar sus infraestructuras de acceso, van a permitir la entrada de buques de mayor tamaño, reduciendo el coste relativo de los mismos.

**Palabras clave:** Estudios de impacto económico, economía portuaria, modelos de Dinámica de Sistemas.

## ABSTRACT

Based on our study on the economic impact of the Port of Seville on the economy of Seville province (2000), in this paper we link its results to a System Dynamics model. This model simulates the decision-making process of vessels carrying merchandise whose final destination is the province of Seville, and which must choose to berth at either the Port of Seville or some other competing port. To this end, a forecast is obtained for Port of Seville traffic, highlighting how public investment influences this entrance decision via improvements in Port of Seville infrastructure and thereby a reduction in its relative costs.

**Keywords**: Economic Impact studies, Port Economy, System Dynamics model.

# 1. INTRODUCTION

One of the structural weaknesses of Economic Impact studies that rely on the Leontief Input-Output methodology resides in its static character. This limitation prevents us from forecasting the results of these studies, and also obliges us to update them periodically if what we want is to analyse the evolution of the most representative variables.

Moreover, Input-Output methodology has been the resource most widely used to elaborate economic impact studies on port infrastructure in Spain during the last 10 years (Consultrans and Centro de Estudios Económicos Fundación Tomillo (1998) for Port of Barcelona and Port of Tarragona; Martínez et al. (1999) for Ports of Santa Cruz de Tenerife; Castillo et al. (2000) for Port of Ceuta; Coto et al. (2001) for Port of Santander; Castillo (coord.) (2001) for Port Bahía de Algeciras).

This paper proposes a potential way to avoid this problem, by linking the Input-Output methodology to the System Dynamics Simulation supported on econometric estimations of certain of the model variables.

Both methodologies together allow us to simulate the evolution of the economic impact and the economic variables related to port activity in the province of Seville, in a 10-year time span.

System dynamics is one approach to modelling the dynamics of population, ecological and economic systems. Systems dynamics was founded in the early 1960s by Jay W. Forrester of The Massachusetts Institute of Technology (MIT). What makes system dynamics different from other approaches to studying complex systems is the use of feedback.

Dynamic simulation models are interesting auxiliary tools to analyse regional economic behaviour, as much for their merely descriptive approach as for their normative one. Studying regional economies requires a method of investigation that can not only interpret complex dynamic processes, but also supports an interdisciplinary vision of the reality in question. Of the techniques available for the construction of simulation models of regional economies, J. W. Forrester System Dynamics has a preferred place (Martínez & Requena, 1986).

The first regional model elaborated with Systems Dynamics as a basic tool concerned the Susquehanna river basin (Hamilton et al., 1969). It described interactions between the demographic, industrial and hydrologic sectors of the region surrounding the Susquehanna river. Taking their cue from this model, which together with Forrester's Urban Dynamics model (Forrester 1961, 1969a, 1969b) represented a new method of regional analysis, authors from many countries have applied System Dynamics to regional analysis. It is now accepted as a technique uniting the right features to build models on the regional reality.

In this paper we have tried to go a step further and link both methodologies, Economic Impact and System Dynamics, in the belief that the advantages of the latter can overcome the staticity problems of the former. The System Dynamics characteristics

that convinced us of its usefulness as a tool, especially for local-regional analysis, can be summarized as follows (Aracil 1982 and Aracil 1986):

1. Helps to adopt a systemic perspective. In contrast to the reductionist perspective, where the whole is just the sum of the parts, it offers a holistic vision.

2. Offers a simple graphical model structure.

3. The model structure, which is not predetermined, rests upon the modeller's skills and experience.

4. It leaves room for specialist opinions as well as scientific laws.

5. Allows for partial, incomplete states of knowledge regarding the facts to be modelled and takes close account of expert opinions on the same.

6. Helps to explain how the system reacts to changes.

7. Allows for long-run trend forecasting

Despite the benefits of the System Dynamics approach, the resulting estimates have to be interpreted with care, since much of the information factored into the model, which is most often incomplete, comes from the expert view on the facts, which may be biased by value judgments.

In other words, models are to be taken with a grain of salt. Beside, models are not definitive but, on the contrary, can be continually upgraded as more and better information becomes available on the behaviour of the system.

The System Dynamics model we have elaborated simulates the decision-making process of vessels carrying merchandise whose final destination is the province of Seville and which can choose to berth at the Port of Seville or some other competing ports. In this way, a forecast is obtained of Port of Seville traffic, highlighting how public investment influences this decision via improvements in the Port of Seville's infrastructure and thereby a reduction in its relative costs. These improvements are necessary, since Seville's is an inland port with difficult access.

The main problem to bear in mind relates to this differential characteristic of the Port of Seville. Entrance to the port is conditioned by the estuary and by the size of the lock that regulates the water level in the port's commercial area – the depth of the estuary waters and the length and width of the lock impose significant size limitations on the vessels that can call at the Port of Seville. The sources for financing investments would basically be European Funds (external financing), the sale of obsolete Port of Seville land, and internal financing (profit). These resources would allow the Port of Seville to gain competitiveness and prevent traffic deviation to competing ports, mainly Huelva and the Bay of Cadiz[1].

For impact results, we have based ourselves on the two studies available on the impact of the Port of Seville on the economy of Seville province, (1995 (López-Valpuesta and Castillo 2001) and 2001 (Castillo et al. 2003)), written by the authors.

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[1] We have assumed that the infrastructure of competing ports remains constant during the period in question.

The paper is organised as follows: this introductory section is followed by Section 2 describing the System Dynamics model of the Port of Seville. Section 3 shows the main economic impact results. Section 4 links the main employment impact results to the simulation model. Section 5 is devoted to a sensitivity analysis of the model, and conclusions are set forth in Section 6. Finally, model equations and a graphic overview are included in the Appendix.

## 2. SYSTEM DYNAMICS MODEL OF THE PORT OF SEVILLE[2]

The model describes the whole process from the moment that the Port of Seville is chosen for the goods to be unloaded to the moment that the vessel leaves the port, with special consideration to the limitations of the Port of Seville infrastructure. The Port's lack of capacity means that a significant percentage of Andalusian port traffic, which might consider Seville as a discharge port, ends up in some other competing port[3].

The origin of the port's activity is its traffic, TR (in thousands tons), which we have calculated as a linear regression (with a correction error term to avoid autocorrelation problems and to obtain a long-run relation between the variables) with respect to province GDP[4] (constant prices):

$$\nabla TR_t = 0.282 \; \nabla GDP_t - 1.130 \; (TR_{t-1} + 409.739 - 0.211 \; GDP_{t-1})$$
$$(0.044) \qquad (0.221) \qquad (165.202) \; (0.010)$$

$$n = 14, \; R^2 = .869, \; \overline{R}^2 = .830$$

The System Dynamics model has been structured into three parts, which basically coincide with the functional phases of harbour activity:

A) **Port of Seville entrance decision**. The variables LUW (Length Units waiting to berth at the Port of Seville) and LUB (Length Units of ships berthing at the Port of Seville per year) are analysed in this initial phase.

B) **Dockage at Port of Seville docks**, in which the variable analysed is LUD (Length Units berthed at Port of Seville docks at any given time).

C) **Unloading of goods in Port of Seville warehouses and merchandise flow to market.** In this last phase the variable GW is analysed (volume of goods in warehouses).

As we said above, the model is completed with an analysis of how public investment could impact on port functioning. This investment involves the following two projects:

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[2] The model has been elaborated into one System Dynamics computer simulation environment. Specifically, we have used VensimDSS.

[3] We have only considered the entrance traffic originated by the Port of Seville hinterland, which we take to be the province of Seville.

[4] We use provincial GDP as a demand indicator for the Seville hinterland. We base this relation on International Trade Theory in which imports are a function of the income of the importing region.

D) **Building a new lock and deepening the draught,** which would enable larger vessels to access the Port of Seville. The influence of these investments on Port of Seville activity is analysed through the variable GTMPS (mean size in GT of vessels berthing at the Port of Seville[5]).

E) **Building new docks**, so a greater number of vessels call at the Port of Seville. This investment is analysed by means of the variable MDC (Maximum dock capacity at the Port of Seville[6]).

We now go on to describe and define each of the aforementioned model phases, analysing the level variables implied and how they interrelate:

### A) Port of Seville entrance decision.

**LUW**. This variable shows the number of vessels (in length units) waiting to berth at the Port of Seville per year. It is defined as the difference between the rate of vessels (in length units) choosing to unload in the Port of Seville in each period (CHPSR) and dock entry frequency (EF).

This variable is related to dock capacity because, the Port of Seville being an inland port with limited capacity, there tend to be delays between vessels getting to the lock and finally berthing at the docks. LUW includes vessels that are on their way to berth but haven't yet reached the dock. Dock saturation problems may cause delays and thus push up global transport costs, although in this first version of the model we have not introduced those costs.

$$LUW = \int_0^{10}\bigl(CHPSR(t) - EF(t)\bigr)dt$$

CHPSR represents the rate of vessels that choose Port of Seville for discharging in each period. We have stripped out the captive traffic (PSCT) that would berth at Seville in any case from global Port of Seville traffic. The remainder, termed potential traffic (PSPT), is the only part affected by the Port of Seville entrance decision, because it may choose between berthing at Seville and berthing at some other port. The traffic is initially expressed in tons, so it has been necessary to change it into length units (LU) by means of the TONUL ratio.[7]

PSCT is defined as a function of the captive traffic entrance rate (CTER) and the rate of traffic in tons (TRAUX). PSPT is defined as residual, subtracting the captive traffic (PSCT) from the flow of traffic in tons (TRAUX).

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[5] The bulk vessel has been chosen as the standard because of its high relative weight in total Port of Seville traffic.

[6] We have considered neither dock specialization nor each dock's specific facilities for distributing merchandise.

[7] The definition of CHPSR is similar to that of LUER – length units entrance rate – as described later in the text. This is because the entrance flow of vessels per year is similar to those that choose the Port of Seville as their berthing port.

CTER is a constant that shows the Port of Seville captive traffic rate, and has been calculated with reference to previous analyses by the Port Authority of Seville (Autoridad Portuaria de Sevilla 1999).

ED represents the Port of Seville entrance decision. It is a key variable because it determines the higher or lower number of vessels - represented by higher or lower traffic - that choose the Port of Seville for introducing their merchandise into Seville province. We have assumed that this decision is based on a comparison of the tariffs and costs of the Port of Seville with those of the competing port; only Huelva in this version.

1) In the event that berthing costs at the Port of Seville (PSC) are lower than those at the Port of Huelva, (PHC), the Port of Seville is chosen.

2) In other cases, the decision depends on the entrance rate (ER), defined as an inverse relation between the difference in costs of the Port of Seville vs the Port of Huelva (PCD), and the proportion of vessels that choose Seville. The function determines the proportion of length units that might choose the Port of Seville, despite its costs being higher than those of the Port of Huelva.

PSC represents the costs to potential traffic of berthing at the Port of Seville and is defined as a function of TRIPS and PSCGTM. TRIPS stands for the mean number of vessels that would berth at the Port of Seville - apart from captive traffic - considering the mean size of vessels (in GT) allowed to berth there at any given moment. So TRIPS is defined as a function of the mean GT of the Port of Seville (GTMPS).

PHC is equivalent to PSC for the Port of Huelva - costs to potential traffic of berthing at the Port of Huelva – and is defined in a similar way, TRIPH being equivalent to TRIPS.

PSCGTM and PHCGTM represent the cost structure of an average-size vessel at the Port of Seville and the Port of Huelva respectively[8]. They include the following items:

1. Tariffs[9]: of all tariffs charged by Port Authorities (T-0 Maritime Navigation, T-1 Vessels, T-2 Passage, T-3 Cargo, T-4, Fresh Fishery, T-5 Sport and Leisure Craft, T-6 Gantry Cranes, T-7 Storage, T-8 Supplies and T-9 Various Services) we have factored T-0, T-1 and T-3, because they are the most directly linked to vessel and merchandise traffic. In the case of the Port of Seville, tariff T-9.2 (Vessels mooring at the lock) has also been considered.

2. Indirect Services: vessels pilotage and mooring.

3. Stowing and unstowing costs.

4. Freight.

5. Land transport from Huelva to Seville, in the case of the Port of Huelva alone.

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[8] The vessel cost structures of the Port of Seville and the Port of Huelva have been calculated according to the published tariffs of these institutions, supplemented by information available from the Autoridad Portuaria de Sevilla (1995).

[9] Neither discounts nor special tariff reductions have been considered.

PSCGTM is based on the vessel's size - in GT- since some of the costs are not fixed but vary according to this parameter. If bigger vessels could berth at the Port of Seville, the costs associated to merchandise transport would be smaller.

The determination of pilotage and moorage costs (PILSE, MOORSE for Port of Seville and PILHU and MOORHU for Huelva), as well as Seville freight costs (FREIGSE), is also related to the vessel's size – in GT. So we have had to define them by relating each of these costs to the GT of the vessels calling at each port. Stowing costs (STOWSE and STOWHU) are set at a fixed amount per ton.

An additional term is factored (TCHTOS) in the case of the Port of Huelva to reflect the merchandise transport costs from Huelva to Seville, because we confine ourselves here to merchandise whose final destination is the province of Seville. This cost has also been set at a fixed amount of €3.005 per ton transported (Autoridad Portuaria de Sevilla 1995).

The vessel freight for Huelva has been defined as a function of Seville's, with the tonnage data consulted (Autoridad Portuaria de Sevilla 1995) showing an approximately 4.41% difference in Huelva's favour.

Each port competes to attract the potential traffic. The cost of the potential traffic is determined by comparing the relative costs of the Port of Seville and the Port of Huelva, PSCGTM and PHCGTM. The utility of these variables resides in their comparability, so it is possible to determine the most competitive port and, consequently, the one that will likely be chosen for calling at and for merchandise unloading.
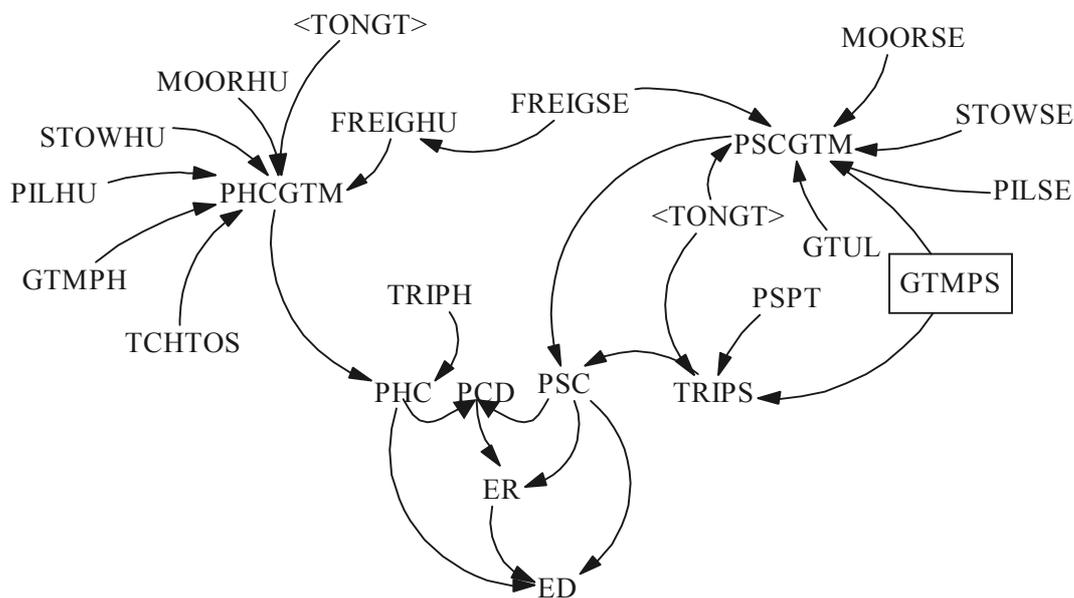


Figure 1. ED and ER flow diagram.

LUW is defined as the difference between CHPSR and EF. Having already defined CHPSR, we will now focus on EF. This variable, which represents dock entrance frequency, is based on dock capacity (MDC) relative to the vessels (in length units) berthed at each given moment. Hence:

1. If the dock is busy, that is to say, if the vessels berthed at the dock - in length unit (LUD) - occupy the whole dock capacity (MDC), the entrance frequency is necessarily 0.

2. Conversely, if there are metres of dock available, the entrance rate is determined by REF - real entrance frequency.

$$EF = \begin{cases} 0 & \text{if} & LUD = MDC \\ \\ REF & \text{if no} & LUD = MDC \end{cases}$$

REF - real entrance frequency - is obtained by applying the rate of entrance (ERT) to the minimum between the vessels waiting (LUW) and the dock space available. The dock space available is calculated as the difference between maximum dock capacity (MDC) and the vessels berthed at dock (LUD).
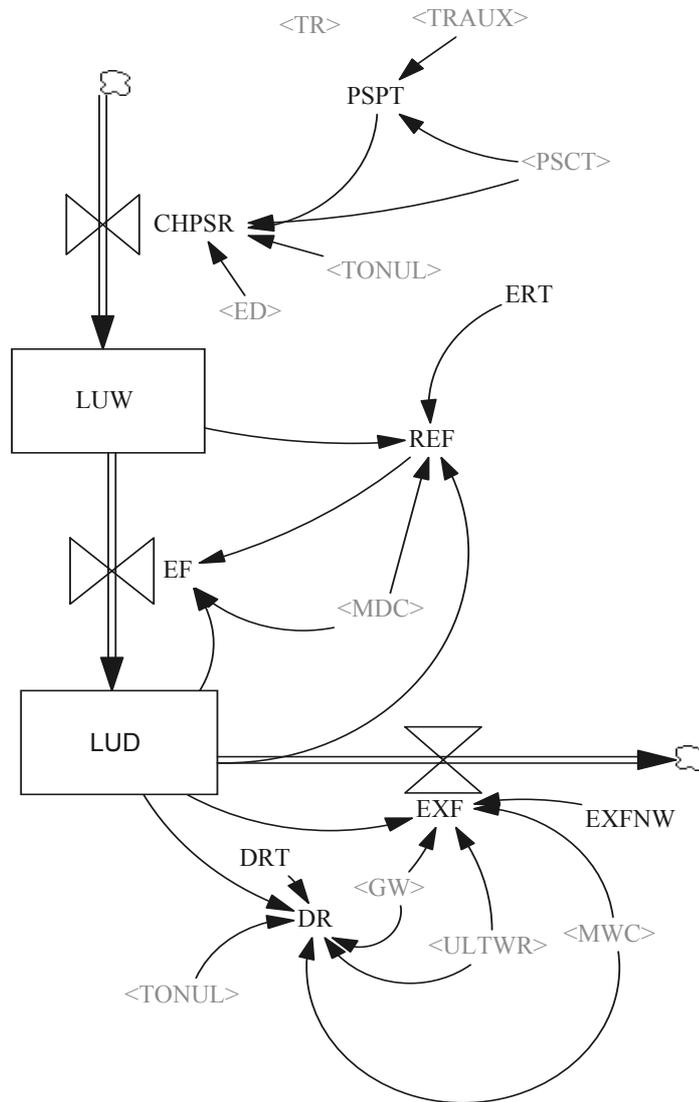
Figure 2. LUW and LUD flow diagram.

**LUB** is a variable defined with the aim of annualising the rate of vessels berthing at the Port of Seville each year, so we can calculate the tariff income obtained by the Port Authority of Seville and its corresponding profit. LUB is defined as the difference between the rate of vessels (length units) berthing in each period with respect to that of the former period (LUER and LUER1, respectively).

$$LUB = 57 + \int_{0}^{10} \left( LUER(t) - LUER(t-1)dt \right)$$

where LUER is the length units' entrance rate and it is similar to CHPSR defined above.

Figure 3. LUB flow diagram.

### B) Dockage at Port of Seville docks

> **LUD** represents the part of the Port of Seville dock which is busy at any given time. It is defined as the difference between entrance frequency (EF) and exit frequency (EXF), and depends mainly on dock capacity, MDC.

$$LUD = \int_{0}^{10} (EF(t) - EXF(t)) dt$$

Entrance frequency (EF) has already been defined in the previous section. Exit frequency (EXF) is defined as a function of maximum warehouse capacity, MWC[10]. Two alternative options may be used:

1) If the total warehouse capacity (GW) is occupied by discharged merchandise, those vessels wishing to unload their merchandise in the Port of Seville warehouses will not be able to, so will not leave the Port. However this is not the situation of those vessels whose merchandise is to be unloaded directly onto trucks or into external warehouses. The exit frequency of these vessels is determined by EXFNW (exit frequency of vessels not discharging at the Port of Seville's own warehouses) and their percentage share in total traffic by ULTWR.

2) Conversely, if there is warehouse room available, and assuming the merchandise discharging rate to be equivalent to the vessel exit rate from the Port of Seville, we also have to factor discharging flow (DR), which is defined as the minimum between the warehouse room available (MWC - GW) and the discharged merchandise from vessels whose cargo goes to Port of Seville warehouses, according to the discharging rate DRT.

$$
EXF = \begin{cases} EXFNW(1-ULTWR)LUD & \text{if} \quad MWC = GW \\ \\ DR + EXFNW(1-ULTWR)LUD & \text{if no} \quad MWC = GW \end{cases}
$$

### C) Unloading of goods in Port of Seville warehouses and merchandise flow to market.

**GW** represents the level of occupancy of the Port of Seville warehouses devoted to storing merchandise from vessels. All the ships considered enter the Port of Seville to discharge merchandise into either Port of Seville or third-party warehouses, or else directly onto lorries for transport to the final destination. This variable indicates how warehouse capacities might influence Port of Seville traffic due to the impossibility of ships discharging if warehouses are busy. This being so, ships at the Port would be unable to leave, meaning no new ships could enter. In this version, however, we are not considering this to be the case.

GW is defined as the difference between the entrance rate and the exit to market rate.

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[10] Representing the capacity of the Port of Seville warehouses in 2000. In the Port Authority of Seville Annual Report ("Memoria anual 2001"), this capacity is expressed in $m^2$ so we have changed it into tons via the ratio 3 tons – 1 $m^2$, provided by the Port Authority of Seville staff.
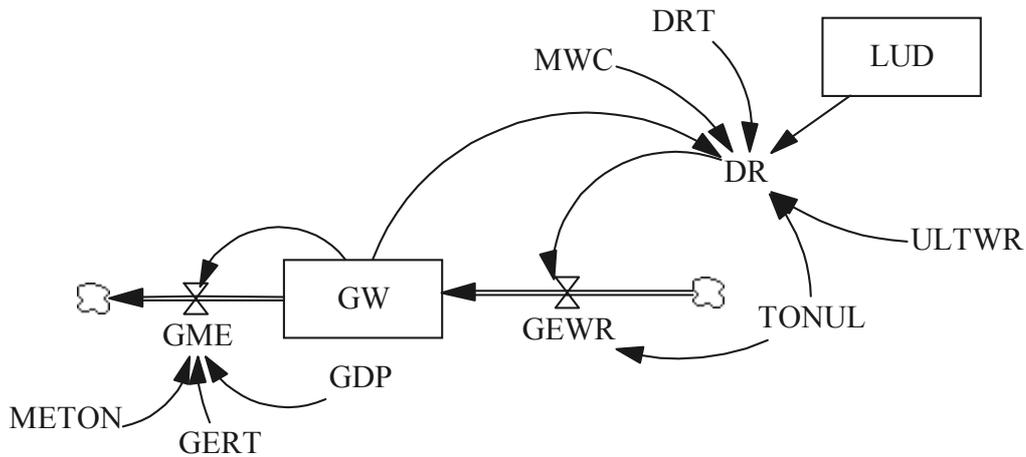
Figure 4. GW flow diagram.

whose analytical expression would be:

$$GW = \int_0^{10} \left( GEWR(t) - GME(t) \right) dt$$

→ GEWR is the rate of merchandise entrance to warehouses and can be taken as equivalent to DR, the discharge flow of vessels unloading at the Port of Seville warehouse. Length units must be converted to tons because of the different units of measurement involved.

→ GME represents the outflow of merchandise to the market. It has been defined such that merchandise leaves the warehouses at an exit rate (GERT) which depends on market demand at each given moment. In the present version of the model we have assumed this flow to be continuous.

### D) Building a new lock and deepening the draught

➢ **GTMPS** represents the mean GT of vessels calling at the Port of Seville. GTMPS is a level variable that increases with investments via GTIPSI and does not decrease.

GTMPH stands for the mean size - in GT- of vessels calling at the Port of Huelva. In this port it has a fixed value.

GTMPS is defined as follows:

$$GTMPS = 4500 + \int_0^{10} GTIPSI(t) \, dt$$

→ We can calculate GTIPSI for two different scenarios:

1) If there is no Public Investment (PI), the size of the vessels that can call at the Port of Seville will not increase, so GTIPSI will be 0.

$$GTMPS = 4500 + \int_0^{10} GTIPSI(t)dt = 4500 \qquad \text{if } PI = 0$$

2) Conversely, GTIPSI would be arrived at by multiplying public investment (PI) by the percentage devoted to draughting the lock, that is, the funds spent to increase the size of ship IGTR. It will also depend on the increase in GT admitted at the Port of Seville per monetary unit (million euro) invested (GTIUI). Finally, it also depends on the execution rate (ERI).

$$GTMPS = 4500 + \int_0^{10} GTIPSI(t)dt = 4500 + \int_0^{10} \left((PI(t) \times IGTR \times GTIUI) \times ERI\right)dt$$

$$\text{if no } PI = 0$$

We calculate PI as an aggregate of 3 items: external investment (EXINV), the useful profit of the Port Authority of Seville (UP) weighted by the rate of invested profit (PIR), and Port Authority land sales (LS).

We calculate EXINV assuming an initial 0 (EXINVini = 0) with later contributions distributed as follows:[11]

o 16 million euro in 2004

o 17 million euro in 2005

o 16 million euro in 2006

o 14 million euro in 2007

In order to stop negative profits interfering in profit P calculation, we introduce the variable UP such that P having a negative value, UP is 0 and P being positive, UP equals P. P represents Port of Seville profit, so is calculated in terms of the difference between cost and income[12].

These are the three possible sources of income:

a) Tariff income (TEUL) which depends on the traffic calling at the Port of Seville. TEUL is calculated by aggregating income per length unit from T-0, T-1, T-9.2 and T-3 tariffs.

b) Income from storage tariff T-7 (TW) has been considered a constant.

c) PSAOI includes other Port Authority of Seville income.

PSAC represents the costs borne by the Port Authority of Seville, which include total operating expenses.[13]

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[11] Data provided by Port Authority of Seville staff.

[12] For the sake of simplicity, profit has been calculated as the difference between income (port services - T-0, T-1, T-9.2, T-3 and T-7 tariffs - and concession fees and administrative authorizations) and operating expenses. Amounts received from/given to the Contribution Fund have not been considered.

[13] Income and costs forecasts as provided by the Port Authority of Seville (2003).

We have considered that non-tariff income and Port of Seville costs increase from their initial values, Iini and Cini, according to OIGR and CGR rates.

Expected land sales of the Port Authority of Seville have the following yearly distribution:[14]

- o 5 million euro in 2003
- o 10 million euro in 2004
- o 30 million euro in 2005
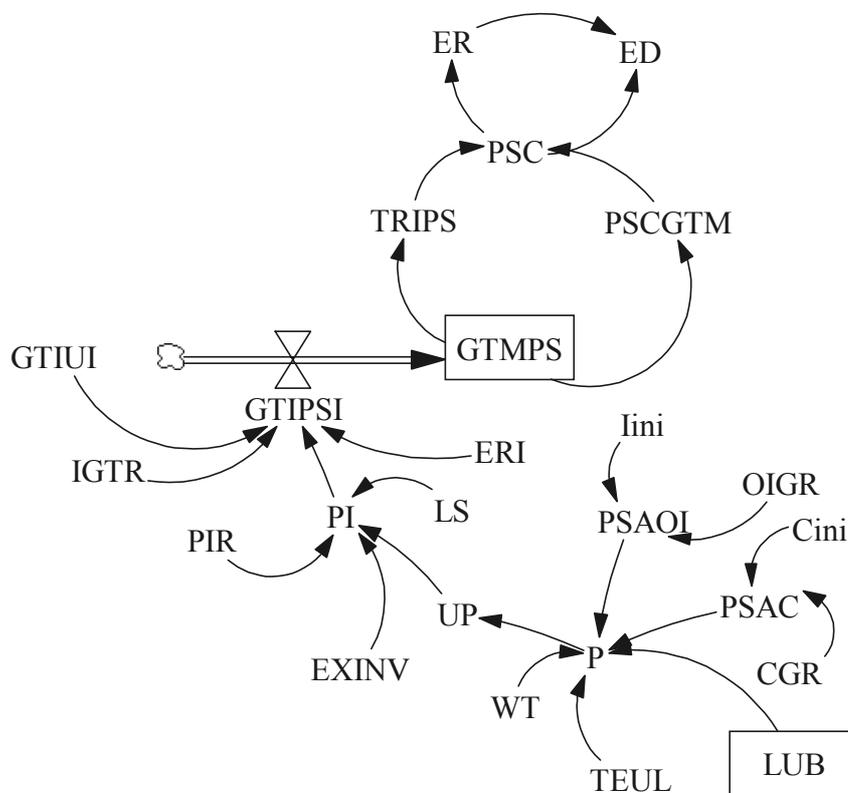- o 28 million euro in 2006
- o 18 million euro in 2007

Figure 5. GTMPS flow diagram

### E) Building new docks

> **MDC** is the maximum dock capacity, in length units. This variable shows how many length units are available for berthing. Its significance lies in that it can potentially limit the number of vessels that may berth, imposing a certain waiting time (**LUW**). This may even be one of the reasons why some vessels would not choose the

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[14] Data provided by Port Authority of Seville staff.

Port of Seville as a berthing port. We have assumed that maximum dock capacity (MDC) increases from its initial level[15] along with the investment made (via DIPSI, dock capacity added) and does not decrease.

$$MDC = IDC + \int_{0}^{10} DIPSI(t)dt$$

→ DIPSI, that is, the dock capacity increase due to investments, has been defined as follows:

1) If there is no public investment (PI = 0), DIPSI will also be 0, that is, the dock will maintain its present capacity.

$$MDC = IDC + \int_{0}^{10} DIPSI(t)dt = IDC \qquad \text{if } PI = 0$$

2) Conversely (PI > 0), DIPSI will depend on the part of the global investment devoted to increasing dock capacity – depending on the dock investment ratio (IDR). We must also factor the growth of dock size per funds invested, DIUI. All of this will depend furthermore on the execution rate (ERI).

$$MDC = IDC + \int_{0}^{10} DIPSI(t)dt = IDC + \int_{0}^{10} \big((PI(t) \times IDR \times DIUI) \times ERI\big)dt$$

$$\text{if no } PI = 0$$

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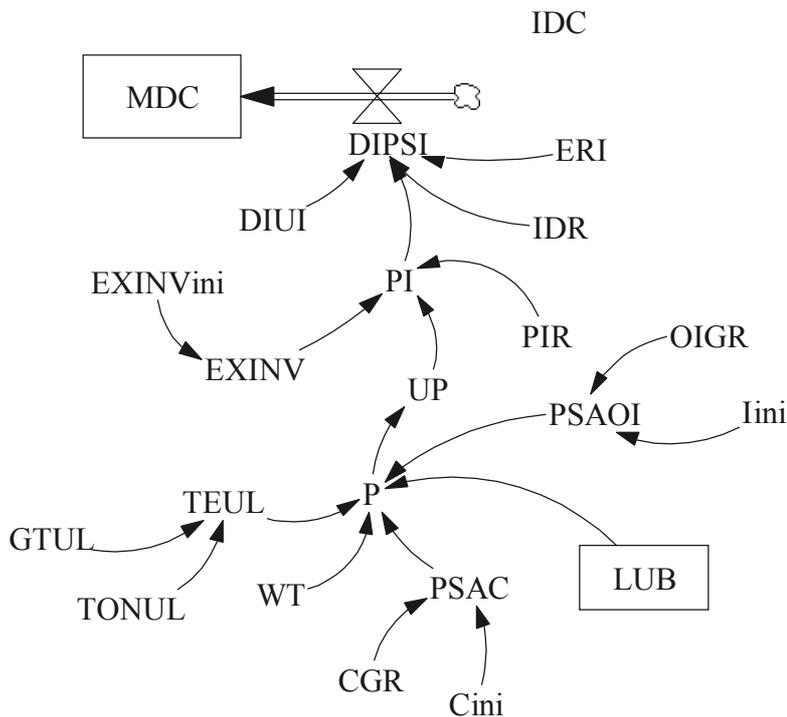[15] Present dock capacity includes all the public docks in the commercial area.

Figure 6. MDC flow diagram.

## 3. ECONOMIC IMPACT OF THE PORT OF SEVILLE ON THE PROVINCE OF SEVILLE

The methodology for calculating the Port of Seville's economic impact is based on the Input-Output model. Our analysis is based on the adaptation of this model designed by "Puertos del Estado" for the Spanish Port System by the consulting firm TEMA (1994), applying different variations to this adaptation. The main change is due to the need to convert the last available input-output regional table (TIOAN-95) into a provincial one, in order to model the indirect and induced effects of port activity.

The following table shows the main global results of port activity in the province of Seville. There are three different ways to quantify the total impact of a port on its area of influence[16]. We have chosen the one that excludes from the induced effect both the indirect effect generated by the Port Industry and the consumption generated by the wages that the Port Industry generates indirectly. This approach to quantifying the total impact appears to provide the best methodological solution to the problem of double accounting, since the Port Industry is only related to the rest of the economy through the

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[16] The first way consists of adding direct, indirect and induced Port Industry and Dependent Industry effects; the second consists of adding direct and induced effects from both industries, but only taking into consideration the indirect effect caused by the Dependent Industry.

Dependent Industry. It is therefore important to eliminate all the indirect impacts generated by the Port Industry (either in the indirect effect, or in part of the induced effect).

| VARIABLE | TOTAL EFFECT 1995 | Consumer Price Index 2000/1995 | TOTAL EFFECT 1995 (capitalized) | TOTAL EFFECT 2000 |
|---|---|---|---|---|
| STAFF EXPENSES (1) | 179922350.87 | 1.13798 | 204747311.11 | 242748215.70 |
| EBITDA (1) | 111823157.69 | 1.13798 | 127252065.94 | 234903438.09 |
| TAXES (1) | 100186841.32 | 1.13798 | 114010217.57 | 133824838.92 |
| SALES (1) | 920854075.50 | 1.13798 | 1047909806.50 | 1619972059.86 |
| EMPLOYMENT (2) | 9349.27 | | 9349.27 | 12326.64 |

(1) Euro
(2) Employees

**Table 1. Port of Seville Total Effect (1995 and 2000).**

Taking the employment data for 1995 and 2000 shown in the previous table, and using province of Seville employment in 1980-2000 as our reference, we have drawn up the Port of Seville employment generation series for the said period. From the total employment generated by port activity, we had to differentiate that attributable to Port of Seville entrance traffic. To do so, we calculated the weighting of Port of Seville entrance traffic in total traffic (1980-2000). Employment could then be linked to Port of Seville entrance traffic through a linear regression.

## 4. DYNAMIZING EMPLOYMENT THROUGH THE SIMULATION MODEL

The model described in section 2 simulates public investment effects on the functioning of the Port of Seville.

Once public investment effects had been determined, the variable EMP (employment) was introduced into the model with the aim of linking the results obtained from the economic impact study (table 1) to the simulation model, so that we could obtain forecasts for job creation relative to infrastructure investments.

We constructed a linear regression with a correction error term from the employment EMP data obtained in section 3, and from entrance traffic to the Port of Seville (in thousands tons). We used the long-run relation between both variables from that linear regression:

$$\nabla EMP_t = 2.542\, \nabla TRPSAUX_t - 0.620\, (EMP_{t-1} - 1775.903 - 2.288\, TRPSAUX_{t-1})$$
$$\quad\; (0.469) \qquad\quad (0.285) \qquad\quad (676.540)\;\; (0.354)$$

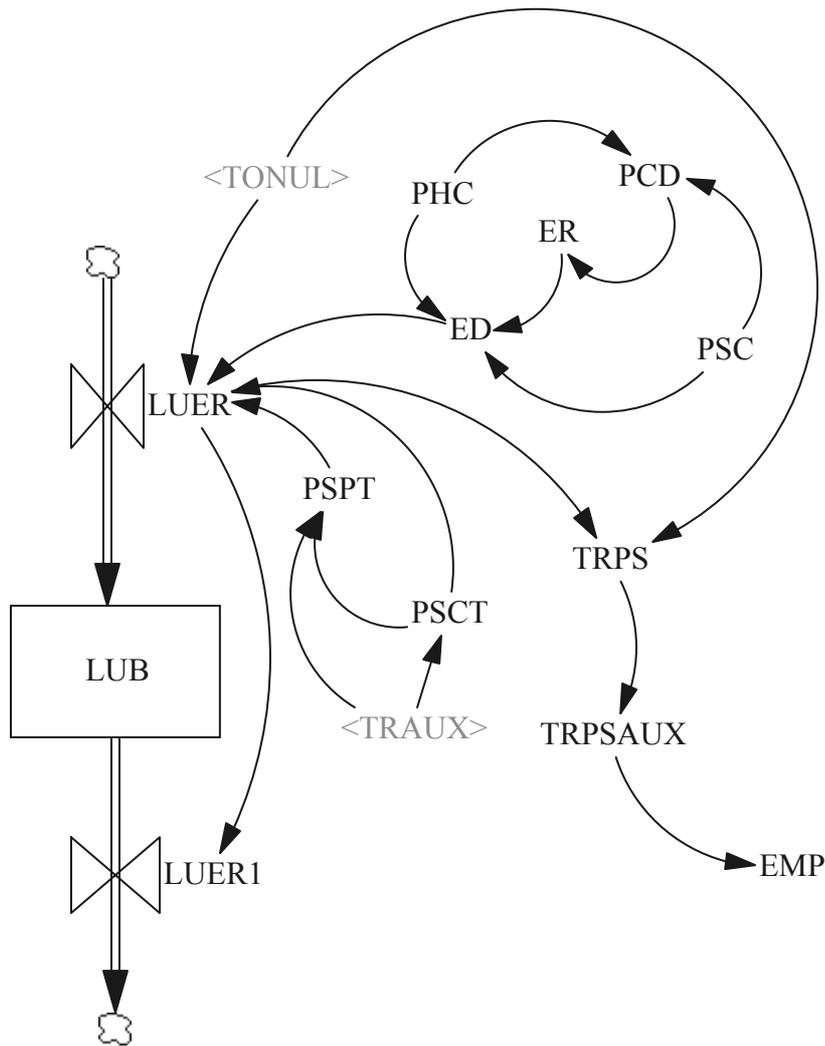$$n = 14,\; R^2 = .759,\; \overline{R}^2 = .687$$

Figure 7. Adding EMP to the LUB flow diagram.

## 5. SENSITIVITY ANALYSIS

System Dynamics has a real advantage over alternative procedures for mathematical modelling in situations where the nature of some of the variables involved makes it difficult to give them specific values. To address this difficulty, System Dynamics models are usually subjected to a sensitivity analysis, that is, running a series of simulations in which the model parameters are changed for each simulation. This can be of great help in testing the robustness of model-based policies.

This section sets out the sensitivity analysis run on the model we constructed. The main variables we focused on to identify model sensitivity were LUB and EMP. Tables 4 and 5 show the results of this analysis for main parameters (Table 4) and secondary parameters (Table 5): the first column shows the parameters we considered, and the

second, the fluctuation range set for each parameter[17]. The third and fourth columns show the effects of this parameter value change. We have performed univariate simulations, that is, changing only one parameter at a time, with the exception of external investments and land sales. In these two cases, we have performed both multivariate and univariate simulations. The reason is that we believed it could be more interesting to analyse the effect of changing all EXINV variables at once, and also all LS (Land Sale) variables. We present the results in the table as EXINVG and LSG.

According to Table 4, parameters can be roughly classified into three main groups: parameters to which the model shows no sensitivity; parameters to which it shows some sensitivity; parameters to which it displays a high sensitivity.

| Parameter nominal value | Range | Effect on LUB | Effect on EMP |
|---|---|---|---|
| DIUI = 0.07134 | 0.0535 to 0.089 | None | None |
| IDC = 2.764 | 2.073 to 3.455 | None | None |
| IDR= 0.08 | 0.06 to 0.1 | None | None |
| MWC= 665733 | 499299 to 832166 | None | None |
| WT= 1 | 0.75 to 1.25 | None | None |
| METON= 246,76 / $10^6$ | 0.00018507 to 0.00030845 | None | None |
| ULTWR = 0.7 | 0.525 to 0.875 | None | None |
| OIGR= 0.0812 | 0.0609 to 0.1015 | None | Very weak |
| LS3= 5 | 3.75 to 6.25 | None | Very weak |
| $C_{ini}$ = 8.46 | 6.34 to 10.57 | Very weak | Very weak |
| PIR= 0.8 | 0.6 to 1 | Very weak | Very weak |
| LS4 = 10 | 7.5 to 12.5 | Very weak | Weak |
| LS5 = 30 | 22.5 to 37.5 | Weak | Weak |
| LS6 = 28 | 21 to 35 | Weak | Weak |
| LS7 =18 | 13.5 to 22.5 | Weak | Weak |
| LSG (above values) | Above values | Weak | Weak |
| CGR = 0.0799 | 0.0599 to 0.0998 | Weak | Sensitive |
| EXINV4 = 16 | 12 to 20 | Weak | Weak |
| EXINV5= 17 | 12.75 to 21.25 | Weak | Weak |
| EXINV6= 16 | 12 to 20 | Weak | Weak |
| EXINV7= 14 | 10.5 to 17.5 | Weak | Weak |
| EXINVG (above values) | Above values | Weak | Weak |
| $EXINV_{ini}$= 0 | 0 to 10 | Weak | Sensitive |

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[17] We have estimated that they vary 25% from their nominal value (up and down).

| $I_{ini}$= 5.51 | 4.13 to 6.88 | Weak | Sensitive |
|---|---|---|---|
| IGTR= 0.92 | 0.69 to 1.15 | Sensitive | Sensitive |
| GTIUI= 29.06 | 21.795 to 36.325 | Sensitive | Sensitive |
| TONUL = 50000 | 37500 to 62500 | Quite sensitive | Very weak |
| CTER = 0.6651 | 0.498825 to 0.831375 | Quite sensitive | Quite sensitive |
| GTMPH = 15000 | 11250 to 18750 | Quite sensitive | Quite sensitive |
| GDPGR = 0.03 | 0 to 0.08 | Quite sensitive and Potential Behaviour Change | Quite sensitive and Potential Behaviour Change |

**Table 4. Sensitivity Analysis: Results for Main Parameters**

| Parameter       nominal value | Range | Effect on LUB | Effect on EMP |
|---|---|---|---|
| DRT = 1 | 0.75 to 1.25 | None | None |
| ERT = 1 | 0.75 to 1.25 | None | None |
| EXFNW = 1 | 0.75 to 1.25 | None | None |
| GERT= 1 | 0.75 to 1.25 | None | None |
| ERI = 1 | 0.75 to 1.25 | Sensitive | Sensitive |
| TONUL = 50000 | 37500 to 62500 | Quite sensitive | Very weak |

**Table 5. Sensitivity Analysis: Results for Secondary Parameters**

The first group is formed by parameters whose changes of value are not relevant for the behaviour of the model, such as DRT, ERT or DIC. For example, the result of the sensitivity analysis for the parameter DIC is shown in figure 8, where we can see that EMP follows the same trajectory for all DIC values within the range considered. Therefore, we conclude that variations in the value of DIC have no effect on model behaviour.

Graph for EMP
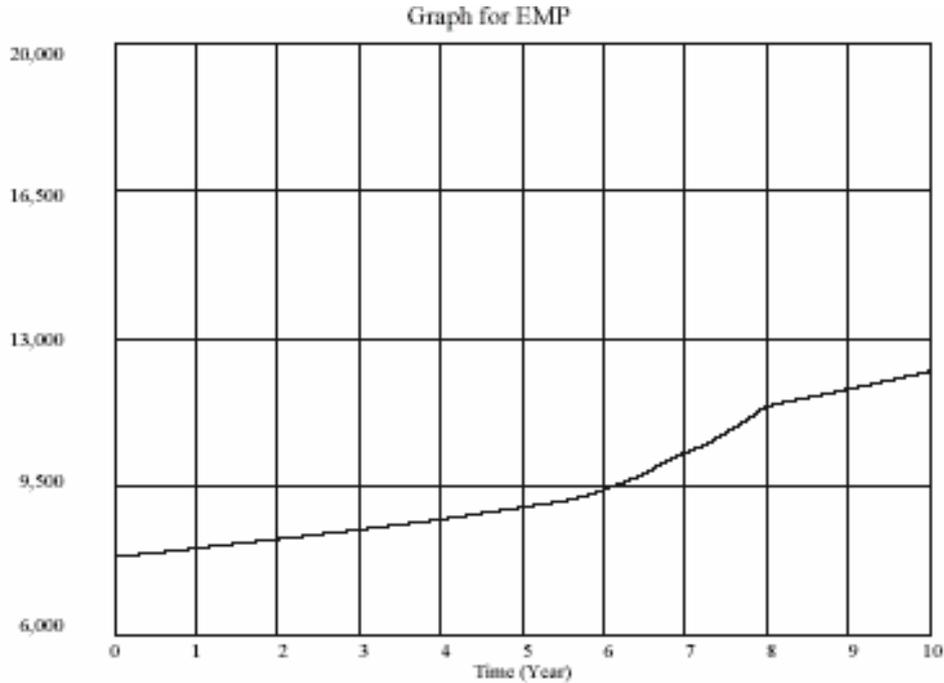
**Figure 8. Sensitivity analysis of variable EMP when parameter DIC is changed**

The second group is formed by parameters that have some effect on model behaviour, but whose effect is not that relevant. Examples would be CGR or GTIUI. In figure 9 we can see a narrow range of variability.

LUB

Time (Year)
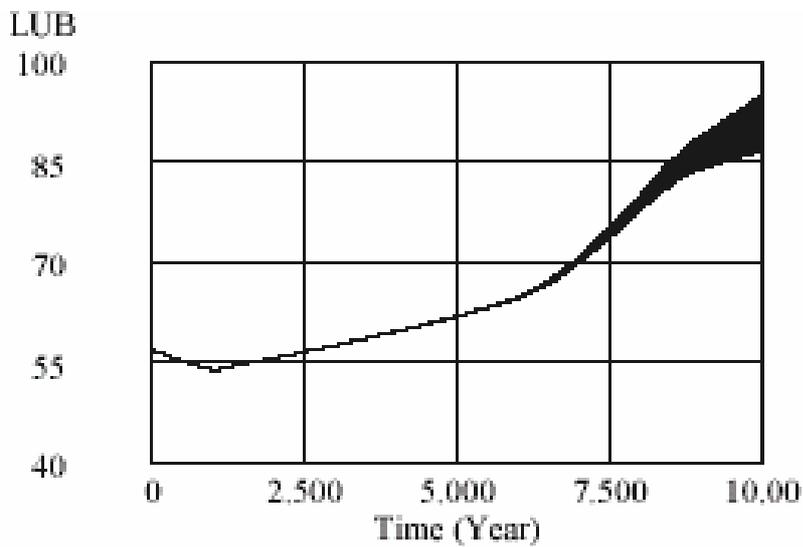
**Figure 9. Sensitivity analysis of variable LUB when parameter CGR is changed.**

The third group is formed by parameters to which the model displays a high sensitivity. There is a special case in this third group, which is parameter GDPGR. In this case, the sensitivity analysis detects qualitative changes in behaviour. Figure 10 shows the occurrence of a qualitative change, clearly evidenced in the two different long-term conducts; growth and stabilisation. In this figure, EMP alters

when we change the value of GDPGR and, as stated, we can observe two different behaviour modes.
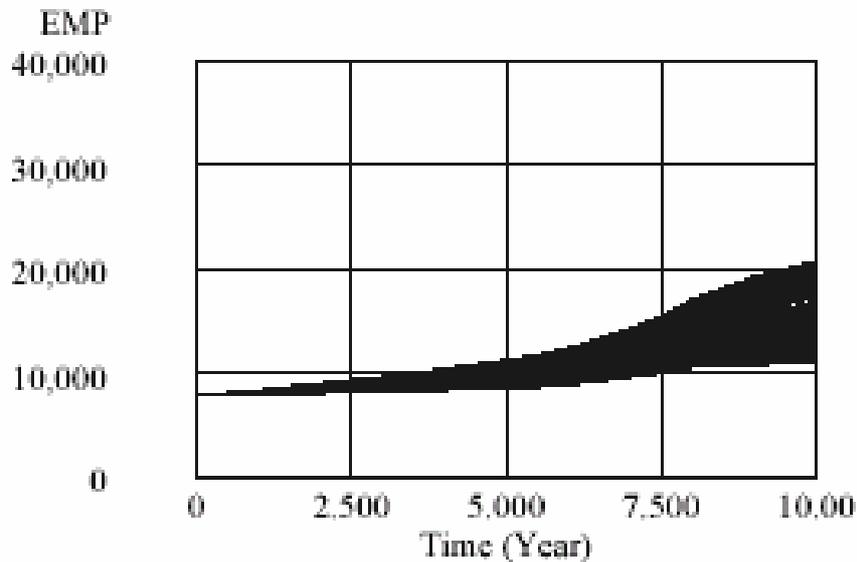


**Figure 10. Sensitivity analysis of variable EMP when parameter GDPGR is changed.**

## 6. MAIN RESULTS AND CONCLUSIONS

Simulating the model described in the previous sections allows us to obtain conclusions on some of the most relevant aspects related to the present and future of the Port of Seville. However, it should be noted that this is a first approach to a future global model of the Port of Seville - and for this reason simplifying assumptions have been adopted. Nevertheless, they do not weaken the result because our goal is to indicate the qualitative character of the model's behaviour, which shows a traffic increase.

Figures 11 to 15 show a foreseeable future of the port in which infrastructure reforms have been carried out in comparison to what would happen if no public investments were forthcoming.

Figure 11 a) shows the tendency of the traffic that would annually berth at the Port of Seville assuming no public investment occurs. As we can see, it does not reach 75 million length units (about 3750000 thousand tons of entrance traffic). In contrast, investments on the draught of the river go ahead as planned, the number of million length units that would berth at the port would reach 90 million (about 4500000 thousand tons of entrance traffic). In this last case, we can see that traffic growth is not so linear as it was with no investment, and intensifies as of the seventh year from the construction of improvement works on the Port of Seville entrance. This investment would give rise to the Port of Seville average vessel size increase shown in figure 12.
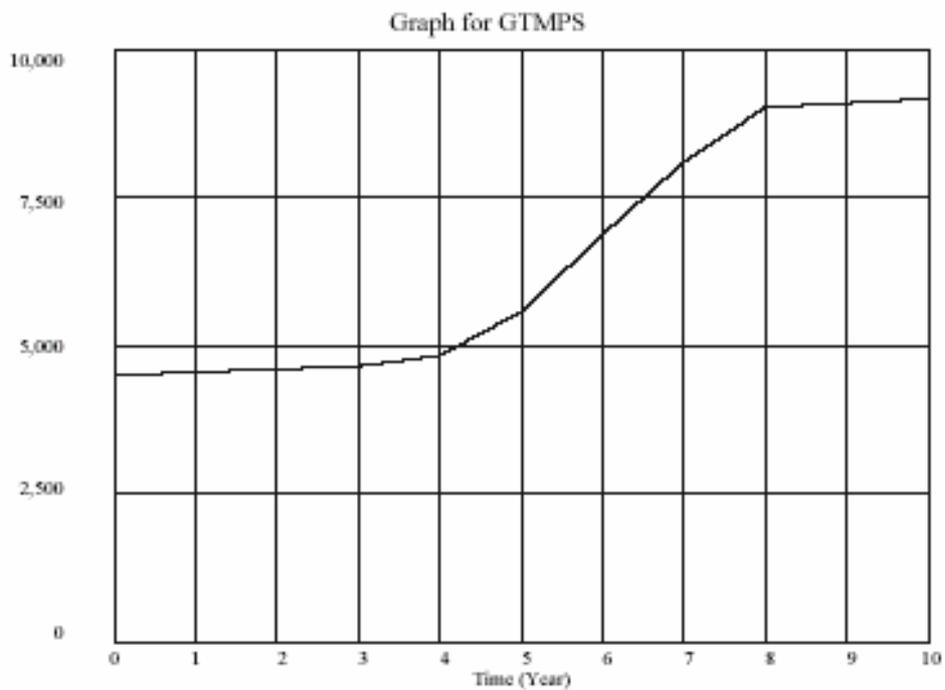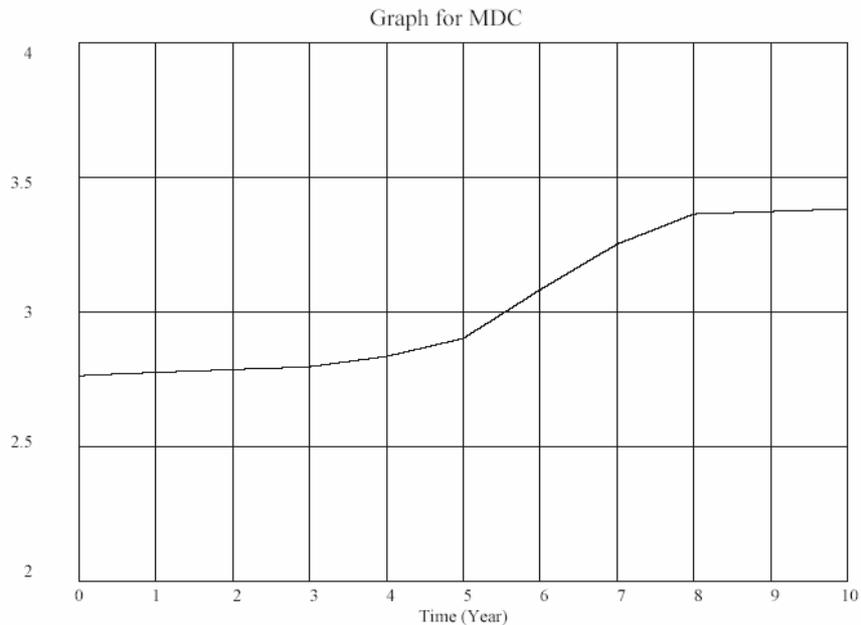
Graph for LUB
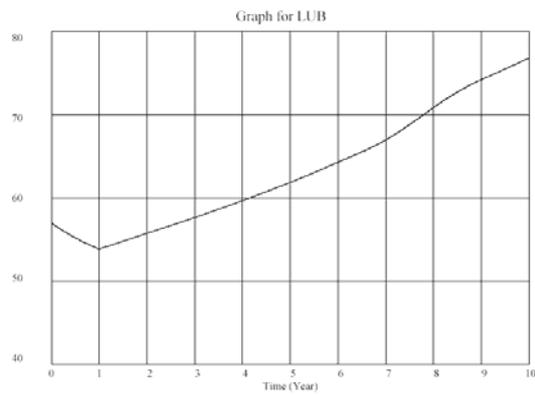
a) LUB evolution with no public investment

Graph for LUB
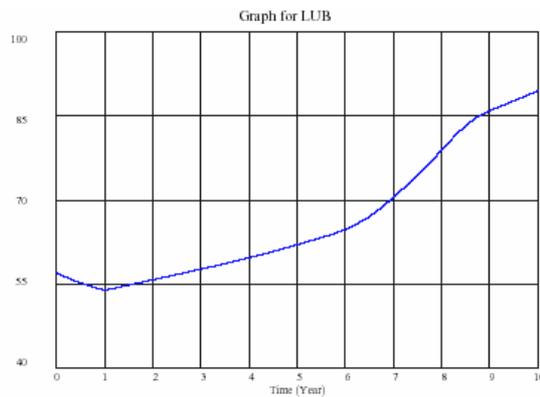
b) LUB evolution if planned public investment occurs.

**Figure 11. Port of Seville traffic (LU) evolution**
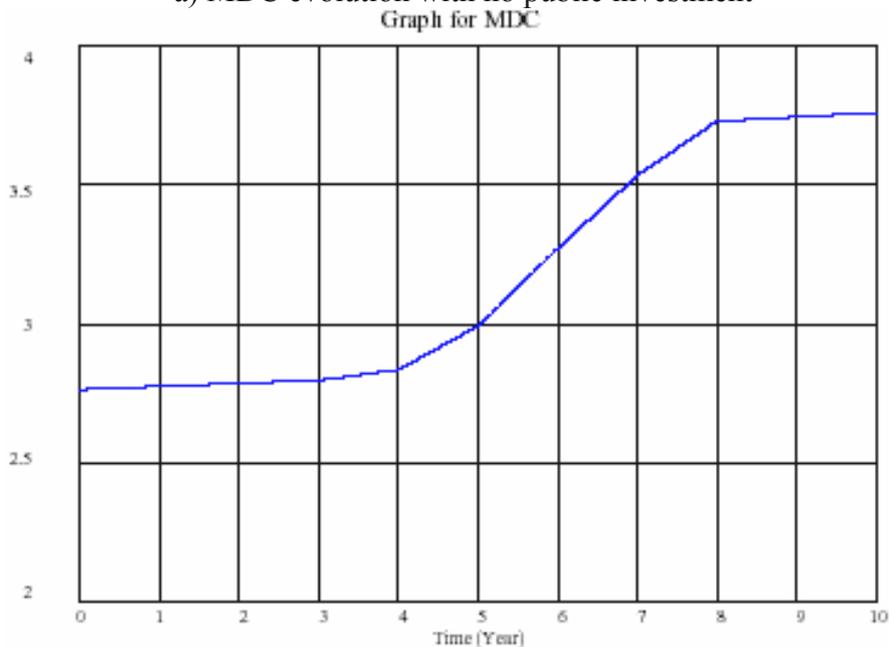
Graph for GTMPS

**Figure 12. Evolution of Port of Seville average GT**

We have also included the potential increase in the number of docks, which would allow more vessels to berth, therefore increasing the Port of Seville's profits. This increase is shown in figure 13.


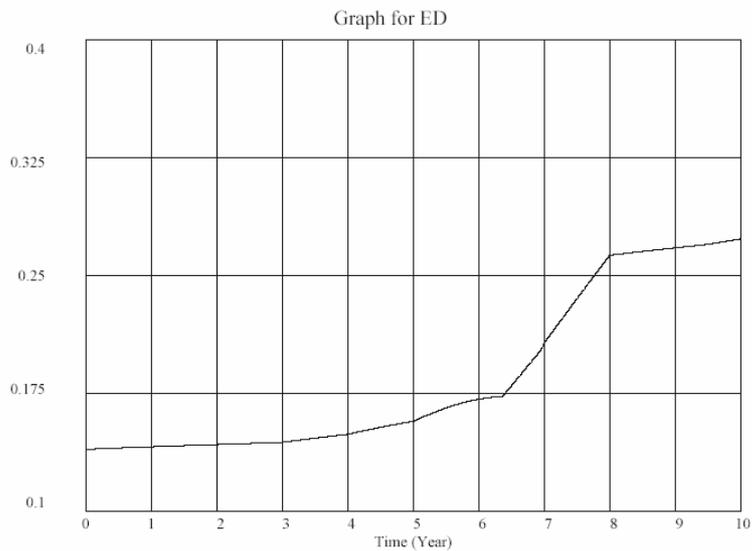
a) MDC evolution with no public investment



b) MDC evolution if planned public investment occurs

**Figure 13. Port of Seville dock capacity evolution (LU)**

The possibility of admitting larger vessels would bring down relative costs, which would enhance the competitiveness of the Port of Seville. This competitiveness gain is even more important if we consider the Port of Seville's geographic location, surrounded by three ports of general interest, Huelva, Bay of Cadiz and Bay of Algeciras, within a radius of approximately 300 kilometres.

In this version of the model, this would lead to an increase in the percentage of traffic (in terms of potential Port of Seville traffic) that would choose the Port of Seville as a berthing port. The evolution of this percentage is shown in figure 14.



a) ED evolution with no public investment



b) ED evolution if planned investment occurs

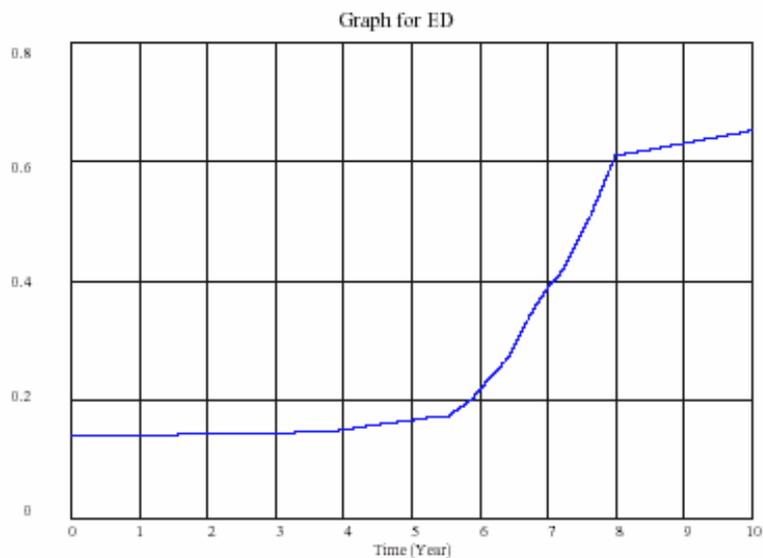**Figure 14. Port of Seville entrance decision evolution**

The positive impact on Port of Seville activity shown in previous figures also has a marked influence on employment creation. Thus, according to figure 15 b), in ten years time, the number of jobs created by Port of Seville activity - considering the increase in entrance traffic as a result of public harbour infrastructure investment - would sum

about 12,500 in the province of Seville. If no investment occurred, the employment generated would be as shown in figure 15 a).



a) EMP evolution with no public investment



b)  EMP evolution if planned investment occurs
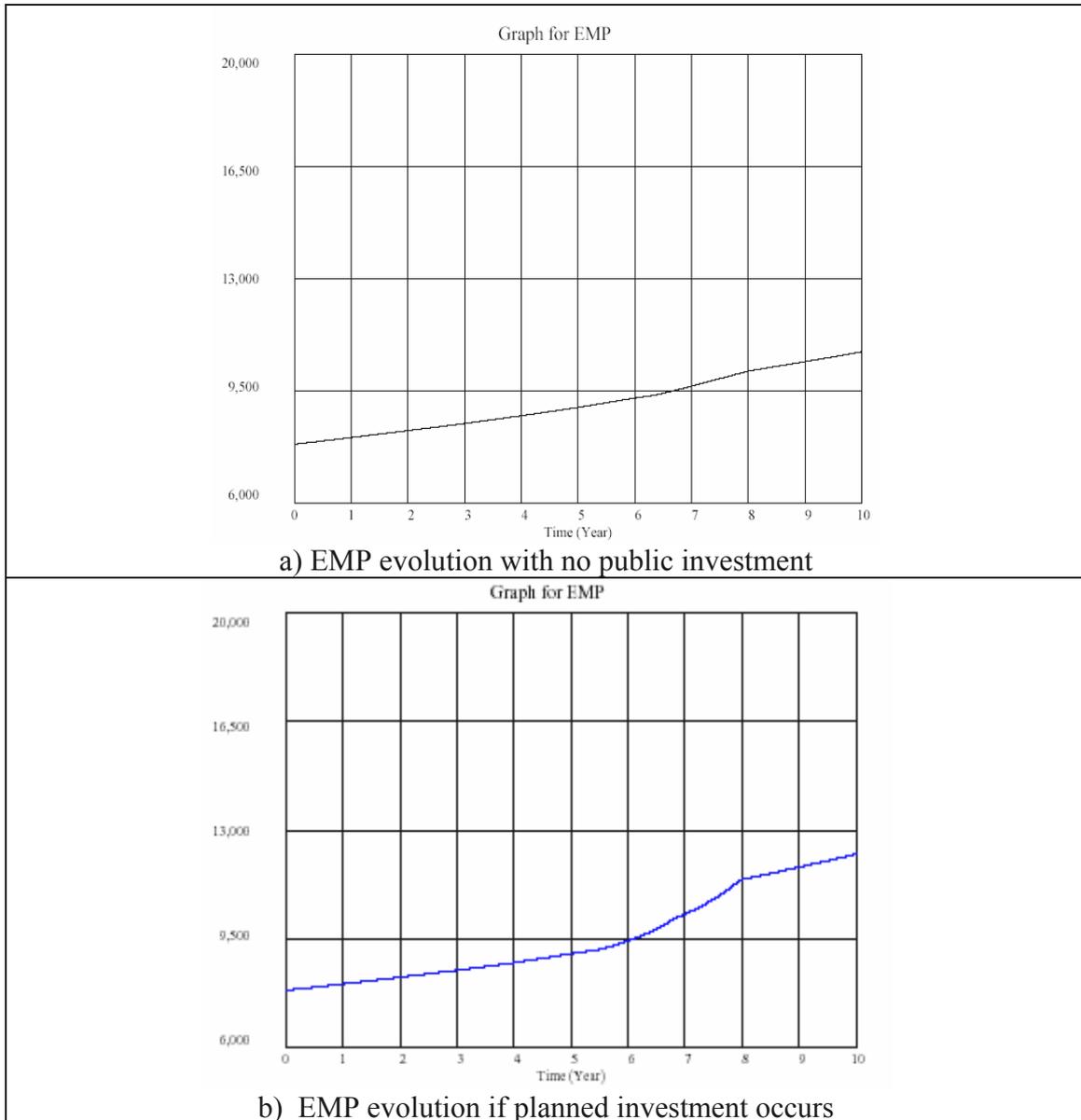
**Figure 15. Evolution of employment generated by entrance traffic to the Port of Seville**

Independently of the nominal values obtained, the most significant aspect of this analysis involves the introduction of methodological solutions to dynamise static Economic Impact studies based on the Leontief Input-Output model.

The proposed solution can be applied to any of the numerous Economic Impact studies on transport infrastructure conducted in Spain in the last fifteen years.

## 7. APPENDIX

In this appendix we reproduce the equations of the model for the sake of completeness. Table 6 shows the model variables while Table 7 gives the nominal values of the parameters.

| Variable | Meaning | Definition | Units |
|---|---|---|---|
| CHPSR | Choosing PS Rate | (PSCT + PSPT x ED) x (1/TONUL) | LU/year |
| DIPSI | Dock Increase in PS through Investment | IF THEN ELSE (PI = 0, 0, PI x IDR x DIUI) x ERI | LU/year |
| DR | Warehouse Discharge Rate | (1/TONUL) x [MIN (MWC - GW, TONUL x ULTWR x LUD) x DRT] | LU/year |
| ED | Entrance Decision to PS | IF THEN ELSE (PSC < PHC, 1, ER) | Dmnls[18] |
| EF | Entrance Frequency to Dock | IF THEN ELSE (LUD = MDC, 0, REF) | LU/year |
| EMP | Employment | 1775.90+2.2881 x TRPSAUX | Employees |
| ER | PS Entrance Ratio | $\varphi_6$ (PCD) | Dmnls |
| EXF | Exit Frequency from Dock | IF THEN ELSE (MWC = GW, EXFNW x (1-ULTWR) x LUD, DR + EXFNW x (1-ULTWR) x LUD | LU/year |
| EXINV | External Investment | EXINVini + STEP (EXINV4, 4) - STEP (EXINV4, 5) + STEP (EXINV5, 5) - STEP (EXINV5, 6) + STEP (EXINV6, 6) - STEP (EXINV6, 7) + STEP (EXINV7, 7) – STEP (EXINV7, 8) | Mill. € |
| FREIGHU | PH Freight Costs | FREIGSE x (1 – 0.0441) | € |
| FREIGSE | PS Freight Costs | $\varphi_5$ (GTMPS) | € |
| GDP | GDP | GDPini x EXP(GDPGR x Time) | Mill. € |
| GEWR | Goods-Entrance-to-Warehouses Rate | DR x TONUL | Ton/year |
| GME | Goods-to-Market Rate | (GERT x IF THEN ELSE (GW > (GDP/METON), (GDP/METON), GW) | Ton/year |
| GTIPSI | GT Increase in PS through Investment | IF THEN ELSE (PI = 0, 0, PI x IGTR x GTIUI) x ERI | GT/year |
| GTMPS | PS Medium GT | INTEG (GTIPSI, IGTMPS) | GT |
| GTLU | GT – LU Ratio | $\varphi_3$ (GTMPS) | Dmnls |
| GW | Goods in Warehouses | INTEG (GEWR - GME, IGW) | Ton |
| LS | Land Sales | STEP (LS3, 3) – STEP (LS3,4) + STEP (LS4, 4) – STEP (LS4, 5) + STEP (LS5, 5) - STEP (LS5, 6) + STEP (LS6, 6) - STEP (LS6, 7) + STEP (LS7, 7) - | Mill. € |

[18] Dimensionless.

26

| | | STEP (LS7, 8) | |
|---|---|---|---|
| LUB | Length Units that Berth every year | INTEG (LUER - LUER1, ILUB) | LU |
| LUD | Length Units in Docks | INTEG (EF – EXF, ILUD) | LU |
| LUER | Length Units Entrance Rate | (PSCT + PSPT x ED) x (1/TONUL) | LU/year |
| LUER1 | LUER delayed one period | DELAY FIXED (LUER, 1, 57) | LU/year |
| LUW | Length Units Waiting (from Lock to Dock) | INTEG (CHPSR – EF, ILUW) | LU |
| MDC | Maximum Dock Capacity | INTEG (DIPSI, DIC) | LU |
| MOORHU | PH Moorage Costs | $\varphi_{2HU}$ (GTMPH) | € |
| MOORSE | PS Moorage Costs | $\varphi_2$ (GTMPS) | € |
| P | Profit | TEUL x LUB + WT + PSAOI – PSAC | Mill. € |
| PCD | Port Costs Differential | ((PSC - PHC) / PSC) x 100 | Dmnls |
| PHC | PH Costs (LU that Berth at PH) | PHCGTM x TRIPH | Mill. € |
| PHCGTM[19] | PH Costs (Medium Vessel) | (0.003065 x GTMPH + 0.042912 x 6 x GTMPH + 1.0295 x TONGT x GTMPH + PILHU + MOORHU + FREIGHU + STOWHU) / $10^6$ + TCHTOS | Mill. € |
| PI | Public Investment | MAX (0, EXINV + UP x PIR + LS) | Mill. € |
| PILHU | PH Pilotage Costs | $\varphi_{1HU}$ (GTMPH) | € |
| PILSE | PS Pilotage Costs | $\varphi_1$ (GTMPS) | € |
| PSAC | Port Authority of Seville Costs | Cini x (1+ CGR)^Time | Mill. € |
| PSAOI | Port Authority of Seville Other Income | $I_{ini}$ x (1+OIGR)^Time | Mill. € |
| PSC | PS Costs (LU that Berth at PS) | PSCGTM x TRIPS | Mill. € |
| PSCGTM | PS Costs (mean vessel size) | (0.003065 x GTMPS + 0.042912 x 8 x GTMPS + 730.632 x 2 x (1/GTUL) x GTMPS + 1.40401 x GTMPS x TONGT + PILSE + MOORSE + FREIGSE + STOWSE) /$10^6$ | Mill. € |
| PSCT | PS Captive Traffic | CTER x TRAUX | Ton |
| PSPT | PS Potential Traffic | TRAUX – PSCT | Ton |

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[19] For the T1 tariff, second addend, 8 3-hour periods (2 days) have been considered for the Port of Seville and 6 periods (1.5 days) in the case of the Port of Huelva.

| | | | |
|---|---|---|---|
| REF | Dock Real Entrance Frequency | ERT x MIN (LUW, MDC - LUD) | LU/year |
| STOWHU | PH Stowage Costs | 2.28 x TONGT x GTMPH | € |
| STOWSE | PS Stowage Costs | 2.4 x TONGT x GTMPS | € |
| TCHTOS | Transport Costs from Huelva to Seville | 0.000003005 x TONGT x GTMPH | Mill. € |
| TEUL | Tariff Earnings per LU | $(0.003065 \times GTUL + 0.042912 \times 8 \times GTUL + 730.632 \times 2 + 1.40401 \times TONUL)/ 10^6$ | Mill.€ |
| TONGT | Ton – GT Ratio | $\varphi_4$ (GTMPS) | Dmnls |
| TR | Traffic Rate to hinterland | -409.74 + 0.2106x GDP | Thousands Ton |
| TRAUX | Traffic Rate to hinterland (auxiliary) | TR x 1000 | Ton |
| TRIPH | Traffic if PH is chosen | (PSPT x (1/TONGT))/GTMPH | Ships |
| TRIPS | Traffic if PS is chosen | (PSPT x (1/TONGT))/GTMPS | Ships |
| TRPS | Traffic Rate to PS | LUER x TONEL | Ton |
| TRPSAUX | Traffic Rate to PS (auxiliary) | TRPS/1000 | Thousands Ton |
| UP | Useful Profit | MAX (0, P) | Mill. € |

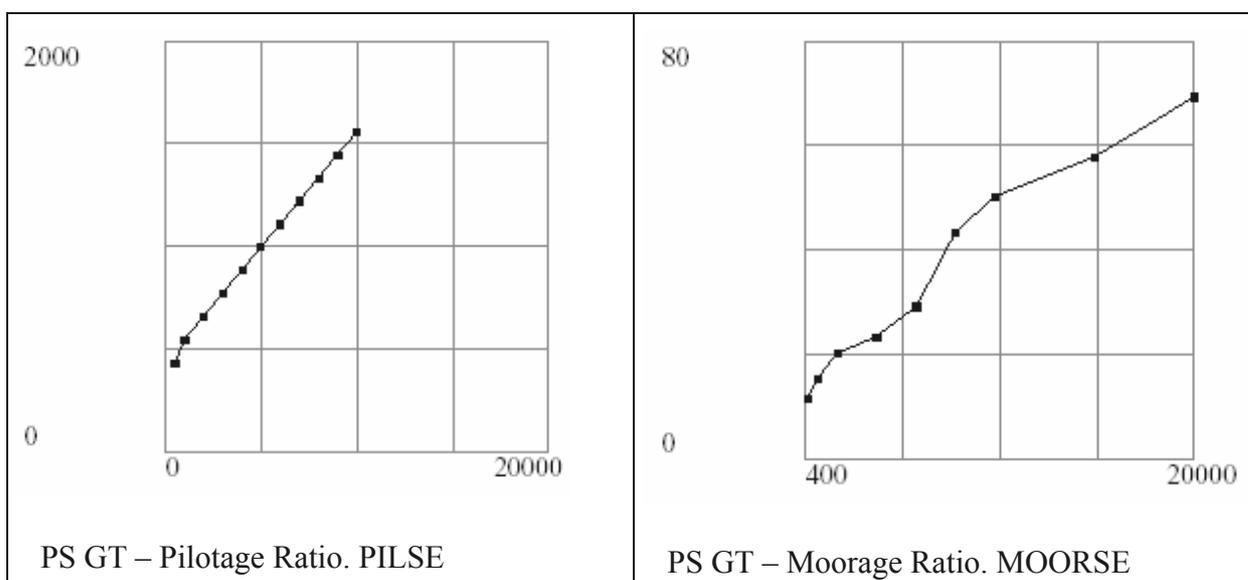Note: PS = Port of Seville; PH = Port of Huelva
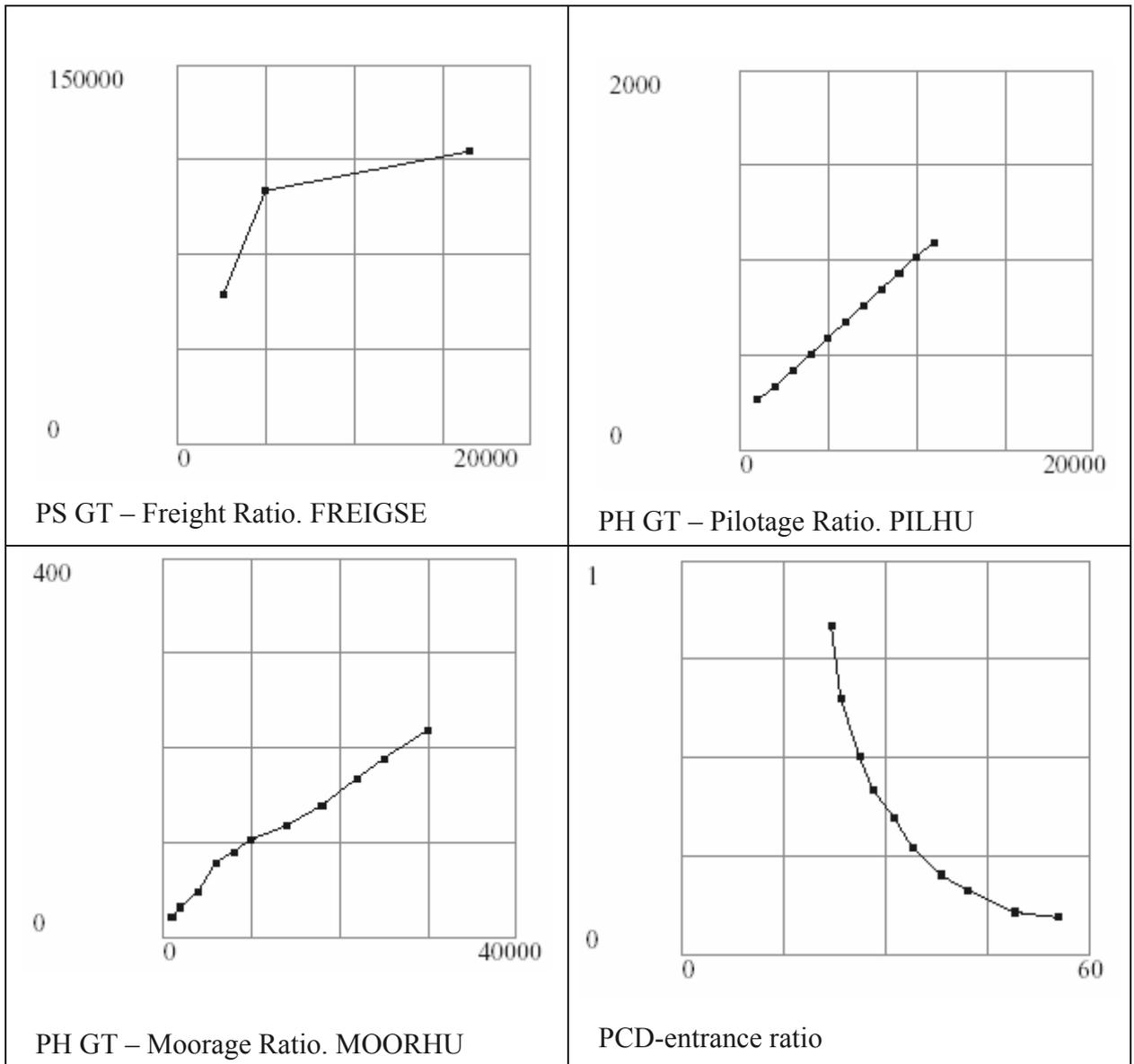
**Table 6. Model variables**.

| *Parameter* | *Definition* | *Value* | *Units* |
|---|---|---|---|
| CGR | Costs Growth Rate | 0.0799 | Dmnls |
| Cini | Initial Costs | 8.46 | Mill. € |
| CTER | Captive Traffic Entrance Rate | 0.6651 | Dmnls |
| DIUI | Dock Increase in PS per Unit Invested | 0.07134 | LU |
| DRT | Warehouse Discharge Rate | 1 | Ton/year |
| ERI | Works Execution Rate | 1 | 1/year |
| ERT | Dock Entrance Rate | 1 | 1/year |
| EXFNW | Exit Frequency of Ships not unloading in Warehouses | 1 | 1/year |
| EXINV4 | External Investment in 2004 | 16 | Mill. € |
| EXINV5 | External Investment in 2005 | 17 | Mill. € |
| EXINV6 | External Investment in 2006 | 16 | Mill. € |
| EXINV7 | External Investment in 2007 | 14 | Mill. € |
| EXINVini | Initial External Investment | 0 | Mill. € |
| GDPGR | GDP Growth Rate | 0.03 | Dmnls |

| Parameter | Definition | Value | Units |
|---|---|---|---|
| GDPini | Initial GDP | 19620.9 | Mill. € |
| GERT | Goods Exit Rate | 1 | 1/year |
| GTIUI | GT Increase in PS per Unit Invested | 29.06 | GT |
| GTMPH | Mean GT at PH | 15000 | GT |
| IDC | Initial Dock Capacity | 2.764 | LU |
| IDR | Investments in Dock Ratio | 0.08 | Dmnls |
| IGTMPS | Initial PS Mean GT | 4500 | GT |
| IGTR | Investments in GT Ratio | 0.92 | Dmnls |
| IGW | Initial Goods in Warehouses | 0 | Ton |
| Iini | Initial Other Income | 5.51 | Mill. € |
| ILUB | Initial Length Units that Berth every year | 57 | LU |
| ILUD | Initial Length Units in Docks | 0 | LU |
| ILUW | Initial Length Units Waiting (from Lock to Dock) | 0 | LU |
| LS3 | Land Sales in 2003 | 5 | Mill. € |
| LS4 | Land Sales in 2004 | 10 | Mill. € |
| LS5 | Land Sales in 2005 | 30 | Mill. € |
| LS6 | Land Sales in 2006 | 28 | Mill. € |
| LS7 | Land Sales in 2007 | 18 | Mill. € |
| METON | Mill. € per Ton | 0.0002467 | Mill. € |
| MWC | Max Warehouse Capacity | 665733 | Ton |
| OIGR | Other Income Growth Rate | 0.0812 | Dmnls |
| PIR | Profit Investment Ratio | 0.8 | Dmnls |
| TONUL | Ton – LU Ratio | 50000 | Ton |
| ULTWR | LU to Warehouses Ratio | 0.7 | Dmnls |
| WT | Warehouses Tariff | 1 | Mill. € |

Note: PS = Port of Seville; PH = Port of Huelva

**Table 7. Model Parameters.**



PS GT – Pilotage Ratio. PILSE

PS GT – Moorage Ratio. MOORSE

PS GT – Freight Ratio. FREIGSE

PH GT – Pilotage Ratio. PILHU

PH GT – Moorage Ratio. MOORHU

PCD-entrance ratio

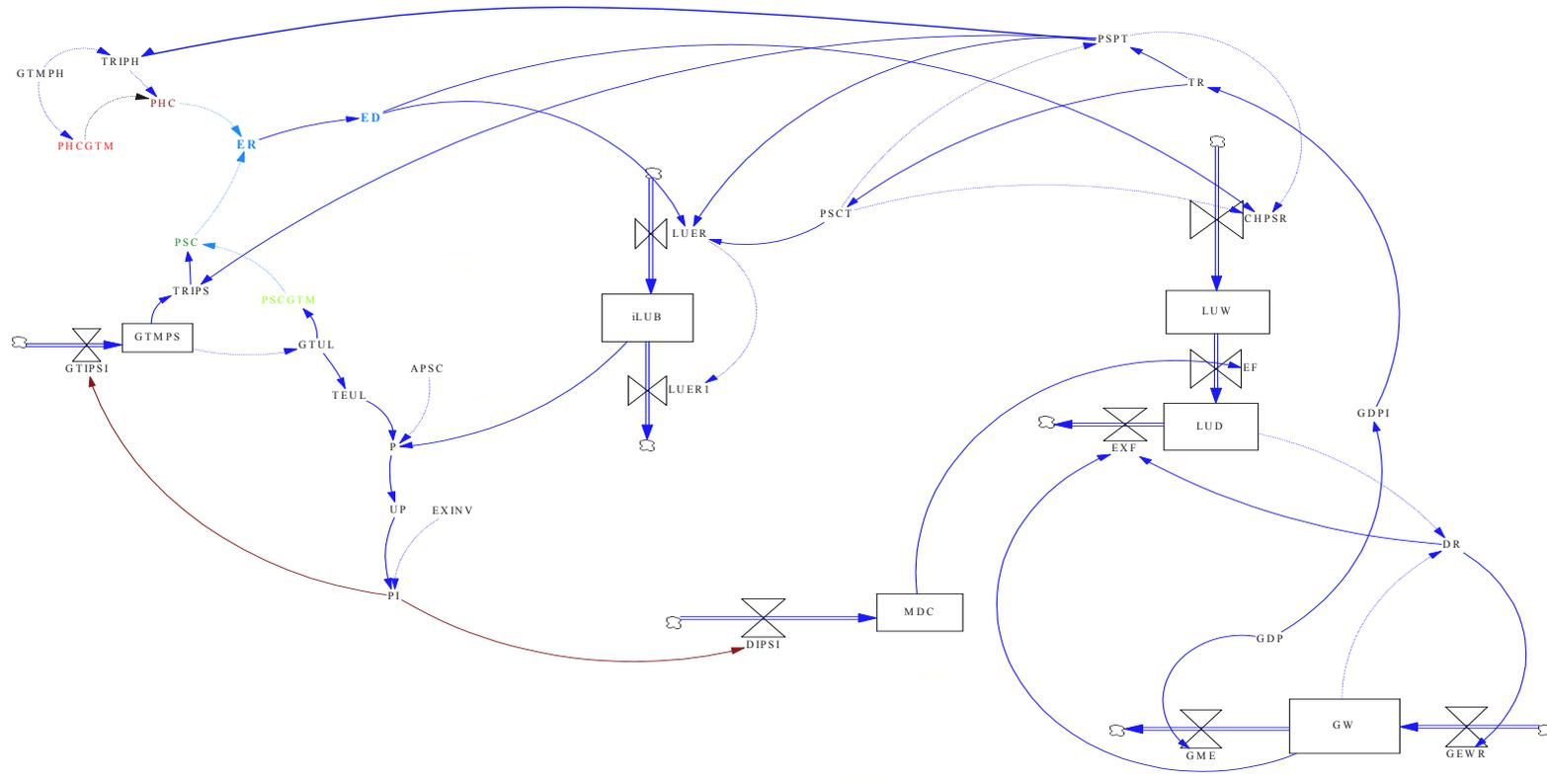**Figure 16. PILSE, MOORSE, FREIGSE, PILHU, MOORHU and PCD-entrance ratio lookups.**

**Figure 17. Model Overview.**

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