FITNESS: AN AGENT BASED MODELLING APPROACH TO FREIGHT INTERMODAL CHAINS

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Abstract

A major shipping company has recently decided to change its sea route from the port of Lisbon to the port of Sines, which is located around 200 km south. This change would mean a considerable increase in the continental distances, as the shipping company's hinterland stretched to north east of the port of Lisbon. Such increase of distance could originate an increase of the transport cost, which could ultimately undermine its competitiveness in the market. The option was to implement an intermodal transport solution that yield similar levels of transport costs.

The goal of this paper is to identify and evaluate the eventual model choice factors involved in the decision making process. To achieve that goal, the performance of two transport solutions (pure road from the port of Lisbon versus intermodal from the port of Sines) was analysed for the four main factors, as usually considered in the literature, namely: cost of transport, transit time, reliability and flexibility.

The results show that the intermodal transport service would perform worst in every quality factor (transit time, reliability and flexibility) than the pure road configuration, in a scenario with demand equal to the existent one. Improvements could be obtained, in all four factors, if demand increases up to the limit capacity of the rail link. Yet, even so, the intermodal transport solution would deliver quality than road transportation solution.

The main conclusion to draw is that price seems to have been the only factor taken into consideration in the decision making process. Consequently, the value of time seems to be near zero.

Keywords: freight, intermodality, performance, rail

1. Depicting the intermodal background

The shipping company[1] has had a regular shipping line to the port of Lisbon (Portugal). This port was centrally located in relation to the hinterland that roughly stretched from the centre of Portugal (Leiria) to the south of Portugal (Sines), and from the east (Lisbon) to the border with Spain at west (Vila Verde). The hinterland is represented in Figure 1. Table 1 depicts both the weight of each region of the hinterland, and presents by region the relative importance of exportation and importation flows. The destination Figueira da Foz is a special case, because it corresponds to a single client. Moreover, this client has a private connection to the national railway system.

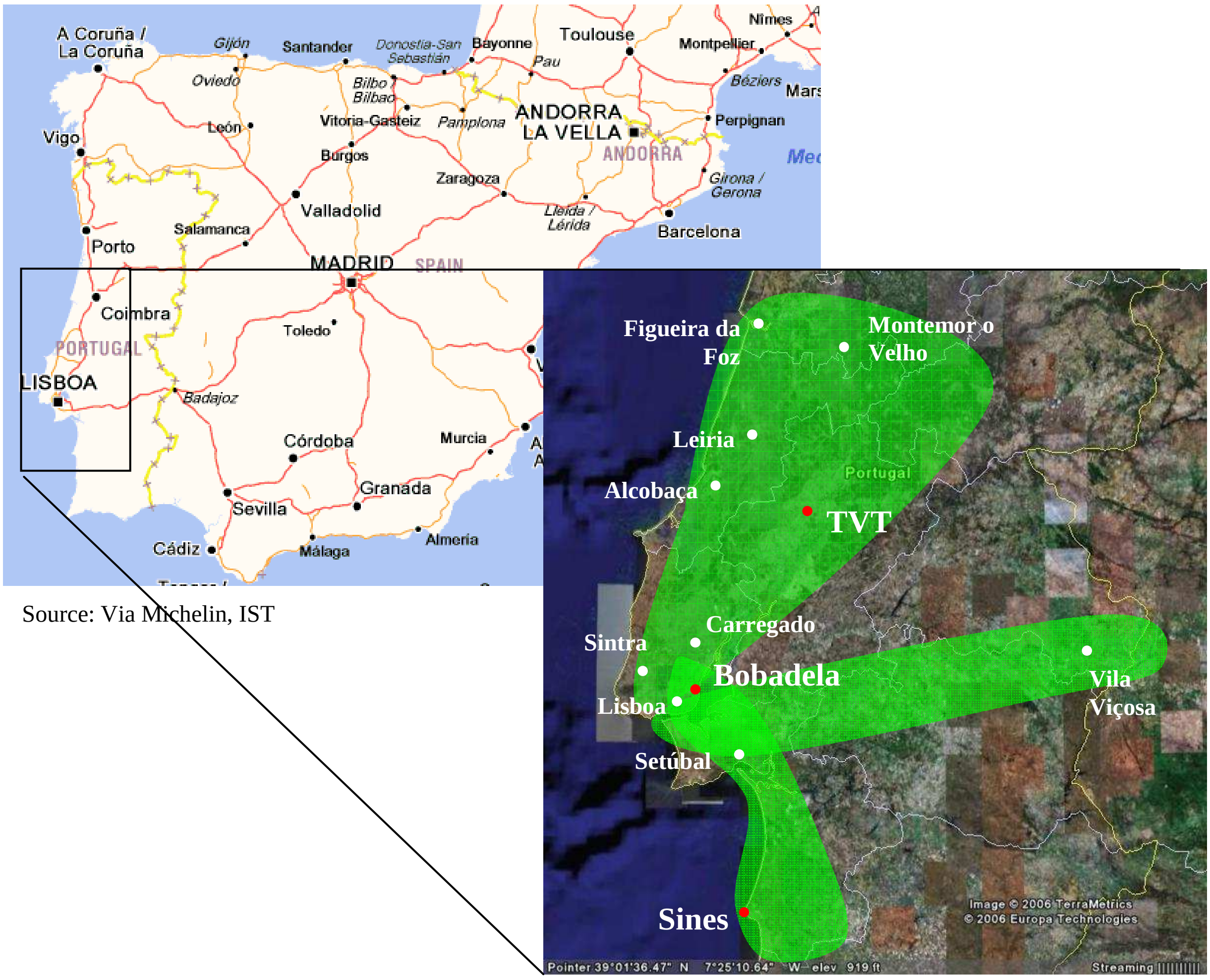
The SC offers transport service of containers from Portugal to the rest of the world. Yet, the majority of the traffic was to the Middle East and Asia. The range on the nature of the goods is quite widespread, owing to the fact that they are conveyed within containers. Nonetheless, exportations concern mainly natural products (such as marble and other decorative rocks), material for civil construction, waste paper, plastic scraps. On the importation side, the main products concerns goods for home and leisure (such as toys, appliances, clothing), alcoholic drinks, and iron. The products, in particular on the exportation side, tend to be of low unitary value and low depreciation rates.

Looking to these figures two main conclusions may be drawn. Firstly, more than 80% of the traffic is located in the east and nort regions. Secondly, although in overall terms exportation and importation flows are identically, they change considerably amongst region.

Owing to a broader strategic change in its global network, the SC has decided to move the shipping line south from the port of Lisbon to the port of Sines. Notwithstanding no official reason has been pointed out for this decision neither being relevant for the purposes of this paper, it is nonetheless possible to point out some factors. Firstly, the port of Lisbon is the busiest Portuguese port in terms of movement of containers, while the port of Sines (despite inaugurated in the sixties) had never had in practical terms any expression. Moreover, that time coincided with a new attempt of revitalising the port of Sines and attracting shipping lines. In these circumstances it is natural to assume the port of Sine would have offered more interesting conditions, than the port of Lisbon. Secondly, the port of Sines offers far better operational conditions than the port of Lisbon. The port of Sines, on the sea side, has virtually no restrictions being able to received and handle ships of any size (this is a sea port located in a zone of deep waters), while the port of Lisbon is located on a river with some restriction of the size of ships. On the land side, Sines also offered goods conditions. By that

[1] Owing to confidentiality reasons neither the name of the company nor any data would be disclosed. Therefore, the shipping company will be generically designated as SC and all data will appear in relative terms.

time it was fully equipped but had no shipping line, therefore, it was in position of offering very high efficiency levels (which would be difficult to attain by a busiest port like the Lisbon one). Therefore, Sines would possible offer better conditions than the port of Lisbon.



Source: Via Michelin, IST

Source: Google Earth, IST

Figure 1 – Hinterland of the Shipping Company

Yet, the port of Sines has a far worst location than the port of Lisbon (and this is the main reason for that port had never been able to attract shipping companies). Sines is located around 200 kilometres south the port of Lisbon (although this may not seem relevant, it should be interesting to note that Portugal is a relatively small country with a rectangle shape of 600 and 250 kilometres of dimension). Moreover, Sines is located in the middle south of Portugal a depressed economic region[2] with few economic activity (with the exception of tourism) generator of cargo flows. On the other hand, the port of Lisbon is located in the Lisbon city, which is the capital of Portugal and the most economically developed region in

[2] The wealthiest regions in Portugal are located between the border of Spain at north and the Lisbon region at south, and along the coast.

the country, which is reflected in the SC's business: the Lisbon area is a most relevant region (see Table 1).

Table 1 - Hinterland of the shipping company

Location of Region in the SC's hinterland		Export	Import	Total	Partial Total
North	Leiria	24%	76%	4%	
	Montemor o Velho	23%	77%	4%	
	Alcobaça	24%	76%	4%	
	Figueira da Foz	100%	0%	17%	***30%***
		64%	***36%***		
East	Lisbon	27%	73%	25%	
	Sintra	19%	81%	10%	
	Carregado	18%	82%	12%	
	Setúbal	56%	44%	6%	
		37%	***63%***		***53%***
West	Vila Viçosa	92%	8%	10%	***10%***
South	Sines	99%	1%	8%	***8%***
	Total	***46%***	***54%***	**100%**	**100%**

A move to Sines automatically implies an increase of the transit time and (eventually) costs because the continental leg increases as the hinterland is located far north. Consequently, a decision to move Sines would result in a loss of competitiveness versus the maintenance in the port of Lisbon and particularly versus those shipping companies that remained operating in this port.

Regardless the determinant reasons (which has already mention are irrelevant for the purposes of this paper) the fact is that the SC has decided to move to Sines. The SC has hired a Freight Forwarder[3] company for, in a first phase, drawing alternative transport solutions, and later on managing the transportation system.

As already referred, Sines is located roughly 200 kilometres south the south border of the SC's core hinterland. If moved by road, such distance would entail in practical terms to double the transport distance for many customers, and necessarily the transport costs. It was

[3] Although no information was possible to obtain on the actual reason leading to the change of ports, it was possible to obtain information on the rationale underlying the assemblage of the transport solution from the port of Sines, interviews with the Freight Forwarder, (which was called after the decision of moving to Sines has already been taken).

therefore necessary to find a suitable continental transport solution that would minimise the extra burden of moving the containers from Sines. A single factor was taken into account in the decision of the transport solution that was of not increasing the transportation costs, as the SC was not willing to pass into the customers any eventual increase. An eventual increase in the transit time was not considered as being relevant for the SC, as it was assumed the client would understand and adapt its production schemes accordingly.

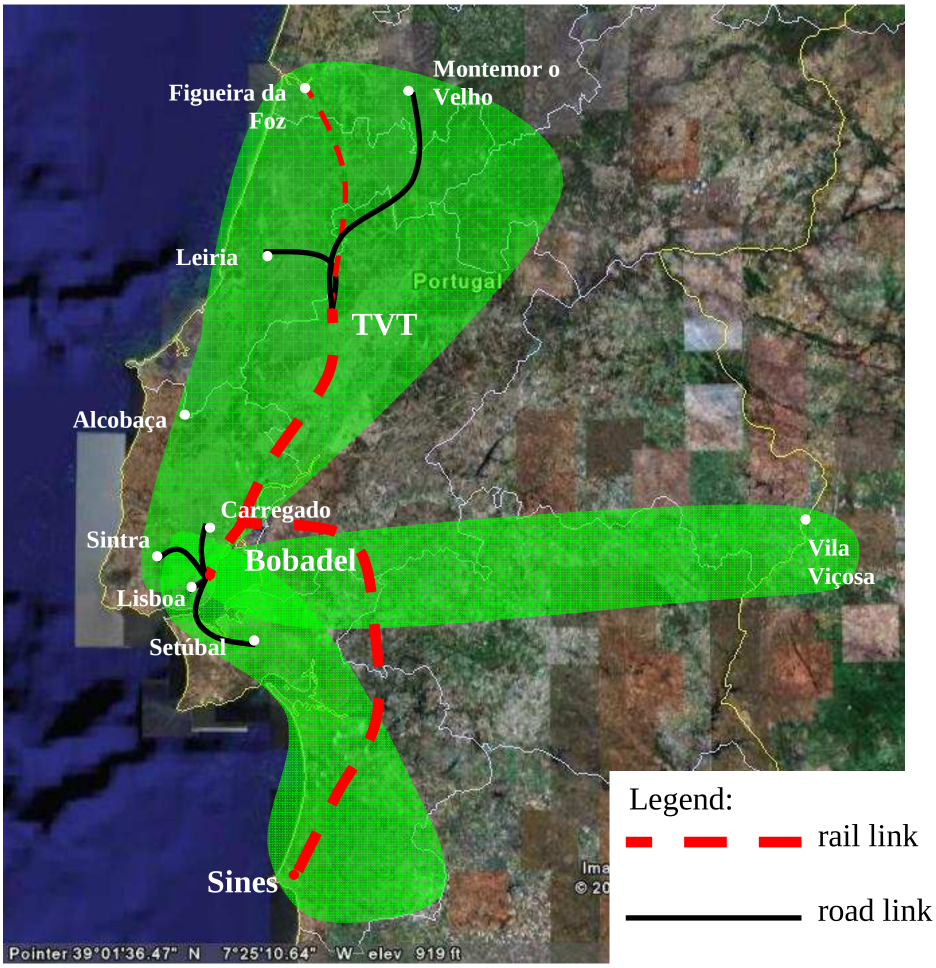
Under these conditions, the decision was to implement an intermodal transport, as depicted in the following scheme, involving two modes of transport: road and rail.

The rail leg provides the transport in between the port and the hinterland. Rail transportation can be more costly efficient than road transport, if demand is enough to enjoy from the economies of density. In situations of low demand or high capillarity with no concentration of flows between points, where is not possible or technically difficult to fill in train, this transport solution can hardly compete with road, owing to its high costs. On the other hand, in situations of high demand and high concentration of flows, train can be highly cost competitive against road transportation. This is the situation, in between the port of Sines and the hinterland. Furthermore, the transhipment terminals were chosen to be as near as possible of the core regions of the hinterland: central and north regions.

The Bobadela terminal is located near the Lisbon region and in the vicinity of the port of Lisbon. This terminal will receive containers to Lisbon, Sintra, Carregado, Setúbal and Vila Viçosa. The Riachos terminal is located in the middle of the north region, what would allow a reduction of the road transport costs (in comparison with the costs from the port of Lisbon), and will receive containers with destination of Leiria, Alcobaça, Figueira da Foz and Montemor o Velho. Figure 3 presents the distribution of expected demand for each terminal, and the weight of each link in total demand. The link port of Sines to Bobadela is not 100% because some of the demand is for the region of Sines and Vila Viçosa, which will be distributed directly by road (and not taken into consideration in this present analysis).

The road leg assures the capillary distribution to the customers, in between the transhipment terminals and the final customers.

This transport configuration maximises the rail leg and minimises the road leg, reflecting the concern of keeping the transports as low as possible. Thus, containers arriving to the port of Sines are transported by rail either to the terminal of Bobadela or Riachos, in function of the final destination and to minimise road transport, and by road from the terminal to the final customer.



Source: Google Earth, IST

Figure 2 – Intermodal transport service

The model business defined for the beginning of operations was, as already mentioned, exclusively based on the costs of transport. The main purpose was to not increased the overall transport costs. The following table presents the road transport costs for the services between the various terminals and respective destinations[4].

The table shows that, with the exception of Sines, all other destinations would suffer a significant increase in the transport cost if transported directly by road from the port of Sines. Conversely, the utilisation of the terminal in Riachos will result in a reduction of transport costs from the north region of the SC's hinterland, in comparison with the transport from the port of Lisbon.. The terminal in Bobadela does not change the road transport costs, because as referred the terminal is located near the port of Lisbon.

[4] These are the costs charged by the Freight Forwarder, who also is a Road Operator and that has initially provided the trucking services.

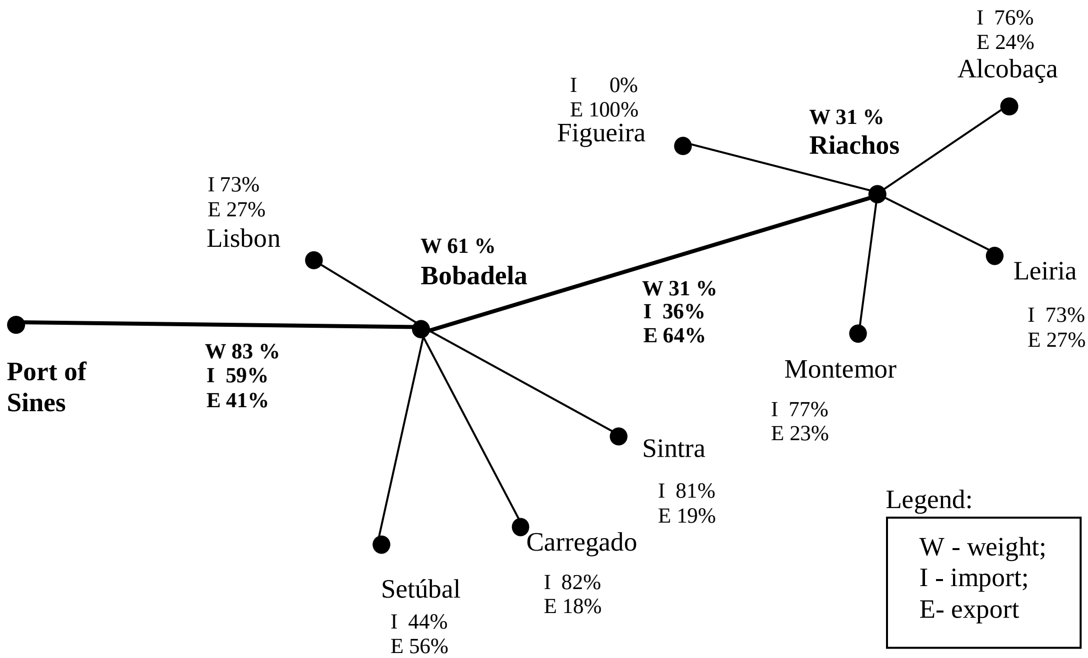


Figure 3 – Expected demand by destination and terminal

Table 2 - transport costs from the ports and terminals (*)

Location of Region in the SC's hinterland		Port of Lisbon	Terminal		Port of Sines
			Bobadela	Riachos	
North	Leiria	0%	-	46%	86%
	Montemor o Velho	0%	-	44%	36%
	Alcobaça	0%	-	35%	78%
	Figueira da Foz (**)	*-10%*	-	-	*320%*
East	Lisbon	0%	0%	-	115%
	Sintra	0%	0%	-	110%
	Carregado	0%	0%	-	74%
	Setúbal	0%	0%	-	53%
West	Vila Viçosa	0%	-	-	135%
South	Sines	0%	-	-	54%

(*)Percentage increase in relation to the cost from the port of Lisbon. Therefore, 0% in increase corresponds to the minimum distance.
(**)This client owing to its dimension benefited from a 10% reduction on the road transport services

The negotiations with the Portuguese rail operator - Caminhos de Ferro (CP) - where conducted to yield similar costs to the initial conditions (from the port of Lisbon). This resulted in a rail transport service with the following characteristics:

- The transport product is a block train. By default a block train is composed of 11 trailers, that can convey 44 TEUs (22 containers of 40 feet, or 44 containers of 20 feet);
- The cost of train is 2857% the minimum road transport service.
  - If fully loaded (2 x 44 TEUs) the cost per containers is 32.5% of the minimum road transport service;
  - The rail service was dimensioned for an average loading factor of 70%, which corresponds to a cost per containers of 46.4% of the minimum road transport service;
- The trains leave from either Bobadela or Riachos, and have to necessarily return to the origin point (may not start at Riachos, but can end in Riachos is needed);
- By default one block train will operated per week day (5 block trains per week) between Riachos - Bobadela - Sines - Bobadela - Riachos;
- The transit time are as follows:
  - Bobadela - port of Sines: 5 hours and 25 minutes;
  - Riachos - port of Sines: 14h and 25 minutes.
- It is possible to cancel, request new, or request longer trains as long as deadlines are respected:
  - Cancelation - minimum of 24 hours in advance (otherwise train is charged);
  - Request - minimum of 48 hours in advance (normal charge).
    - maximum of 12 trains per week (2 trains per day from Monday to Saturday);
  - Extension - minimum of 48 hours in advance, and up to 14 trailers (no extra charge).

The configuration for the operation of this intermodal transport system is schematised in the following picture (Figure 4). There are seven agents working together to provide the intermodal transport service. The main roles of each one are as follows:

- *Client* either buys transport services to the Shipping Company, or is the consignee of one or more containers.
- *Shipping Company*:
  - Negotiates with the Client transport services: door to door maritime transport;
  - Notifies the Freight Forwarder on the amount and origin (in case of exportation) or destination (in case of importation) of containers, and schedule of ships;
- *Freight Forwarder*:

- o Manages the intermodal transport chain with consists in:
  - To hire road transport services;
  - To cancel or request block trains;
  - Customs clearance of containers.
- o *Port handling company* unloads and loads ships and trains;
- o *Terminal Operator* unloads and loads trains and trucks;
- o *Rail Operator* is in charge for the rail leg;
- o *Road Operator* is in charge for the road leg.

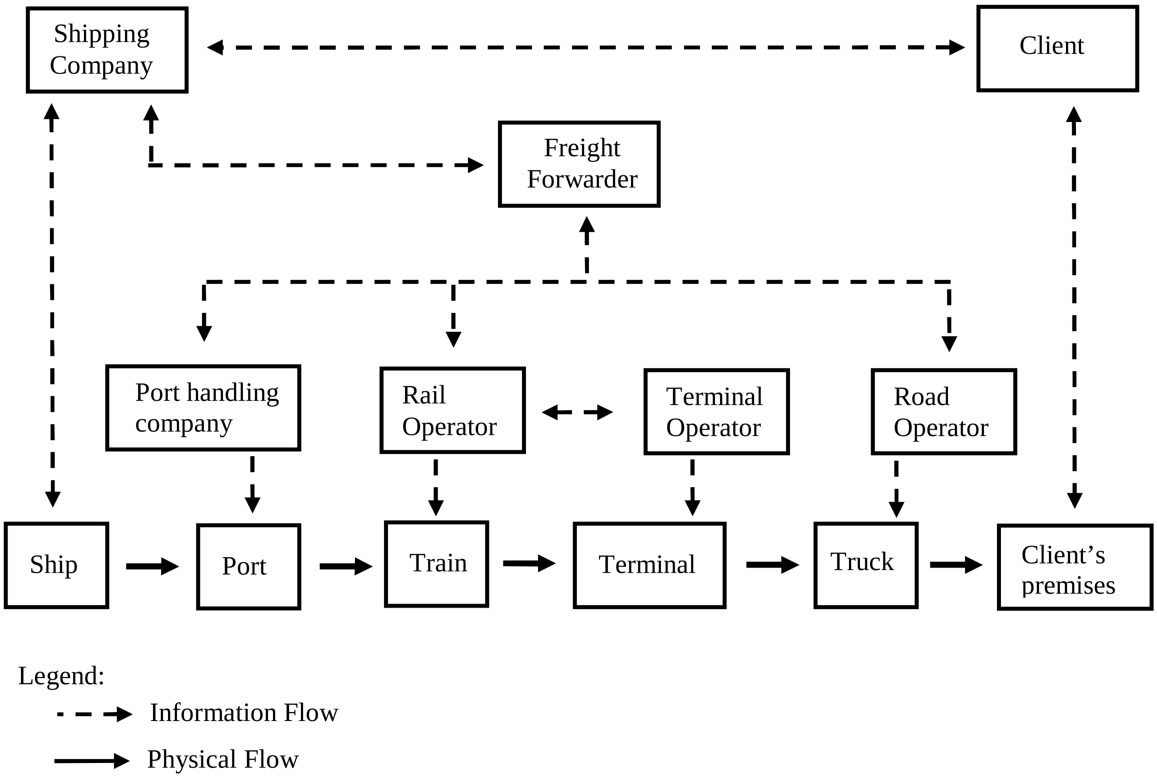


Figure 4 - Organisation of the intermodal transport service

The SC has planned to have three ships per week (Monday, Wednesday and Friday) arriving mid afternoon (16 hours). In terms of operations, SC requests that all containers should be in the client's premises in a maximum period of 72 hours (3 days), which means that containers can only stay up to 48 hours in the port of Sines.

Recalling the condition described so far and looking into the organisational scheme results the risk of this transport service lies entirely in Freight Forwarder and consequently in SC. Rail operator takes no risk both because train are paid in both directions (terminal - port - terminal) even when there are no containers in one of the directions, and secondly because deadline are considerable bearing in mind that in exportation a considerable fraction of service are hired up to 36 hours of the ship departure, and the arrival of the ship is not reliable (owing to unpredictability of weather conditions). Moreover,

The Freight Forwarder's main task is to optimise the system in order to minimise the transport costs, while respecting the maximum transit times. In this system, the largest unitary cost corresponds to the rail service, therefore, the main purpose resumed to maximise the train operations (while respecting the transit times).

2. The analytical model

2.1. Structure of the model

Recalling that the overall purpose of the research was to compare and study the relative competitiveness of the intermodal transport service versus an eventual pure road transport service; two micro level simulation models[5], based on agent technology, have been developed. One model recreates the intermodal transport service, while the other recreates the pure road transport service. Yet, the basic architecture is identical, and based on two levels: one level simulates the physical flow of containers, and the other level simulates the decision making process.

Both models recreate the import side of the business, which raises a question worth of analysis. A major issue in the profitability of rail operations is the ability of balancing flows. Because in case a journey has low demand, the fixed costs of rail transport will inevitably increase the unitary cost per container. And this situation is particularly important in the present research, because the portuguese rail operator charges both directions. Yet, from Figure 3 we may conclude the existence of a significant balance in both flows from the port of Sines to Bobadela; therefore, we do not to expect that issue to be relevant in this research[6].

The data feeding the models was obtained both from the freight forwarder's records and from the real field operations, as the intermodal transport has already entered in service for some time now. During the description of the models below, reference will be made on the origin of the data. The model concerning the intermodal transport service mirrors the actual transport service (Figure 5) while the model of the pure road service is a simplification, which corresponds to the elimination of the rail operator.

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[5] The models were developed using the agent based software: AnyLogic 6.0 Educational Version (www.xjtek.com)

[6] The unbalance in the link Bobadela - Riachos is not significant because the rail operator does not surcharge for this link. Therefore, the Freight Forwarder can transport the containers to Riachos with no extra costs.

The agents built in each model, and the overall architecture are depicted in the following schemes. The total number of agents is of 10 agents in the intermodal transport model (Figure 5) and of 7 agents in the pure road transport model (Figure 6).

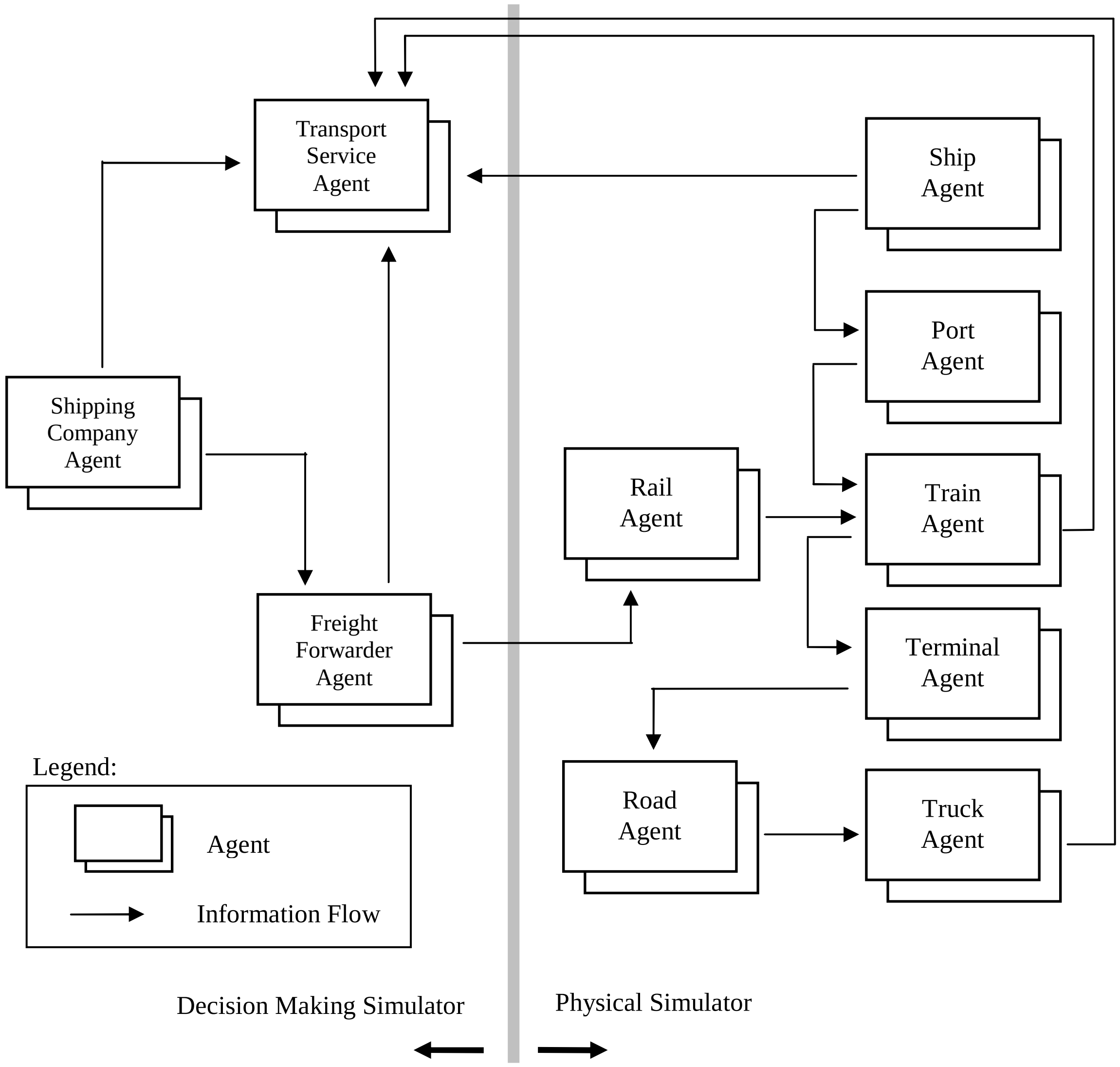


Figure 5 - Intermodal transport service model

The *transport service agent* represents each transport order placed by the customer. In the model, this agents gathers all relevant information concerning its status and properties, namely:

- destination;
- expected time of arrival of the ship to the port;
- effective time of arrival of the ship to the port, time of unloading and ready for transport, time of loading on train or road (depending on the model), time of start and end of the rail leg (only for intermodal transport model), time of unloading from the

train and loaded on the truck (only for intermodal transport model), time of start and end of road leg;

- o actual cost of road and rail legs journeys;

In the model this agent does not have any active behaviour, instead he gathers and provides information to the other agents.

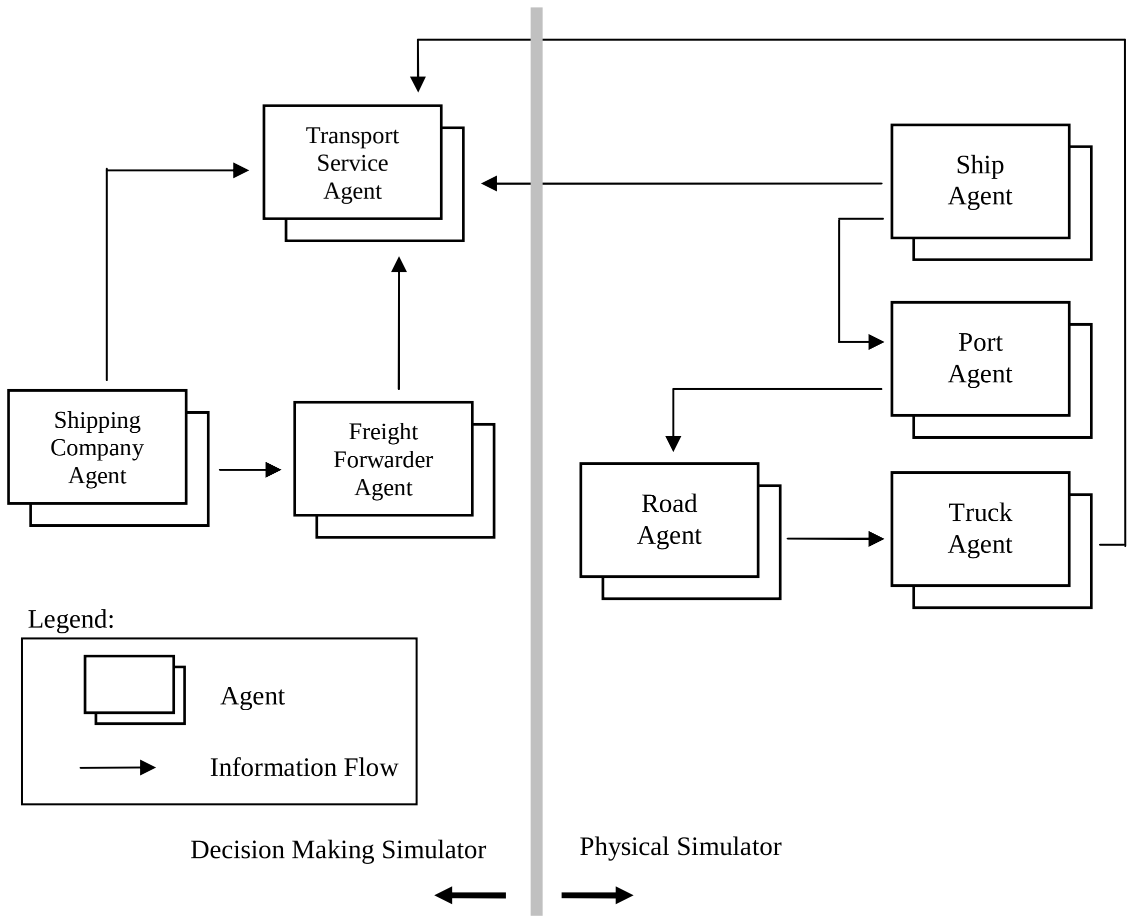


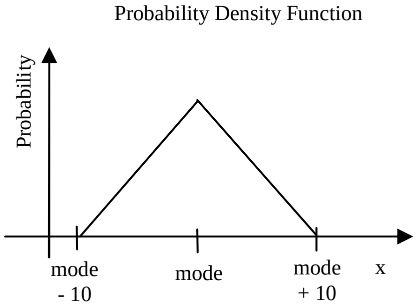
Figure 6 - Pure road transport service model

The *shipping company agent* represents the SC and the client. This agent is solely responsible for the generation of the list of containers for every shipment. Its behaviour was constructed to mirror the real world behaviour.

In terms of the number of shipments by week, 3 shipments are generated by week (Monday, Wednesday and Friday).

Demand ranges between minus and plus 10 containers the expected demand. It was therefore decided to implement on the model a random triangular distribution, with the following profile and equations (Figure 7) , to simulate demand behaviour. The distribution of the containers per destination follows the average weight of each one, as presented in Table

1. A ship is generated 48 hours in advance expected arrival, and the list of containers is sent to the freight forwarder agent. The same amount of time of what happens in real operations.



let u being a random number uniformly generated between [0, 1]

$$x \begin{cases} \min + \sqrt{u\,(\max - \min)(\text{mode} - \min)} & if\ \ u \le \dfrac{\text{mode} - \min}{\max - \min} \\ \max - \sqrt{(1-u)\,(\max - \min)(\max - \text{mode})} & else \end{cases}$$

$$x \begin{cases} \text{mode} - 10 + \sqrt{200u} & if\ \ u \le \dfrac{\text{mode} - \min}{\max - \min} \\ \text{mode} + 10 - \sqrt{200(1-u)} & else \end{cases}$$

Figure 7 - Distribution used for simulating demand

The *ship agent* represents the ships of the SC. This agent is generated by the shipping company agent, who sends the information concerning the expected arrival time to port and list of containers. The real field operations reveal ships are not highly reliable, with a considerable probability out of schedule (either late or earlier). Ships are due to arrive around the 16 hours, yet real behaviour reveals being unpredictable. Data from real world enable to build the following profile of arrivals:

- 5 % Arrival earlier (in the morning);
- 70 % Arrival on schedule;
- 10 % Arrival late (next morning);
- 10 % Arrival late (next day);
- 5 % Arrival late (next day and half);

Time arrivals are discrete because ships may only enter into the port in some determined hours of the day. When into the port, this agent notifies the port agent to begin unloading of containers.

In case of change of arrival time, the freight forwarder is warned 24hours after the ship's generation. Once again, this time is the same of what happens in real world operations.

The *port agent* represents both the port authority and the handling companies within port. This agent is responsible for unloading the containers from ship and subsequently loading them either on the train (in case of the intermodal transport model) or truck (in case of pure road model). The port agent productivity was defined based on interviews with employees. For the ship unloading process was defines a random function following a triangular distribution, with mode of 20 containers per hour, and maximum and minimum values of 25 and 15 containers per hour.

In what concerns the train loading process, productivity ranges between larger intervals. The issue is that the time of loading depends on the distance of the reach-stacker's initial position to the container and from this to the trailer. Nonetheless, there was a consensus in the upper level of productivity of 20 containers per hour. In function of this information the following random function was implemented to simulate the trailer hour productivity:

let x being the hour productivity measured in number of containers per hour

$$u \sim \mathrm{N}(20, 4)$$

$$x \begin{cases} \mathrm{u\ if\ u} \geq 20 \\ 20\ \mathrm{else} \end{cases}$$

The productivity of the truck loading process is higher than the train process, because the truck can park near the train, the terminals' hour productivity is higher than in the port. The hour productivity was defined as follows:

let x being the hour productivity measured in number of containers per hour

$$u \sim \mathrm{N}(24, 4)$$

$$x \begin{cases} \mathrm{u\ if\ u} \geq 24 \\ 24\ \mathrm{else} \end{cases}$$

Finally, it was assumed a daily working period of 12 hours (from 8 to 20 hours), during which train or truck handling activities may occur (ship handling activities run 24 hours per day).

The *rail agent* represents the rail operator and, therefore, it is only implemented in the intermodal transport model. This agent receives and evaluates the requests of the freight forwarder agent to cancel, add or resize trains. The behaviour of the rail agents follows the lines of the agreements established by the Portuguese railway operator, and the freight forwarder and SC (explained above). In case of a change to the default schedule situation, the trains' timetable is updated accordingly. Moreover, this agent is responsible for the timely generation of the train agents, in function of the time table.

The *train agent* represents the trains (and, once again, this agent is only implemented in the intermodal transport model). Because, the model only simulate import flows, train start from the port of Sines. In function of the current timetable, there is time window with a minimum of three hour for loading the train. In the models, trains are available for loading three hour before departure. When a train arrives to the port, the loading process starts following the port agent's productivity. Whenever, a train is generated the bill is sent to the freight forwarder agent, and the rail leg cost per container is computed.

Real world behaviour shows train's transit time is not total reliable, existing some fluctuations, yet variability is discrete. In railways operations, trains' timetables are defined based on slot availability, which means that in case of delay, a new slot needs to be requested. This means that the distribution of the train's transit time is not continuous but instead discrete, depending on the rail operator's slot availability. In the models, the engine for the simulation of the transit times was built from information collected from the field. The next table presents the transit time for the two rail legs, reliability and delay. Reliability[7] was obtained from record data sheets and interviews.

Table 3 - Train's operations reliability and transit time

Leg	Transit Time [hours]	Reliability [%]	Delay Time [hours]
Port of Sines - Bobadela	5.4	85	4
Bobadela - Riachos	9	70	4

The *terminal agent* represents the terminal operator and terminal handling operator (once again, this agent is only implemented in the intermodal transport model). This agent is responsible for handling containers in the terminals, namely: unloading from trains and loading on trucks. For the computation of productivity, it was used a function similar to the port agent, model of pure road transport.

Again, like in the port agent, it was assumed a daily working period of 12 hours (from 8 to 20 hours), during which train or truck handling activities may occur (ship handling activities run 24 hours per day).

The *road agent* corresponds to the road operator, and has the mission of providing road transport services. This agents generates the truck agents in request of the port agent, in case of the pure road transport model, or terminals in case of the intermodal transport model. The cost of a transport service is deterministic and a function of distance. The cost table used in both model corresponds Table 2.

It was made a simplification in the model concerning the requisition of road transport services. In real world, upon a requested for a transport service, the road operator depending upon availability of vehicles and a set of factors (such as distance, customer's loyalty, quantity, etc.) formulates a proposal, which may follow a negotiation process. In the model, there is no negotiation, meaning the price is fixed. Such situation may introduce some bias, because road operators could offer lower proposals. The decision for not including

[7] Reliability is defined as the ration between the total number of arrivals on time over the total number of trips, in percentage.

negotiation process was, firstly, because (and at least in the first times) road transportation would be provided by the freight forwarder operator, which would follow the a fixed cost table; and, secondly, due to the absence of information on the level of discounts and real nature of the negotiation process.

The *truck agent* corresponds to the truck operations. A truck agent is generated whenever the road agent receives info from the terminal (in case of the intermodal transport model) or port (in case of the pure road transport model) on the existence of a container for transport. This means that the truck 'materialises' in front of the train whenever a new container is ready for departure, which is a simplification from the real world. In real world operation the road operator sends their trucks to the origin points in function of order and schedules. This simplification was introduced, because information collect from the freight forwarder indicates trucks are always available and the common situation is the truck waiting for the arrival of the train. Since, the truck awaiting for the train does not increase the cost of transport nor the total transit time, we decided to introduce this simplification.

The transit time was modelled based on information gathered from the freight forwarder operations. The next table presents the distances between meaningful pairs, along with the average speed. The reasoning is to increase the average speed with distance.

Table 4 - Matrix of distances and road speeds

Destination	Bobadela	Riachos	Sines
Alcobaça	-	75 km (60 km/h)	235 km (65 km/h)
Carregado	30 km (50 km/h)	-	165 km (65 km/h)
Leiria	-	60 km (60 km/h)	260 km (65 km/h)
Lisbon	20 km (50 km/h)	-	160 km (65 km/h)
Montemor o Velho	-	115 km (65 km/h)	330 km (65 km/h)
Setúbal	km (55 km/h)	-	
Sintra	40 km (50 km/h)	-	180 km (65 km/h)

In real world operations, the freight forwarder recognised a considerably variability of the transit times owing to external factors, such as: congestion or accidents. Nonetheless, maximum average speed was limited to 75km/h. The following function was used to simulate the behaviour of the truck's transit times.

let x being the truck speed measured in kilometres per hour

let y being the average truck speed taken from Table ??

$$u \sim \mathrm{N}(\mathrm{y}, 0.1 * \mathrm{y})$$

$$x \begin{cases} 75.\ \mathrm{if}\ \mathrm{u} \geq 75 \\ u\ \mathrm{else} \end{cases}$$

Road operations' costs are allocated to the transport service whenever a truck agent is generated. Finally, it was assumed truck operations only occur during working period from 8 to 20 hours.

The *freight forwarder agent* represents the freight forwarder, and it is the agent responsible for the assemblage and optimisation of the transport service. In the pure road model, the actual work of freight forwarder is rather limited since road operations are quite deterministic: price is fixed and road agent has infinity availability of trucks. Yet, in the intermodal transport model, the freight forwarder performs a key role in the model (just like happens in real world operations). Knowing the list of containers and the expected time of arrival, this agent evaluates the supply of containers up to 48hours (after the ship's expected arrival). If supply is enough, nothing is done; otherwise, either new trains are required or more trailers are required (respecting a minimum period of 48 hours in advance) in function of demand. If trains are expected to arrive but there are no containers on the port, then trains are cancelled (respecting a minimum of 24 hours in advance).

2.2. Interaction Protocol

An agent based model works by triggering agents behaviour in some way and letting them to interact. Through monitoring some variables, the system's behaviour and properties are evaluated. In any models, the following actions take place in any order, in function of the specific characteristics of the system.

1 Shipping Company Agent
   - 1.1 Generates a ship with a list of containers;
   - 1.2 Generates Transport Services Agents;
   - 1.3 Sends information to the Freight Forwarder Agent;

2 Ship Agent:
   - 2.1 If any, sends information to Freight Forwarder Agent on its schedule status (on time, early arrival, late arrival);
   - 2.2 If any, upon arrival on port notifies Port Agent;

2.3 Sends information to every Transport Service for updating status and time variables;

2.4 Upon completion of journeys, it is terminated;

3 Port Agent:

3.1 On the sea side:

3.1.1 If ship on port, retrieves information on the list of containers from Ship Agent - unloading process;

3.1.2 Sends information to every Transport Service Agent for updating status and time variables;

3.2 On the land side:

3.2.1 If train and containers on port and within working hours, loads containers on trains (only in intermodal transport model);

3.2.1.1 Notifies train agent on the list of containers on board;

3.2.2 OR, If containers on port and within working hours, loads containers on trucks, and sends request of truck to road agent (only in pure road transport model);

3.2.3 Sends information to every Transport Service for updating status and time variables;

4 Rail Agent:

4.1 Evaluates requests upon request of freight forwarder agent for cancelling, adding, or resizing trains;

4.2 Generates trains;

4.3 Sends information to Freight Forwarder updating information on rail costs;

5 Road Agent generates truck agents upon request of either terminals or port agents;

6 Train Agent:

6.1 Upon arrival on terminal, notifies terminal agent on the list of containers for unloading;

6.2 Sends information to every Transport Service Agent for updating status, time variables and costs;

7 Truck Agent sends information to every Transport Service Agent for updating status, time variables and costs;

8 Terminal Agents:

8.1 Upon notification of train, retrieves information on the list of containers from Train Agent - unloading process

8.2 Send request of new truck for Road Agent, and sends info on the Transport Service to newly created Truck Agent - loading process;

8.3 Sends information to every Transport Service Agent for updating status and time variables;

9 Freight Forwarder Agent:

9.1 Upon receiving information from Shipping Company Agent or Ship Agent, evaluates supply and demand, and if necessary, sends request to Rail Agent (only in intermodal transport model);

10 Transport Service Agent receives or provides information from and to all other agents;

2.3. Model Variables

In order to be able to evaluate the performance of both models, some variable were monitored along the simulations. In this paper, it is known that the cost was the key factor taken into consideration by the SC. Yet, it is unknown if any other variable was as a matter of fact considered. Moreover, regardless being or not other factors used in the decision making process, it is relevant to understand the behaviour of other variables in different transport system configurations.

The literature is nor consensual on the key factors on the decision making process. The problems is that modal choice process is still a not well understood process and the evidence is the vast amount of literature dedicated to the subject, particularly, in the identification of the decision markers' key attributes or factors for modal choice. Contributing for this situation, besides its inherent complexity and dynamics, it is the considerable subjectivity involved in the decision making process, which often yields non-rational (or logical) situations.

In its work in 1990, later on updated by Paul Murphy and Patricia Hall in 1995 (Murphy et al., 1995), McGinnis compares twelve studies on modal choice process in the United States before and after the 1980 transportation deregulation process (McGinnis, 1990, pp 13). Deregulation in the United States brought a growth in competitiveness and complexity, as freight transport suppliers began competing each other and freight shippers began imposing new demands and conditions for their transport services. Nonetheless, McGinnins acknowledges that shippers' priorities have not changed with this process (McGinnis, 1990, pp 17).

For his literature review, McGinnis identifies six chief attributes in modal choice process, being: freight rate, reliability, transit time, safety, shipper market considerations and carrier considerations (McGinnis, 1990, pp 14). The author does not ranks these variables, nevertheless he refers that freight rates although of being important, are often overcame, by the other quality attributes (McGinnis, 1990, pp 17). Paul Murphy and Patricia Hall went a little further and ranked the McGinnis' attributes, being: first, reliability; second, freight rates;

third, carrier considerations; fourth, transit time and shipper market considerations; and sixth, safety (Murphy et. al., 1995, pp 35).

In their seminal work, Jeffs et al. (1990) analysed the modal choice process in the industrial category of paper, printing and publishing sector, in the region of West Yorkshire (United Kingdom). The purpose was the identification of the key influential variables in that process.

Authors found out evidences of bias in the process: firstly, they identified some sort of loyalty to either transport supplier or mode of transport (either because of inertia to change or actually good service); and secondly, they found out that there is a cut-of point for the process of searching for alternative transport solutions (because it is a costly process) (Jeffs et al., 1990, pp 33). Both situations introduce some lack of transparency and rationality to the process.

The study comprehended one hundred interviews, in which it was asked to identify the most relevant attributes influencing modal choice. Using factor analysis technique, authors identified most significant variable in explaining modal choice process, being: reliability, monitoring, safety, security, transit time, flexibility, length of haul and size of shipment (Jeffs et al., 1990, pp 44). The costs of transport were not found to be significant in these industrial sector.

Cullinane et al. (2000) conducted an extensive literature review to some seventy five bibliographic references on route and mode choice (with a geographical focus in Western Europe). The emergence of Stated Preference techniques and the need of offering respondents a manageable array of alternatives have led the authors to identify the major attributes in the modal choice process (Cullinane et al., 2000, pp 41). Following the content analysis methodology, they have identify five key attributes influencing mo1dal choice process, being: cost, speed, transit time reliability, characteristics of the goods, and service[8] (Cullinane et al., 2000, pp 49).

Norojono et al. (2003) conducted a stated preference technique to a set of freight shippers of Java Island (Indonesia) to determine the most relevant modal choice criteria for road and rail transportation. Reliability, safety and flexibility were ranked amongst the top three (Norojono et al., 2003, pp 207). On the other hand, cost and transit time were not seen as much relevant as expected. These situations have to do with market geographic specificities. In what concerns the former, in Indonesia transport costs are passed on to the consumers and

[8] Service is by itself a subjective variable and depends upon the transport decision maker's perspectives or expectations (Cullinane et al., 2000, pp 49).

cost structure is rather similar across industry; while concerning the latter, in Indonesia there is a great tolerance towards time and costs (Norojono et al., 2003, pp209).

The European Commission founded project Intermodal Quality (IQ) was carried out with the purpose of improving the quality of intermodal transportation within European Union (INRETS, 1999, pp 5) and ultimately fostering this type of transport solution. IQ acknowledges that quality attributes may vary in function the nature of goods, type of freight shippers and length of the transport service. In this way, twenty three freight transport market segments have been identified (INRETS, 1999, pp 20). Nonetheless, IQ identified a core group of quality attributes that tend to be present in modal choice process, albeit the relative weight of each one, differs amongst segments. The segments are: time indicators, reliability, flexibility, qualification, accessibility, monitoring, and safety and security (INRETS, 1999, pp 13-14)

The LOGIC project identified the main actors in the decision-making process and to provide information on underlining criteria and constraints in the use of intermodal transport (GRUPO CLAS, 2000, pp 6). In order to identify the key modal choice variables, LOGIC has proceed to a set of interviews to some transport decision makers, namely: freight forwarders, freight shippers and shipping lines (GRUPO CLAS, 2000, pp 37). The group has been segmented in function of the type of decision orientation, namely: cost oriented, quality oriented, and specific group. The cost oriented group has on price its main decision attribute. Any change on price has significant consequences of modal choice process. Quality is perceived as a by-product and therefore not fundamental for transport decision. On the other hand, for the quality oriented group both quality factors and cost are equally evaluated in the modal choice process. The key quality factors are: reliability, flexibility, safety and frequency. Finally, on the specific group cost and quality play different roles upon the type of specificity (GRUPO CLAS, 2000, pp 40).

The following table gathers the attributes found by the authors just reviewed and adds some others.

Table 5 - Most relevant modal choice factors

Author	Quality attributes
Oum (1979)	Transit time Reliability
McGinnis (1989)	Price Transit time Reliability Safety Shipper market considerations
McGinnis (1990)	Reliability

Updated by Murphy et al. (1995)	Freight rates Carrier considerations Transit time and shipper market considerations Safety
Jeffs and Hills (1990)	Reliability Monitoring Safety Security Transit time Flexibility Length of haul Size of shipment
Norojono (1990)	Reliability Safety Flexibility
Matear et al. (1993)	Fast response to problems (flexibility) Safety Punctuality Availability of freight space High frequency of service
Jovicic (1996) as quoted by De Mayer et al (2003, pp 27)	Transit time Reliability Price Customer service level Flexibility
Murphy et al. (1997)	Reliability Equipment availability Transit time Pick up and delivery service Freight suppliers' financial stability Operating personnel
INRETS (1999)	Reliability Flexibility Qualification Monitoring Safety Security
Cullinane (2000)	Cost Speed Transit time Reliability Characteristics of the goods Service
GRUPO CLAS (2000)	Reliability Flexibility Safety Frequency
Shinghal, N and Fowkes T (2002)	Frequency of service

	Reliability Transit times
Garcia-Menéndez, Leandro; Martínez-Zarzoso, Inmaculada and De Miguel, Piñero (2004)	Costs Transit time Frequency of shipments

Albeit the vast body of literature has shed some light over modal choice process, it still remains considerably unclear and not well understood. Firstly, not all decisions variables as well as their relevance have been depicted. Secondly, subjectivity tends to have an important role in the decision making process. Thirdly, the wide range of decision making situations renders almost impossible to identify and have common reference frameworks.

Nonetheless, looking into the literature a core number of attributes consistently appears and are always ranked amongst the top. Such situation evidences the possibility of existing a few number of attributes that regardless the case specificities make always part of the equation. Looking into the previous table they become quite clear being: cost, flexibility, reliability, safety and transit time. The weight and relevance of each one varies from situation to situation.

In this paper four variables have been chosen: out of pocket cost and three quality variables (transit time, reliability and flexibility).

The out of pocket costs refer to the overall transport costs, and will be computed as the sum of all costs.

The transit time refers to the time necessary to convey cargo from the origin to the destinations. In this paper, transit time is the time spanning the moment the ship arrives on port to the moment cargo arrives to the final client.

In what concerns reliability, there is no universal method accepted in the literature. In this paper, we decided to use the entropy concept, presented by Claude Shannon (Shannon, 1948) in his seminal paper related with information theory. Although the name of the concept is entropy, actually it measures the level of uncertainty associated with the transmission of a message over a network. The basic formula is as follows:

let X being a discrete random variable with possible values {x1, x2, …, xn}

$$E(X) = -\sum_{i=1}^{n} p(xi)\ln(p(xi))$$

In case of a deterministic system, probability of the state is 1. In this case, the uncertainty level is null, and accordingly, Shannon's entropy is zero. In case of a random system, the

Shannon's entropy is bigger than zero. There is no upper level for the value of entropy, which means that the higher the level of entropy, the higher the uncertainty level of the system.

At the maximum extend of our knowledge, no one has ever used this concept to evaluate reliability. We considerer this concept appropriate for utilisation in the evaluation of reliability, because in case of fully reliable transportation system, the transit times would be always identical. The system would be deterministic. In transport systems not fully reliable, the transit time is uncertainty and varies within certain interval. This interval grows with a the reduction of the level reliability. Thus, the lower the level reliability of a transport system, the higher will be the level of uncertainty and the higher will be the interval of the transit times. This behaviour seems to fit in the concept of entropy: deterministic systems have zero level of entropy, while uncertainty system has a positive level of entropy.

Finally, flexibility is associated with the capacity of the system to respond and react to unforeseen situations. In this paper, flexibility was measured as the recovery time of the transport system - the time necessary for the transportation system to recovery from peak in demand. The recovery time is measured in hours and the unforeseen situation is an excess of capacity (the weekly demand increases by three folds). We chose to have an excess of demand, instead of cut in demand, because this situation is easily solved by cancelling trains and trucks.

2.4. Calibration

The calibration process was necessary to evaluate and ensure on the robustness and validity of the models. This process was conducted in two steeps: firstly, the results of a model simulating the transport process from the port of Lisbon were compared against real data. In order to complete this steep, the pure road transport model was modified to simulate the transport from the port of Lisbon, instead of the port of Sines. The parameters of comparison were: transport costs and transit times, because this was the only information available from the field.

Secondly, the results of the intermodal transport model using the initial demand conditions were compared with the real data. The assumption was that the freight forwarded has designed the intermodal transport service to yield equal transport costs to the initial conditions. Assuming that that conditions was achieved, we may conclude the intermodal transport service model should yield similar cost of transport to the initial situation. After completion of the calibration process the models were considered ready for utilisation.

2.5. Simulations

Each model was run 200 times simulating 1 year of operation. In order to have a broader picture of the behaviour of both transport solutions, it was decided to run the model for different conditions of expected demand. Eleven intervals of demand were considered, the difference between intervals of 10 containers per ship, which corresponds to a difference of 1560 containers per year. The lower interval corresponds to 67% of the expected demand and the higher demand corresponds to 433% the expected demand. The maximum demand corresponds to a load factor of 100%, or in other words, the maximum capacity of the rail operator. There are two main reasons for having situations with demand over three times the expected one. The first reasons results from the observation that the expected demand was considerably inferior to the maximum capacity of the rail operator. As presented before, the intermodal transport service was designed for a load factor around 73% considering 5 trains per week (with 11 trailers each). However, rail operator can offer up to a maximum of 12 train per week (with 14 trailers), which corresponds to a demand of 27% in relation to maximum supply capacity. Therefore, it would be relevant to analyse the behaviour of the intermodal transport service in situations of higher demand. Moreover, an increase in demand would allow an increase of the loading factor and consequently a decrease of the overall costs. The second reason is because the expectation of the companies is an increase in demand, so it is interesting to understand the range of competitiveness of the intermodal transport solution.

The next graph (Figure 8) presents the evolution of the load factor in function of demand, for two situations. One corresponds to the hypothetical situation of total absence of randomness and participation of the freight forwarder. As it would be expected the load factor is a linear function of demand. As written before the initial supply capacity is rather low and the load factor of 100% is attained after 3 increases. If real, from that point onwards, not all containers would be transported. The other graph corresponds to the actual model implemented. The transport system shows higher capacity, which is attributable to the existence of the freight forwarder. The graph reveals a non linear relationship. The initial growth may be consequence of the freight forwarder attempting to maximise the existent capacity, without request or cancel trains (as this was one of the agreements with the rail operator). After this initial growth the load factor remains relative constant, which corresponds to situation where the freight forward progressively requests capacity. The load factor is not 100% most probably due to the fact of the freight forwarder agent only request more capacity to face demand peeks (or convey containers that are closer the deadline for being in the port). Yet, inevitably the continuous increase of demand has led to an increase of load factor up to 100%.

From this graph, the importance of the freight forwarder in the management and optimisation of a transport system is quite clear.

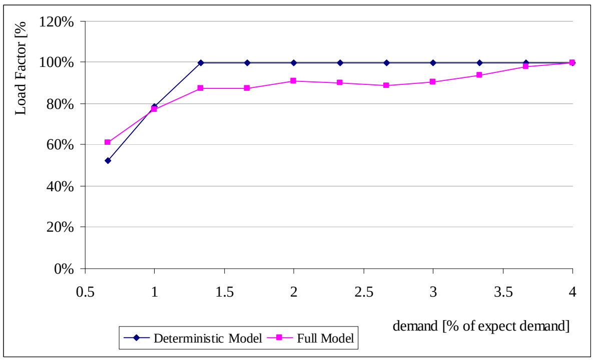


Figure 8 - Load Factor evolution

3. Results

3.1. Costs

Figure 9 presents the transport cost for all destinations and total cost for both models. Figure 10 shows the relative cost of intermodal transport in relation to pure road transportation.

In relation to the pure road transport situation, as expected costs per container are identical regardless the demand. In road leg transport, the load factor of trucks is always 100% (since each truck conveys one container), therefore, costs per container corresponds are always the same and equal to the cost of truck operations.

In what concerns the intermodal transport service, there is a gradual decrease in the transport costs, due to the rail leg. The progressive increase of demand, originates an increase of the loading factor and consequently a reduction in the unitary cost per container. With the exception of Figueira da Foz the costs per containers reduce by an amount of 10% when comparing the minimum and maximum demand cases. Figueira da Foz has a reduction of almost 40%, because (as already explained) this destination refers to a single client with a dedicated rail link.

Figure 10 presents the relative cost of road transport in relation to intermodal transport solution. For the situation of demand equal to 100%, both models yield the same average total cost, which results from the fact of freight forwarder has designed the intermodal transport solution to yield the same costs as the initial situation. Intermodal transport service is progressively more cost competitive than pure road solution, as demand increases, which is a consequence of the decrease of the costs per container.

Moreover, intermodality is only competitive for those destination served by Riachos terminal (Leiria, Alcobaça, Montemor) plus Figueira. While, all destinations served by the Bobadela terminal (Lisbon, Sintra, Carregado and Setúbal) are more economic when served by road.

This results from the cost of road transport from the port of Lisbon or terminal of Bobadela being equal. And in the case of the intermodal transport service, there is to add the rail cost. This means that cost competitive advantage of the intermodal transport service, steams solely from the replacement of road by rail in the link connecting the region of Lisbon (where is the port and the terminal of Bobadela) to the north of the hinterland (which is the terminal of Riachos and Figueira).

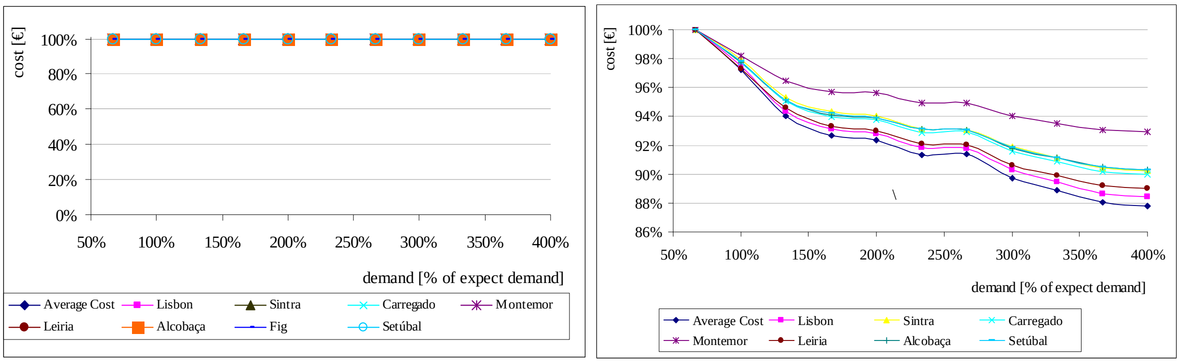


Figure 9 - Cost evolution on the pure road model (left) and intermodal model (right)

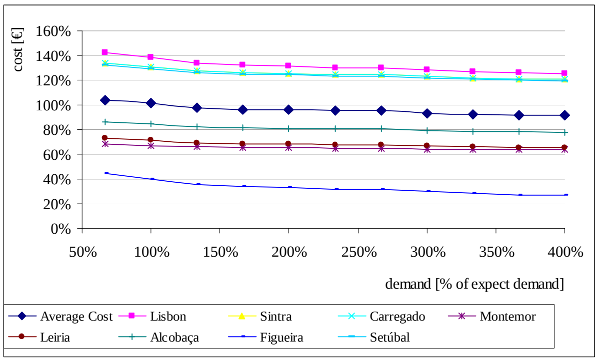


Figure 10 - Intermodal over pure road solutions cost ratio

3.2. Transit Time

The results concerning transit times are displayed in the following graphics. In what concerns, the growth in the transit times is ascribable to the growing congestion in the port. As it is understandable, the influence of port congestion affects those links with shorter road transit times, like Lisbon, Carregado or Sintra. Longer links are not so affected, because the relative importance of the time on port is reduced against the leg transit time, it is the situation of Montemor ou Figueira.

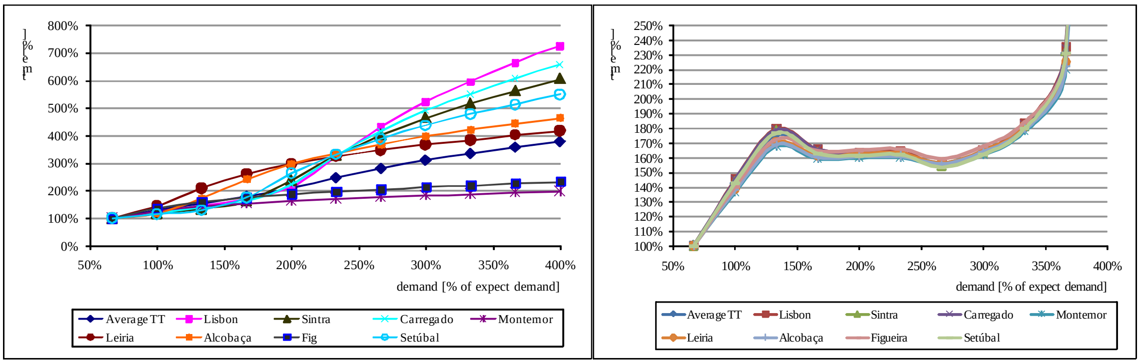


Figure 11 - Transit time on the pure road model (left) and intermodal model (right)

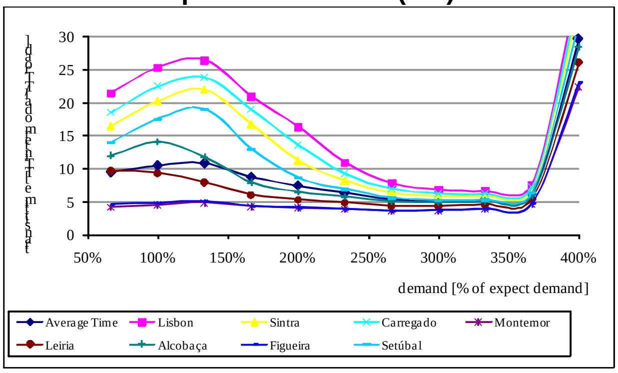


Figure 12 - Intermodal over pure road solutions transit time ratio

In relation to the intermodal transport service, the behaviour is somehow unexpected. Up to the third scenario, the intermodal transport system runs under the default configuration (5 trains per week), with the freight forwarder cancelling or adding on punctual basis (this is the outcome of the rule of not changing the default schedule if containers are due to leave port in a period of 48hours). Therefore, containers that are not loaded have to wait for the next train (which arrive in periods of 24 hours); consequently, the transit time increases. From the third scenario onwards, the default capacity is no longer enough and the freight forwarder is forced to change the default situation by adding extra capacity. Running extra trains reduces the interval between consecutive trains from 24 to 12 hours during week, and plus any eventual introduction during Saturday. The outcome is a slight decrease of the transit time consequence of the reduction containers are pared on port. In the last scenario, demand outpaces supply. As a result, parking time on port increases progressively, the transit time starts accumulating and the transport system collapses.

When comparing intermodal versus pure road transport solutions, the latter is at least five times faster that the former. The maximum difference is occurs at the moments of minimum, when the intermodal transport system is operating under default conditions, and maximum demand, when the intermodal transport system is near the collapse.

3.3. Reliability

Reliability is, in this paper, measured in function of the level of uncertainty of the transit times. Figure 13 presents the transport systems' reliability for the various scenarios for both models.

In both models, as it would be expected uncertainty increases with demand. Several reasons may be pointed out, firstly, the limited capacity of port operator results in an increase of the time containers spend in the port, leading to a broader range of the delivery time. Secondly, an increase in the amount of transport services (both rail and road) results in the increase of the probability of delays, generating more uncertainty. A special note should be made of the final value in the intermodal transport service model. For this level of demand, the system collapses. Supply is not enough, so containers are stored in the port leading to a progressive increase of the transit time. Therefore, transit times tend to infinity, and consequently the level of uncertainty.

Comparing both models, intermodality is more uncertainty than road transport, which denote lower level of reliability. Intermodal transport systems are inherently more complex than single modal transport system, because more agents intervene in the system which increases the probability of error and uncertainty. In particular, in intermodal transport systems, compound of several transport agents with different strategies, goals and perspectives, understandably yield lower levels of reliability.

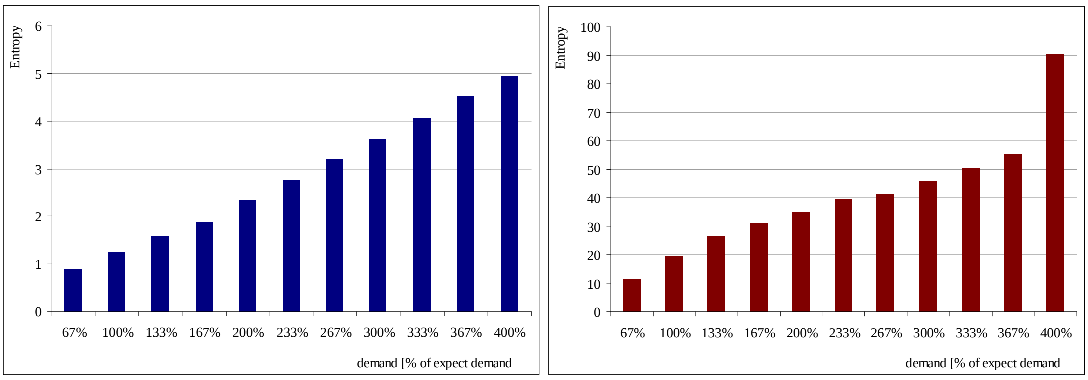


Figure 13 - Transit time on the pure road model (left) and intermodal model (right)

3.4. Flexibility

Flexibility was defined as the ability (measured in hours) of the transportation system to recovery from some sort of destabilisation, in this case a peak of demand over a week. The pure road transport model shows very high flexibility regardless the level of demand; while the intermodal transport model shows lower flexibility moving rapidly to collapse.

The reason underlying the behaviour of the road transport system is the unlimited capacity of the road operator. Therefore, despite the limited capacity of the port operator, all containers are in a short period of time loaded and transported to the final client. In the intermodal transport system, such situation is not possible, because rail operator as limited capacity. If the system is already operating near the maximum capacity, extra rail capacity is zero or near to zero, consequently, any extra demand would never be recovered. This is quite clear in the scenarios of higher demand, when the train's load factor is near 100%, when the system collapses. Nonetheless, intermodal transport system exhibit higher levels of flexibility for the lower levels of demand.

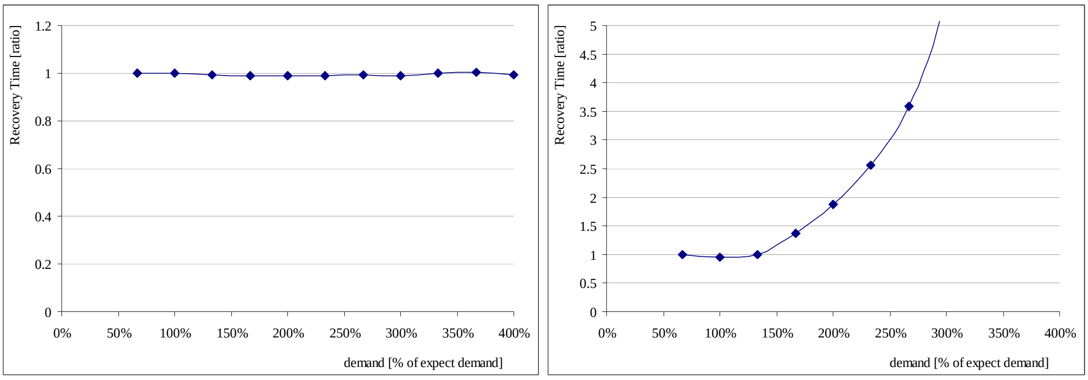


Figure 14 - Transit time on the pure road model (left) and intermodal model (right)

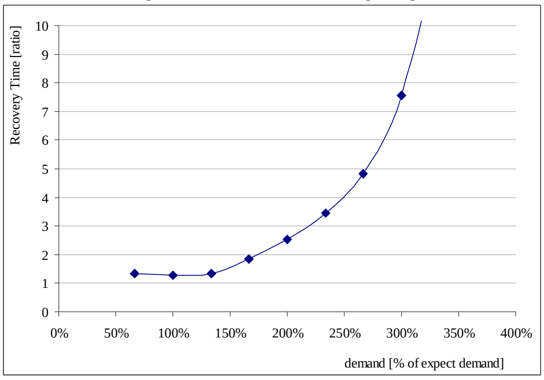


Figure 15 - Intermodal over pure road solutions transit time ratio

4. Conclusions

This paper analyses the process of replacement of a road service by an intermodal rail-road service, as the consequence of a change in strategy of a shipping company. It should be mentioned that the decision of replacing the pure road solution by the intermodal transport solution was dependent upon the possibility of not changing the out of pocket costs. This request was fully achieved.

Two models were developed to simulate the behaviour of both transport system solutions. Ten demand scenarios were considered, ranging from a very low level up to a level of maximum rail operator capacity. The models were then evaluated using four factors: out of pocket cost of transport, plus three quality factors (transit time, flexibility and reliability).

These factors are identified in the literature as being the most relevant ones in the decision making process.
The analysis of the results shows that for the expected demand scenario the out of pocket costs are identical; and that for higher levels of demand intermodal transport solution yields lower costs; while the opposite occurs for lower levels of demand. For all the remaining quality factors, the intermodal transport solution performs worst regardless the scenario.
Being fair to assume that assume the shipping company has acknowledged deterioration in the quality served, and even so, it has assumed the risk of change, we may conclude that quality factors did not play any relevant role in the decision making process, and that cost was the only decision making factor. A possible reason for the high importance of the costs lay on the type of cargo: both the unitary value and the depreciation rate of cargo tend to be very low, which reduces the importance of the quality factors. Other evidence on the low importance of the quality factors, is related with the fact that the port of Lisbon continued to be served by direct competitors. Therefore, final customers could change transport provider, in case of a reduction in quality of transport and maintenance of the transport cost. This does not however seem to be the case, as the first times of running denote an absence of clients' withdrawal.
Yet, we acknowledge that this transport service is the final leg of a longer maritime transport service, and that properties of the final leg might not significantly change the overall properties of the transport service.

The analysis to the initial configuration of the intermodal transport system shows the system is running to a suboptimal level. If considering maximum rail capacity, the system is working with a load factor of around 25%; and if considering default rail capacity the load factor is of 73%. Increase in demand would lead to increase in performance in all factors (with the exception of flexibility). The reason is because rail leg costs play an important role in the overall transport costs, and an increase in demand would lead to an increase of the load factor with the consequent reduction of the unitary cost per container. The only factor that would decrease with an increase of demand would be flexibility, because the rail system would not be able to handle any extra demand. This could be easily solved by using as an emergency back up, road transportation to convey extra demand. The pure road mode shows no sensibility to any peak of demand, which denote high capacity of adaptation. Although, costs would momentarily increase, the intermodal transport system would not collapse, and the extra costs would be recovered by the saving of using the intermodal solution.

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