A parameterised model of multimodal freight transportation for maritime services optimisation

Author: Please indicate who the corresponding author is.

Rosa Rios Prado, Diego Crespo Pereira,
David del Rio Vilas, Nadia Rego Monteil
and Alejandro Garcia del Valle

Integrated Group for Engineering Research,
University of A Coruna,
Escuela Politecnica Superior,
C/Mendizabal s/n 15403, Ferrol (A Coruna), Spain
E-mail: rrios@udc.es
E-mail: diego.crespo@udc.es
E-mail: daviddelrio@udc.es
E-mail: nadia.rego@udc.es
E-mail: agvalle@udc.es

Abstract: Multimodal transport has been promoted by several transport commissions initiatives as an alternative to road transport. A key factor for improving its competitiveness is to provide private and public investors with means of evaluating and selecting the most profitable options. This paper presents a parameterisation schema of a freight transport model for the assessment of a multimodal transport service in terms of its internal rate of return (IRR). Parameterisation enables the application of optimisation algorithms to maximise the profitability. Finally, a case study consisting of the evaluation of a new maritime service for the interregional freight transport in Spain is used to verify the proposed parameterisation.

Keywords: logistics; freight transport; multimodal; simulation; supply chain; optimisation; IRR; internal rate of return; decision maker; transportation planning; route planning.

Reference to this paper should be made as follows: Rios Prado, R., Crespo Pereira, D., del Rio Vilas, D., Rego Monteil, N. and Garcia del Valle, A. (xxxx) 'A parameterised model of multimodal freight transportation for maritime services optimisation', *Int. J. Simulation and Process Modelling*, Vol. x, No. x, pp.xxx–xxx.

Biographical notes: Rosa Rios Prado works as a Research Engineer in the Integrated Group for Engineering Research (GII) of the University of A Coruna (UDC) since 2009. She holds an MSc in Industrial Engineering and now she is studying for a PhD. She has previous professional experience as an Industrial Engineer in an Installations Engineering Company. She is mainly devoted to the development of transportation and logistical models for the assessment of multimodal networks and infrastructures.

Diego Crespo Pereira holds an MSc in Industrial Engineering and he holds a PhD in Industrial Engineering. He is an Assistant Professor of the Department of Economic Analysis and Company Management of the UDC. He also works in the GII of the UDC as a research engineer since 2008. He is mainly involved in the development of R&D projects related to industrial and logistical processes optimisation. He also has developed projects in the field of human factors affecting manufacturing processes.

David del Rio Vilas holds an MSc in Industrial Engineering and he is currently studying for a PhD. He is Adjunct Professor of the Department of Economic Analysis and Company Management of the UDC. He has been working in the GII of the UDC as a Research Engineer since 2007. Since 2010 he works as a R&D Coordinator for two different privately held companies in the Civil Engineering sector. He is mainly involved in R&D projects development related to industrial and logistical processes optimisation.

Nadia Rego Monteil obtained her MSc in Industrial Engineering in 2010. She works as a research engineer at GII of the University of A Coruna (UDC), where she is also studying for a PhD. Her areas of major interest are in the fields of Ergonomics, Process Optimisation and Production Planning.

Alejandro Garcia del Valle is Full Professor (Catedrático) in the Department of Economic Analysis and Company Management of the UDC. He is Head of the Industrial Engineering Area of the GII. He graduated in 1977 in Industrial Engineering by the Polytechnic University of Madrid (Spain) and holds a PhD in Industrial Engineering from the University of Navarra (Spain). He has led many research projects about simulation and optimisation of industrial, logistical and service systems.

---

1 Introduction

Environment and economy are two of the most important issues in the world at the moment. Most countries promote initiatives to make the economic growth compatible with the protection of environment. The promotion of sustainable modes of freight transport is one of the objectives of transport commissions. Multimodal transport has received a great deal of attention in the last few decades as a feasible alternative to road.

Multimodal transport is presented as a solution for unbalanced transport flows. As an example, data from the Spanish–French Observatory of the traffic in the Pyrenees shows (in 2008) a freight flow of 65.9 million tons between the Iberian Peninsula and France. The proportion was 83% by road, 16% by sea and 1% by rail.

One of the most important initiatives in Europe for the promotion of multimodal transport is the European Transport White Paper (2001). It describes the measures that are required to obtain a sustainable European transport in 2010: promoting the balanced growth of all the transport modes and paying attention to multimodality. The main goals of the European transport policy to reach the objectives of the White Paper are the development of the MARCO POLO programme, the promotion of Short Sea Shipping and Motorways of the Sea, the improvement of port connexions by rail and the improvement of the quality of service.

In 2011, a new Transport White Paper was published, reinforcing the need of the multimodal transport and the implementation of actions to support it. One of them is the optimisation of the multimodal chain performance in different terms (raising flows, energy efficiency, profitability, etc.).

The goal is to achieve a freight flow from road to other modes by a percentage of 30% in 2030 and 50% in 2050. To do so, efficient and ecological freight corridors and investment in infrastructure have to be promoted. EU proposes to make the multimodal services more attractive for the shippers in terms of profitability. In Spain, the Strategic Infrastructure and Transport Plan support the development of multimodal infrastructures or services. It also promotes the cooperation between all the elements in the multimodal chain, setting out the possibility that Spain could become an international logistic platform.

Therefore, the EU needs freight corridors specifically developed to ensure a high uptake in the flow of goods. Competitive, reliable and safe routes would attract investors and also respect the environment. This context provides an ideal framework for the development of initiatives for the optimisation of multimodal transport chains.

The model presented in this work takes into account both aspects, i.e., multimodal freight transport services design and its profitability assessment (for public or private developers). An appropriate definition of the parameters of these services is needed for the application of optimisation algorithms.

In the first part of the paper, a brief review of transport simulation and optimisation is provided. Then, the model which has been developed is presented.

2 State-of-the-art

Simulation and optimisation are salient tools in the supply chain management field as a means for increasing performance (Longo, 2011; Longo and Mirabelli, 2008) and reducing the environmental impact of freight transport (Faulin et al., 2011). Modelling and simulation technologies have been applied at different decision levels and for various decision problems, such as the operational improvement of terminals (Longo, 2010), transport networks (Fric[illegible]11) or routing applications (Juan et al., 2010). Transport and logistics services design is an area that can largely benefit from the adoption of modelling and simulation approaches. It requires the collaboration among different disciplines due to the specific characteristics of the systems involved, as pointed out by Bielli et al. (2011). They remarked the need for combining data mining, forecasting methods, and simulation and optimisation techniques to achieve a useful decision system.

The models employed for transport planning applications can be divided in those concerning passengers or freight. The case of Passenger Transport Modelling has been widely studied, generally using the Classical Model of the Four Stages (De Dios Ortúzar and Willumsen, 2011). In this method, the geographical area under consideration is divided in traffic analysis zones (TAZ), which are the smallest regions in which passenger flows are aggregated. This methodology adopts a stepped approach that consists of four main steps:

- *Trip Generation*. The trips generated in each TAZ are estimated.
- *Trip Distribution*. This step connects each of the trips generated in the previous stage with its destination TAZ. The result is a matrix travel between each pair of origin and destination TAZs (commonly called Origin-Destination, OD Matrix).
- *Modal Split*. It gives the transport mode that a trip uses (obviously, in the case that more than one transport mode is available for this trip).

- *Traffic Assignment*. This step gives the links of the network used for a trip.

This model can and has been adapted to the case of goods carry. However, several challenges are faced for a successful adaptation, mostly related to the difficulty of modelling policy makers' preferences. Thus, despite of the research effort carried out in the last decades, the freight transport modelling methods are less developed than those applied in passengers modelling (De Dios Ortúzar and Willumsen, 2011). Freight transport decisions are business management decisions made upon complex criteria. They can be affected by several factors such as those identified by Kreutzberger (2008) spanning the cost of the transported goods, the transport reliability, the frequency of shipments and the transport time.

Unlike passenger transport, the consideration of the carried goods (transported unit and level of disaggregation) is a decision that heavily influences the transport system design. If the study is focused on a specific sector, only a reduced set of types of goods will need to be considered. For instance, Gursoy (2010) presents a case in which only the textile sector is studied. Layered models in which each type of freight is considered as a separate flow in the network have been used to account for the heterogeneity in product characteristics (Souleyrette et al., 1996). However, this approach is often limited in practice due to unavailability of data, especially for national or international transport.

Regarding the type of merchandise, different freight characteristics lead to different storage capacity utilisations and requirements of loading/unloading resources. However, constraining the model to the widely spread containerised cargo allows for a simplification in which all the transport units have homogenous storage and handling properties. Other properties related to time constraints and costs might still be unequal among different goods, but the calculation of transport flows is greatly simplified.

Regarding the application of optimisation methods in transport planning, most of the problems faced are combinatorial optimisation problems notoriously difficult to solve, such as the V [illegible] Faulin and García del Valle, 2008) or network design. This has led to the development of advanced optimisation techniques such as hybrid methods especially suited for real cases applications (Montoya-Torres et al., 2012). Although optimisation tools have been widely and successfully applied to many of these problems, most of the works reviewed focus on business management problems or transport infrastructure or service design for more specific sectors or geographical areas than the ones considered in our work. Aggregated freight transport models have been mostly employed for forecasting transport resources utilisation and for assessing the impact of new facilities without applying optimisation tools. Multimodal freight transport networks are complex systems composed of different links, infrastructure, media and transport operators, which further increases the number of possible combinations and thus increases the difficulty of obtaining good solutions and the computational cost that it would take.

There is abundant literature on the field of simulation and optimisation applied to transport modelling. The majority of previous papers are limited to the analysis of a single mode of transport. Fagerholt et al. (2010) present a methodology for the strategic planning of a shipping company. Optimisation is achieved by solving a route planning problem considering a "rolling horizon" in which information is updated. In the long-term, the solutions can solve strategic problems on fleet size and contracts terms. Chou et al. (2003) raised the problem of optimising shipping routes where there are two types of sub problems: the direct service and the transfer service. Mu and Dessouky (2011) presented their work to optimise the time plans for rail transport. They combine local search heuristics to find optimal feasible solutions in the short-term with a heuristic that optimises the overall total delay.

A noteworthy example in problem solving multimodal transport is the work of Yamada et al. (2009). This work optimises a particular network of multimodal transport for the exchange of goods. On the other hand, Andersen et al. (2009) present an optimised model for tactical design of service networks for several companies, with special attention to the effect of timing and coordination of services as parameters for improvement.

Apart from the infrastructures and operational configuration of the service, economic aspects such as prices policies heavily affect the performance of service. Several works that have focused on this aspect have been reviewed by De Dios Ortúzar and Willumsen (2011), although they are often treated separately from other service design aspects.

The overall profitability assessment of the transport service is an aspect commonly overlooked as an optimisation criterion although it is the ultimate aspect that a private investor would take into account. To provide with a technique that can effectively promote multimodal maritime transport it is an essential component of the model. The investment valuation techniques that have been traditionally employed are based on static net present value (NPV static), which will be adopted in this work.

Our work proposes the development of models of multimodal freight transport with a focus on simulation and optimisation. Unlike the previous works outlined above, this model does not distinguish the freight by its nature but uses an aggregate unit. Thus, it can be applied to the modelling of general freight transport at a national or international level in which maritime transport is a more competitive option. Another significant difference is that restrictions on sending terminals or fixed destinations are not assumed; their choice is expected to be part of the solution obtained by an optimisation method applied to it. It is a computationally expensive optimisation problem because the number of combinations of routes and service parameters increase exponentially with the number of nodes introduced in the network.

This work searches the complete parameterisation of the multimodal freight transportation models to develop and apply optimisation algorithms. An interregional multimodal freight model is developed, defining all the parameters that define the transport services and also the parameters that are required to obtain the profitability of the service. Also a strong work in the development of cost and time formulas has been made. It is an adaptation of the four stages model that is widely used for passenger transportation.

From the point of view of the freight, versus other cases, the model is an aggregated model, because a mix of freight is used. It is taking into account in order of obtain the cost of the transportation.

It is important to note that the parameterisation was made taking into account the idea that the profitability of the service depends on the volume of freight of this service, so the definition of the route is related with the mode choice and the value of the parameters of the service.

3 Methodology

The complexity of transport systems has led to the adoption of hierarchical processes for transport planning (Bussieck et al., 1997). This process begins with the definition of the transport network and finishes with the definition of the characteristics of the transport services. As it was said in the introduction, this work seeks to parameterise a multimodal freight service model to apply optimisation algorithms. It has been applied to the design of a new multimodal maritime and road service, although it could be easily extended to other options of multimodal transport such as the combined rail and road one. A new maritime service is modelled and parameterised in terms of a set of design variables that influence the expected return from the point of view of the shipper. To facilitate the implementation of the model, a geographic information system (GIS) and a transport planning software (TransCAD) have been used.

There are a lot of ways to solve transport planning problems, but most of existing approaches follow analogous steps (Horn, 2003). First of all, it is necessary to locate the origin and destination points of the shipments. All the possible transportation modes for the movement of the goods have to be identified. For each transport mode, cost and time have to be defined. Since multimodal transport involves more than one mode, the terminals where transhipments occur need to be specified along with their associated costs and times. In our case the terminals are the ports.

This work extends and generalises the model of Spanish interregional freight transport developed by Rios Prado et al. (2011). On the basis of the classical four steps method, it allows the evaluation of the traffic flow absorbed by the maritime/road mode from the unimodal road. It was observed that the transport characteristics (fees and times) lead to variations of the take-up of freight flows by the multimodal option depending on different conditions. The model parameters that were modified were the port fees assuming that port services could be liberalised and so, increasing port competition. However, the absorbed flows were low due to the lack of adequate maritime routes and fares. In this paper, we seek to improve the model so that optimisation techniques can be applied and also to propose a more generic definition permitting the model to be applied to other cases.

3.1 Transport network and origin-destination matrices

The model network contains the information about the infrastructure that is employed to carry out the freight trips. It defines all the available links between each point of origin and destination. In practical applications, we need a GIS that contains all the information that is required and also allows us to introduce new layers of data. Figure 1 represents the general structure of the multimodal transport network that will be required to evaluate the competition between the multimodal option and an alternative option, in our case the unimodal road transport. This scheme can be easily extended to include any other alternative mode as far as time and distance between each OD pair can be obtained.

The variables that appear in Table 1 define each link between routes, and we can find their definitions in Table 1.

The nodes in this network span the origin and destination TAZs of the freight flows along with the ports covered by a set of regular maritime routes. The road infrastructure is comprised of all the roads and highways available for freight transportation in the geographic studied area and the maritime lengths are all the links between the ports that are visited in the regular routes. The first parameter to be subject to optimisation is the *number of routes* that will be defined in the network. Another aspect that characterises maritime routes is their capacity, given by the *number of vessels* assigned to each regular route and the *capacity of the vessels*. Given by the characteristics of the vessels chosen for the service. The definition of maritime routes is completed by defining the *sequence of ports* that will be used and the *fare* for each route.

To obtain the distance between each pair of nodes in the network, shortest path methods can be employed. This method is generally supported by the GIS application (as it is the case of TRANSCAD).

The OD matrices contain the number of freight shipments between each pair of TAZ. These zones are defined as the geographic areas capable of attracting or generating shipments. Special care must be taken when selecting the size of these zones. Excessively large areas would reduce the accuracy of distance calculations and small areas would increase the number of TAZs in the model and so, the computational cost. Another important requirement is to have appropriate disaggregated data for the selected TAZ, which cannot always be ensured in real cases.

Figure 1 Multimodal network (see online version for colours)

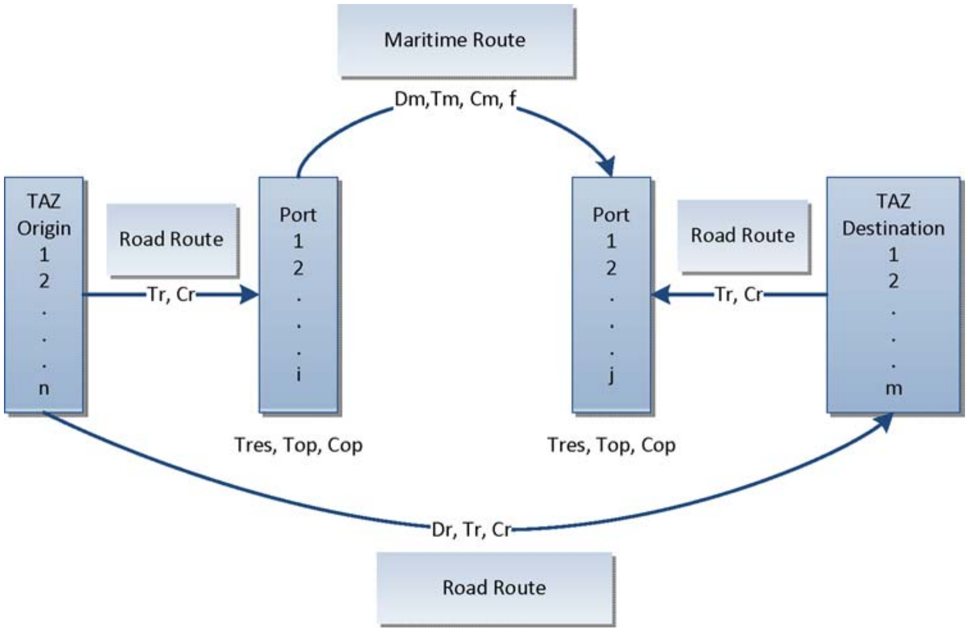


Table 1 Route variables

D_m	Maritime distance
T_m	Maritime time
C_m	Maritime cost
f	frequency
D_r	Road distance
T_r	Time distance
C_r	Road cost
T_{res}	Waiting time in port
T_{op}	Port operation time
C_{op}	Port operation cost

To achieve an accurate model, it must be fed with adequate Origin Destination matrices. However, the geographic aggregation of the OD matrices does not often match the aggregation level that is required by the TAZ definition. In this situation, disaggregation of the OD matrices can be applied. We propose a disaggregation method that consists of a weighted distribution of the flows between the TAZ of each geographic region for which the OD matrices are available. A TAZ indicator must be selected so that it reflects the weight of each TAZ for generating shipments. Indicators commonly available include the population or the gross domestic product of each TAZ.

$$t_{i,j} = \frac{w_i \cdot w_j}{\sum_A w_k \cdot \sum_B w_l} \cdot t_{A,B}, \tag{1}$$

where w_i is the TAZ origin indicator; w_j is TAZ destination indicator; A is Origin Zone (of the available OD matrices) to which TAZ Origin belongs; B is destination zone (of the available OD matrices) to which TAZ destination belongs; w_k is indicator of a TAZ in A; w_l is indicator of a TAZ in B; $t_{i,j}$ is number of shipments from i to j; $t_{A,B}$ is number of shipments from A to B.

In the case of freight transportation, OD matrices available are usually expressed in units of weight or volume. To transform them into the standardised transport unit adopted (such as the TEU, the standardised container of 20 feet) they can be divided by the average weight or the volume of the transport units.

3.2 *Modal split*

In the modal split step the proportion of the flow between each origin-destination pair per transport mode is obtained. This is a crucial step because it is the one in which the competitiveness of the multimodal option is evaluated. Several mathematical models have been developed to reflect the choices that would be made by freight shippers (De Dios Ortúzar and Willumsen, 2011). Logit models (in one of their various forms) are the most commonly used in practice. For simple applications and depending on the available data, regression and cross-classification can also be used.

The most extended logit models are the multinomial logit model (MNL) and the nested logit model (NLM). All of them share a common theoretical framework that is based in the following assumptions (De Dios Ortúzar and Willumsen, 2011):

- decision makers possess perfect information to make their choices and act rationally
- there are a set of alternatives (transport modes) and there are a set of measured attributes that quantify the utility of each alternative for the decision makers
- each alternative has a net utility for each decision maker, which represents how attractive it is for him

- the decision maker acts in a rational way seeking the maximisation of tries to maximise the utility of his choice.

The logit models provide the probability of each mode to be chosen. Since in an aggregate model the number of shipments will be large, the flow of each mode will be obtained as the total flow given by the OD matrices multiplied by the probability of selecting the mode.

The MNL gives the probability of each transportation mode, and each individual as

$$P_n(i) = \frac{e^{V_{ni}}}{\sum_{j\in A_n} e^{V_{nj}}}, \tag{2}$$

where $P_n(i)$ is probability with which the decision maker n chooses alternative i; V_{ni} is utility of alternative i for decision maker n; A_n is set of alternatives.

When alternatives are not independent, or when there are variations in the criteria among decision makers or when there is more than a single response per decision maker, NLM is preferred to the MNL. In this case, the utility function results in the addition of different utility functions for one individual and one alternative, but each one depends on different variables. For example:

$$V(d,i) = V_d + V_i, \tag{3}$$

Where V_d is the utility related with destination; V_i is utility related with cost.

In this case the expression of the probability is

$$P_n(d,i) = \frac{e^{\beta(V_d+V_d^*)} e^{\gamma V_i}}{\sum_{j\in A_n} e^{\beta(V_j+V_j^*)} \sum_{k\in B_n} e^{\gamma V_k}}, \tag{4}$$

where

$$V_j^* = \left(\frac{1}{\gamma}\right) \log \sum_{k\in B_n} e^{\gamma V_k}. \tag{5}$$

$P_n(d, i)$ Probability with which decision maker n choses the alternative defined by d, i.

Owing to de data available and the usefulness of the logit model in this case we use a logit regression model. It provides the probability of one option based on its utility function. This probability is calculated for every origin destination pair under given conditions.

$$p(U_{MM/R}) = \frac{1}{1+e^{-U_{MM/R}}} \tag{6}$$

The variables of the utility function are the values that influence the decision of the shipper. In most of the works, like Kreutzberger (2008), the two most important variables that characterise the transport mode are cost and time, so they are the variables included in the utility function.

The cost of a service is the fee that the user has to pay for it, it means the *Fare*. The fare is measured as the price paid by unit of distance. Each route has a particular fare. A condition is imposed such that the fare must be higher than the route cost; otherwise, the route would generate losses. The effect of the fare in the multimodal service competitiveness is reflected by the modal split model. It determines the flow attracted by the multimodal service and thus determines the incomes calculated as the product of the freight flow by the fare applied to each container. Behrens and Picard (2011) explains the relation between freight flows and the possible fares for every length of a route. Generally, higher flows allow lower fares due to economies of scale.

In this work, the fare is a model parameter whose units are euros per kilometre, defined separately for each maritime route of the network. For the road transportation, since the goal is not optimising its definition, we used the costs chain that determines its fares as provided by the Observatory of Road Freight Transport of the Ministry of Public Works of Spain. Their model takes into account both the cost for the road transport operators as well as their profits.

Table 2 shows the cost terms (as well as the transport time) and the references used for their calculation.

Table 2 Summary of variables calculation

Function	*Elements taken into account*
Road Time	• Break time (E.U. Regulation no. 561/2006) • Time in movement (function of length and speed)
Road Cost	Data of the Observatory of Road Freight Transport of the Ministry of Public Works of Spain: • Vehicle amortisation • Vehicle financing • Staff • Insurance • Fiscal Cost • Allowance • Fuel • Pneumatics • Maintenance • Repairs
Multimodal Time	Road Time + Port Time + Maritime Time
Multimodal Cost	Road Cost + Fare
Port Time	• Operations in port • Waiting time between vessel (if transhipment)
Maritime Time	Function of the length and the speed

To calculate the cost and time of the multimodal option for the user, first of all, the closest port to the origin TAZ is obtained. Then, for all the maritime routes that include this port, the one which includes the closest port to the destination TAZ is selected. The total cost for the user of the multimodal service is computed as the sum of the road link (origin to port and port to destination) and the maritime link. The total travel time is computed in an analogous manner.

For road transport we calculated the short path between origin and destination.

Once the cost and time of each mode have been evaluated, modal split model is employed to calculate the fraction of flow absorbed by the logit model.

3.3 *Traffic assignment*

In the traffic assignment step, the total flow that travels through each link of the network is obtained. Whenever congestion effects in the network can be omitted or are not significant an All or Nothing Assignment can be applied. In this case, it is assumed that the travel time through each link does not depend on its load. Then all the traffic flows between origin and destinations pairs can be assigned by the shortest path method in terms of either time, length, cost or a generalised cost function.

In our model, we adopt the All or Nothing Assignment due to congestion effects in the maritime routes can be simply avoided by arranging a number of ships enough to cope with the freight flow. With respect to the road transport, we assume that congestion effects do not heavily influence the flow at the large-scale (national or international) that we adopt. The main sources of congestion in the road network are due to passengers' traffic and are especially relevant for urban planning.

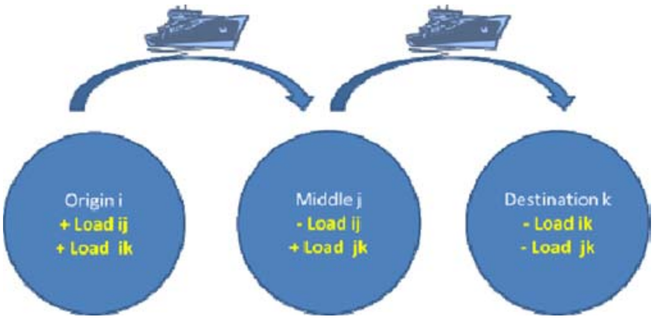
However, if an application requires the consideration of congestion effects, several methods are available that can extend the model presented here. Traffic assignment methods can be divided in equilibrium or non-equilibrium methods. The Equilibrium assignment methods require iteration between the assigned flows and the calculated loaded time. However, the application of this type of methods to large-scale and aggregated models present disadvantages that can be avoided by employing non-equilibrium methods. These methods are:

- *STOCH Assignment*: The probability for each path is calculated by means of a route logit choice model and the proportion of trips assigned to each path is equal to this probability.
- *Incremental Assignment*: It is a method based on All Or Nothing (AON). After every step, the travel time of a link is recalculated.
- *Capacity Restraint*: Try to obtain an equilibrium solution by iterating between AON traffic loading and recalculating link times, taking congestion into account.

Once we have defined the mode choice and the variables of the utility function were calculated, we obtain the freight flow of each one of the transport modes. Thus we can calculate the *Incomes* for the shipper that would operate the maritime routes. Income will depend on both the considered starting and destination points as well as on the freight flow between TAZs. It accounts for the total amount of money that the company receives due to the total number of TEU (freight flows) that moves in a route. However, there might be routes with *Intermediate stops*, so the turnover is the sum of the goods that targets the middle and the end points.

The income for a given route is calculated by adding up all the flows absorbed by each route (for all the origin-destination pairs). The calculation is repeated for the origin-destination matrices for each single year of the time span and thus the incomes of the cash flow can be obtained.

Figure 2 Example of a route with intermediate stops (see online version for colours)



3.4 *Economic assessment*

The steps presented before provide with an evaluation of the flows of freight that would be attracted by the defined multimodal transport service in terms of maritime routes and fares. They provide the expected incomes of an investment in that service. The next step to evaluate its profitability is to calculate the costs and the cash flow for the desired timespan. Then, an economic analysis can be performed in which the profitability each maritime route can be analysed by means of the internal rate of return (IRR) as follows:

$$Fare = Costs + Net\ Profit, \tag{7}$$

$$Income = Fare \times Freight\ Flows, \tag{8}$$

$$Profits\ Before\ Taxes = Income - Costs, \tag{9}$$

$$Profits\ After\ Taxes = (Income - Costs) - Taxes, \tag{10}$$

$$Cash\ Flow = Profit\ After\ Taxes + Amortisation, \tag{11}$$

$$CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_{10}}{(1+r)^{10}} = 0. \tag{12}$$

Where CF_j denotes the cash flow in the time period j (generally years), and r is the IRR. As it was previously explained, the fare is the price for the loader per transport unit. It represents the total cost of moving a transport unit between the origin and the destination and the profit after taxes (per TEU). The Net Earnings account for the decreasing effect of taxes. In our case study the tax rate is the 30% of the profits (the common type of the Spanish Corporate Income Tax). The amortisation of the ship is the annual cost of the ship during its life time due to its initial and residual cost. A life time of 20 years and a 15% of residual cost were supposed in the case of study.

All the costs of the maritime service which have to be taken into account are shown in Table 3.

Table 3 Maritime service cost

Port Time	• Operations in port • Waiting time between vessel (if transhipment)
Port Cost	• Operations in port • Inventory
Maritime Time	Function of the length and the speed
Maritime Cost	• Cost of Capital • Maintenance, Insurance, Administrative Taxes • Crew • Port Taxes • Fuel • Inventory • Port Operations

All the previous steps build the complete multimodal transport model. So once all the components of the transport model have been introduced, an optimisation problem for the maximisation of the maritime transport service profitability could be formulated. The objective function in this case would the IRR as defined in Section 3.5. Its calculation would require the development of the whole transportation model presented before and thus a closed form cannot be provided. Simulation approaches are required for its calculation.

The decision variables (the model parameters) presented before comprise:

- the number of maritime routes
- the number of ships in each route
- the characteristics of the ships employed in each route (capacity, speed and other factors that influence costs)
- the sequence of ports in each route
- the fares of each route.

The rest of the variables in the model could be assumed as fixed parameters. The next constraints should also introduced to obtain solutions that verify the model assumptions:

- the fare of each route should be greater than the costs per unit of distance (the service cannot yield loses)
- the number of ships in each route should be large enough for ensuring that all the flow of freight at each link of the network can be transported.

The optimisation problem thus obtained is quite complex since the objective function cannot be expressed in a close form and it involves continuous decision variables (the fares), integer ones (number of routes, ships, some of the ships characteristics) and also the ports sequences which give a combinatorial nature to this problem. The development of specific optimisation techniques for tackling it has not been addressed in this work. Optimisation procedures for this problem need to be efficient to compensate for the high complexity of the model and the large number of feasible solutions that could be obtained combining the different decision variables. Some existing techniques that could be applied to its resolution are metaheuristics, hyperheuristics or hybrid approaches.

4 Case of study

Following the same steps of the methodology, we can see the results of the work in a specific case. This case of the study allows us to prove the capabilities of analysis of the work. We evaluated a service with two routes. The results that show the main characteristics of the service are obtained, i.e., the occupation of the links of the net, the cash flow distribution, the number of moved TEUs and the IRR.

The first route was aimed to link the ports of Barcelona, Valencia, Cádiz and Avilés (R1) whereas the second route linked the ports of Castellón, Cartagena, Huelva and Barcelona (R2). We chose these routes because of the actual great movement of containers along the Mediterranean area.

4.1 Transportation network and origin-destination matrices

The transportation modes of the model are road and multimodal (road-maritime). So we used a GIS that includes the Spanish main roads, highways, ports and logistics centres. For the maritime legs of the multimodal routes, the GII has added a layer with the maritime legs of the routes mentioned on the beginning of the paragraph. The length of these legs is the real distance by sea between ports, obtained in the before-mentioned website for merchant navy captains. The frequency of travel for the maritime routes is 50 trips per years. The frequency allows to assess that the occupation of the route is always less than a 100% because in other case is necessary increase the number of vessels in that route.

Figure 3 Road network (see online version for colours)

Figure 4 Example of a maritime route (see online version for colours)

The OD Matricesare available on the National Statistics Institute of Spain (INE), but the matrices contain traffic data between Spanish Autonomous Regions and not between the generation (and attraction) zones chosen for the model. It is then necessary to disaggregate these data to the required level for what the following weighted population criterion has been adopted as presented in the previous section (equation (1)).

Also another transformation is needed, because all the trips need a transport unit that represents it. In this case, we choose the twenty foot equivalent unit (TEU), because it is compatible with all transport modes used in the multimodal model. A TEU can be used in road by a container vehicle and also can be carried by a vessel. The available data are expressed in tonnes, so we divide these values between 20 tonnes (average weight of a TEU) to finally get TEU per year and TAZ.

4.2 *Modal split*

The model choice model adopted is based in logistic regression as given by equation (6). The variables introduced in the utility function are the total fare (C) and time (T) from origin to destination.

The time for the road stage takes into consideration the time in movement and the time on rest (equation (5)). d_t is the distance in kilometers between origin and destination and v_t is the speed of the truck in kilometres per hour.

$$T_{road} = 2.7483 \times \frac{d_t}{v_t}. \tag{13}$$

The maritime time is a function of maritime distance (d_m in miles) and speed of the ship (v_m in knots).

$$T_{maritime} = \frac{d_m}{v_m}. \tag{14}$$

The time in port depends on the number of stops, N_s, and the time of the port operations, T_{po}.

$$T_{port} = N_s \times T_{po}. \tag{15}$$

Although a quite rough estimate, which indeed penalises the multimodal option, the time for port operations is proposed as half of the frequency (F, in trips per year) time:

$$T_{po} = \frac{365 \times 24}{2 \times F}. \tag{16}$$

The fare for maritime service is 0.50 €/km and for road transport is calculated by the following expressions. Equation (17) show the cost for truck that is a function of the distance between origin and destination, it value is in euros. Also have an inventory cost that is function of the distance and the speed of the truck (v). It values is in euros per TEU.

$$C_{ij} = 1.221 \times d_{ij}, \tag{17}$$

$$C_{Inventory} = 0.0764 \times 2.7483 \times \frac{d_{ij}}{v}. \tag{18}$$

To obtain the utility function, historical data were used. For a group of Origin and Destination pair, for which the transport mode were known, the time and cost were calculated. With these values the utility function was fitted by means of an external tool (the R Free Statistical Software Environment, 2011). This is a result of a previous work developed by the research group for the GLOBALOG project (Rios Prado et al., 2011).

The utility function represents the attractiveness of the multimodal option compared with the road one. Different utility functions were tested and the most statistically significant was equation (19).

$$U_{multimodal,q} = \beta_0 + \beta_1 \times \frac{C_r}{C_m} + \beta_2 \times \frac{T_r}{T_m} + \beta_3 \times \frac{C_r T_r}{C_m T_m}. \tag{19}$$

Then the multimodal utility function is

$$U_{multimodal,q} = -3.948 + 1.1606 \times \frac{C_r}{C_m} - 3.7944 \times \frac{T_r}{T_m} + 8.955 \times \frac{C_r T_r}{C_m T_m} \tag{20}$$

In this case of study, we consider a time span of 10 year. In Figure 6, we can see the freight flows for every year obtained with the Logistic regression model for the first route (R1).

Applying the probabilities obtained with the model to the O-D matrices (matrices of the total number of TEUs between origin and destination), we have the total freight flow that chose the multimodal option. Figure 6 shows the annual multimodal freight flows in TEUs, for the first route of the case of study.

Table 4 Results of the logistic regression

Coef.	*Value*	*Std. err.*	*t-value*	*p-value*	*S.L* (†)
β_0	–3.948	0.260	–15.209	<2e-16	***
β_1	1.161	0.545	2.130	0.0340	*
β_2	–3.794	0.974	–3.895	0.0001	***
β_3	8.955	1.928	4.644	5.02E-06	***

(†) Significant level codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' '1.

Figure 5 Multimodal probability (see online version for colours)

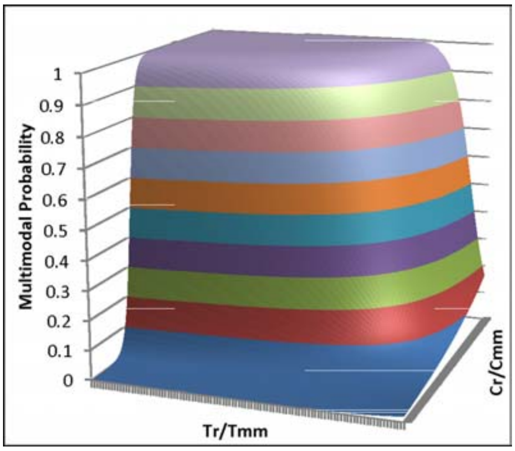
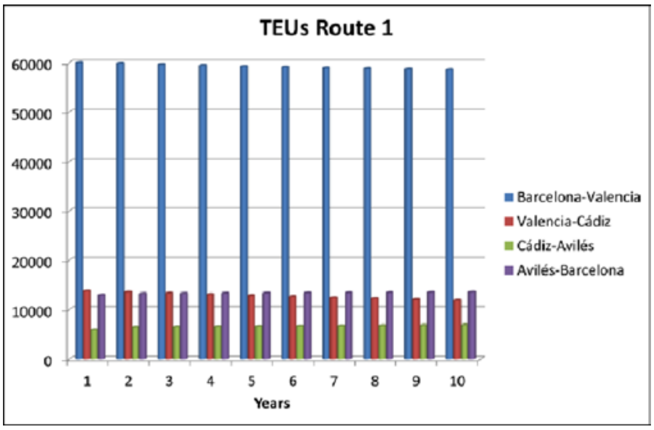


Figure 6 TEUs moved in route 1 (see online version for colours)



4.3 *Traffic assignment*

An All Or Nothing assignment was employed in this step, providing the results shown in Figure 7 shows the occupation of the links of the maritime network.

Figure 7 Occupation percentage of route 1 (see online version for colours)

4.4 *Economic assessment*

Once the freight flows have been obtained, the cash flow for the investment option in the new routes could be obtained according to the procedure explained in Section 3.5. The costs on harbour and the maritime costs were calculated following the methodology used by the Spanish Freight Road Transport Observatory (2012). They depend on the gross tonnage of the ship, *GT*, the port operations times, T_{po}, the distance between ports d_m (in miles) and ship speed v (in knots).

Harbour cost functions are due to the cost of the operations in the port (equation (21)) and the inventory cost of the containers (equation (22)). Port cost operation is the cost of each stop in a port (€/stop) and the inventory cost is in euros per TEU (€/TEU).

$$C_{po} = 22.2925 \times GT^{0.8448}, \tag{21}$$

$$C_{Inventory} = 0.0764 \times T_{po}. \tag{22}$$

The maritime cost is the combination of Capital, Maintenance, Crew, Port Fares, Fuel and Inventory costs. Capital cost (equation (23)) is a daily cost (€/day) and it represents the total cost need to put a project in operation. Maintenance cost (equation (24)) is also a daily cost, and it is the cost to keep in good conditions and repair the vessel. Crew cost, daily cost, is the cost of the salaries and expenses of the crew (equation (25)). Every time that a vessel stops in a port it has to pay the fares of this port (€/stop). Equation (26) represents this cost. The cost of the consumption of fuel is important cost that has to be taking into account. It depends of the distance travelled, so the units are euros per mile, €/mile (equation (27)). The last cost is the inventory one, it is a cost per TEU (€/TEU)

$$C_{Capital} = 0.4228 \times GT, \tag{23}$$

$$C_{Maintenance} = 0.0148 \times GT, \qquad (24), (25)$$

$$C_{Crew} = 386.217 \times GT^{0.1371}, \tag{26}$$

$$\begin{aligned} C_{Port\ Fares} = {} & 1.521 \times \frac{GT}{100} + 53.96 \times 0.3307 \times GT^{0.8448} \\ & + 0.85 \times \frac{GT}{100} + 0.03 \times 14.4 \times 0.3307 \times GT^{0.8448} \\ & + 5.0759 \times GT^{0.4154}, \end{aligned} \tag{27}$$

$$C_{Fuel} = 0.1457 \times GT^{0.5081}, \tag{28}$$

$$C_{Inventory} = 0.0764 \times \frac{d_m}{v}. \tag{29}$$

In this case the taxes are the tax rate is the 30% of the profits (the common type of the Spanish Corporate IncomeTax).

Applying the expressions for the cash flow calculation and IRR explained before, the model obtains the following results shown in Figures 8–11. Tables 5 and 6 display the IRR obtained for each route leg, in which the omitted values represent legs that would operate with loses and thus IRR cannot be calculated. The overall route IRR values are presented at the right of both tables and we can see that both are negative. This initial solution has not been subject to optimisation, and thus is not surprising that yields a negative profit. A better selection of the fares and the selection of the ports could lead to a profitable solution. However the application of optimisation techniques is not addressed in this work.

Figure 8 Cash flow for Barcelona-Valencia (see online version for colours)

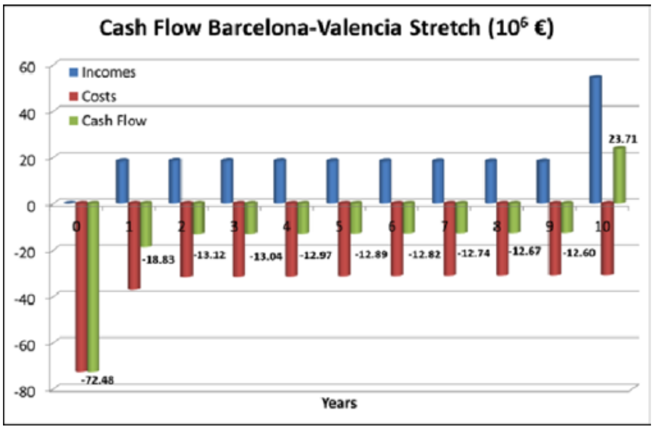


Figure 9 Cash flow for Valencia-Cádiz (see online version for colours)

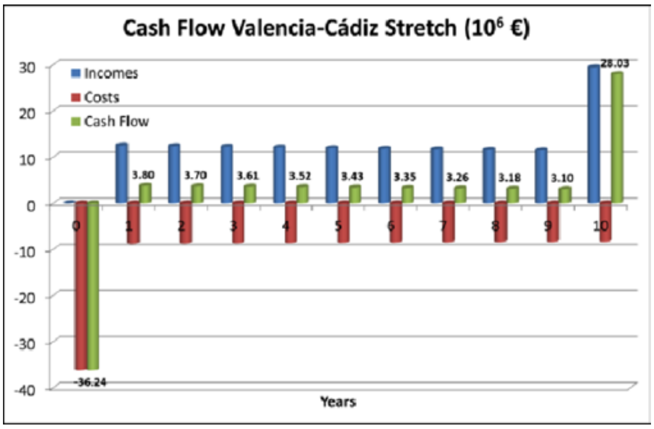


Figure 10 Cash flow for Cádiz-Avilés (see online version for colours)

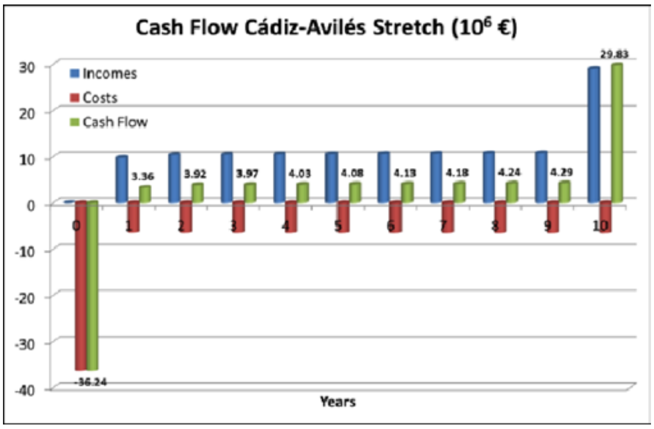


Figure 11 Cash flow for Avilés-Barcelona (see online version for colours)

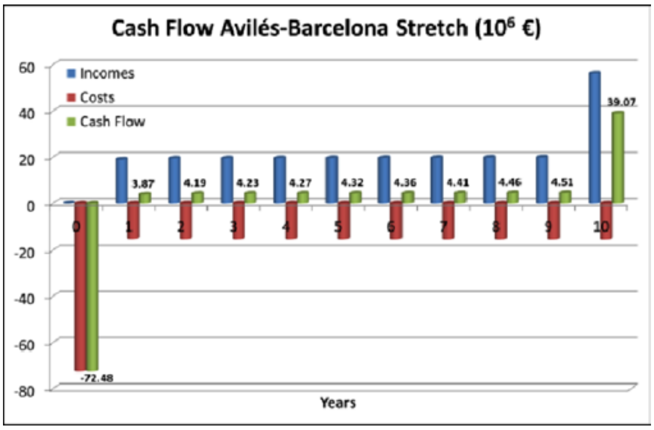


Table 5 Route 1 IRR results

Barcelona Valencia	*Valencia Cadiz*	*Cadiz Avilés*	*Avilés Barcelona*	*IRR Route 1*
–	7.30%	9.08%	0.93%	-6.54%

Table 6 Route 2 IRR results

Castellón Cartagena	*Cartagena Huelva*	*Huelva Barcelona*	*Barcelona Castellón*	*IRR Route 1*
–	–6.46%	12.29%	–19.00%	–11.02%

5 Conclusions and future research

The profitability assessment of multimodal transport services in comparison with road transport is achieved thanks to the development of a valid parameterisation schema both for the multimodal transport model and for the evaluation of the objective function. It sets the foundation for IRR optimisation algorithms, and as a result, the proposal of new and interesting multimodal services. This is the first step to obtain optimised multimodal routes for freight transport in line with the objectives of the Transport White Paper. The developments of the parameterisation together with the transport model also allow the operation conditions that increase the freight absorption rate of the multimodal option to be obtained. So we have the possibility of implementing algorithms for a double optimisation, i.e., absorption rate and service profitability.

Another important aspect to take into account is its versatility. In spite of the fact that a specific software has been employed to develop the model, the approach and methodology are generic and do not depend on it, so any software with GIS networks and transport utilities could be used.

A first line of future work is focused on the improvement of optimisation algorithms for multimodal services, which is on the original roots of this work. In addition, despite the IRR has been employed as a measure of utility, optimisation algorithms should also take into account the possibility of a more flexible kind of assessment, like the ROA (Real Options Assessment).

Although improving the Mode Choice Model really does not have influence on parameterisation, it may improve the results of the optimisation. Obtaining an improved fitted decision function that better represents the shippers choices would increase the future freight flows estimate and so the IRR values.

Last, but not least, as the availability of data is the key factor in transport simulation, future collaborations with shipping companies that provide the necessary data to develop better models would eventually improve the results of the complete model.

References

Andersen, J., Crainic, T.G. and Christiansen, M. (2009) 'Service network design with management and coordination of multiple fleets', *European Journal of Operational Research*, Vol. 193, No. 2, pp.377–389.

Behrens, K and Picard, P.M. (2011)'Transportation freight rates, and economic geography', *Journal of International Economics*, No. 85, pp.280–291.

Bielli, M., Bielli, A. and Rossi, R. (2011) 'Trends in models and algorithms for fleet management', *Procedia Social and Behavioral Sciences*, Vol. 20, pp.4–18.

Bussieck, M.R., Winter, T. and Zimmermann, U.T. (1997) 'Discrete optimization in public rail transport', *Proceedings of 16th International Symposium on Mathematical Programming (ismp97)*, Lausanne, Switzerland, Vol. 79, pp.415–444.

Chou, M., Song, M. and Teo, C.P. (2003) *Inventory-Routing Problem in Sea Freight: Direct v[illegible] Transhipment Model*. AUTHOR PLEASE SUPPLY FULL DETAILS.

De Dios Ortúzar, J. and Willumsen, L.G. (2011) *Modelling Transport*, 4th ed., John Wiley & Sons, Ltd., UK.

Fagerholt, K., Christiansen, M., Hvattum, L.M., Johnsen, T.A. and Vabo, T. (2010) 'A decision support methodology for strategic planning in maritime transportation', *Omega, The International Journal of Management Science*, pp.465–474. AUTHOR PLEASE SUPPLY VOLUME NUMBER AND CHECK IF THE HIGHLIGHTED AUTHOR INITIAL IS OK.

Faulin, J. and García del Valle, A. (2008) 'Solving the capacitated vehicle routing problem using the ALGELECT electrostatic algorithm', *Journal of the Operational Research Society*, Vol. 59, No. 12, pp.1685–1695.

Faulin, J., Lera-López, F. and Juan, A.A. (2011) 'Optimizing routes with safety and environmental criteria in transportation management in Spain: a case study', *International Journal of Information Systems and Supply Chain Management*, Vol. 4, No. 3, 22 pages.

Frick (2011) AUTHOR PLEASE SUPPLY FULL DETAILS.

Gursoy, M. (2010) 'A method for transportation mode choice', *Scientific Research and Essays*, Vol. 5, pp.613–624.

Horn, M.E.T. (2003) 'An extended model and procedural framework for planning multi-modal passenger journeys', *Transportation Research Part B*, Vol. 37, pp.641–660.

Juan, A.A., Faulin, J., Jorba, J., Riera, D., Masip, D. and Barrios, B. (2010) 'On the use of Monte Carlo simulation, cache and splitting techniques to improve the Clarke and Wright savings heuristics', *Journal of the Operational Research Society*, Vol. 62, No. 6, pp.1085–1097.

Kreutzberger, E.D. (2008) 'Distance and time in intermodal goods transport networks in Europe: a generic approach', *Transportation Research Part A*, Vol. 42, pp.973–993.

Longo, F. (2010) 'Design and integration of the containers inspection activities in the container terminal operations', *International Journal of Production Economics*, Vol. 125, No. 2, pp.272–283.

Longo, F. (2011) 'Advances of modeling and simulation in supply chain and industry', *Simulation Transactions of the Society for Modelling and Simulation International*, Vol. 87, pp.651–656.

Longo, F. and Mirabelli, G. (2008) 'An advanced supply chain management tool based on modeling & simulation', *Computer and Industrial Engineering*, Vol. 54, No. 3, pp.570–588.

Montoya-Torres, J.R., Juan, A.A., Huaccho Huatuco, L., Faulin, J., Rodriguez-Verjan, G.L. (2012) *'Hybrid algorithms for service, computing and manufacturing systems' – Routing and Scheduling Solutions*, Information Science Reference (IGI Global), USA.

Mu, S. and Dessouky, M. (2011) 'Scheduling freight trains traveling on complex networks', *Transportation Research Part B*, in Press. AUTHOR PLEASE UPDATE THIS REFERENCE.

R Free Statistical Software Environment (2011) *What is R?. The R Foundation for Statistical Computing*, Available from: http://www.r-project.org/ (Accessed 1 July, 2011). AUTHOR PLEASE CHECK IF THE HIGHLIGHTED CHANGE MADE IS OK.

Rios Prado, R., Crespo Pereira, D., del Rio Vilas, D. and Rego Monteil, N. (2011) 'GLOBALOG: a simulation case of freight multimodal transportation', *Proceedings of the 13th International Conference on Harbor, Maritime and Multimodal Logistics Modelling and Simulation*, pp.170–178. AUTHOR PLEASE SUPPLY LOCATION.

Souleyrette, R.R., Hans, Z.N. and Pathak, S. (1996) *Statewide Transportation Planning Model and Methodology Development Program Final Report*, Iowa State University, Accessed online. AUTHOR PLEASE SUPPLY LOCATION.

Spanish Freight Road Transport Observatory (2012) http://www.fomento.gob.es/MFOM/LANG_CASTELLANO/DIRECCIONES_GENERALES/TRANSPORTE_POR_CARRETERA/SERVICIOS_TRANSPORTISTA/DESCARGA_SOFTWARE/Acotram.htm (Accessed April 2012).

Yamada, T., Russ, B.F., Castro, J. and Taniguchi, E. (2009) 'Designing multimodal freight transport networks: a heuristic approach and applications', *Transportation Science*, pp.129–143. AUTHOR PLEASE SUPPLY VOLUME NUMBER.

Bibliography

Ametller Malfaz, X. (2007) *Optimización del transporte de mercancías mediante el transporte marítimo de corta distancia*, Minor Thesis, Universitat Politécnica de Catalunya. AUTHOR PLEASE SUPPLY LOCATION.

Capitanes (2011) *Capitanes Website*, Available from: http://www.capitanes.com (Accessed 1 July, 2011).

European Transport Commission (2001) *White Paper: European Transport Policy for 2010*, Available from: http://europa.eu/legislation_summaries/environment/tackling_climate_change/l24007_en.htm (Accessed April 2012).

European Transport Commission (2011) *White Paper 2011*, Available from: http://ec.europa.eu/transport/strategies/2011_white_paper_en.htm (Accessed April 2012).

García Menéndez, L. and Feo Valero, M. (2009) 'European common transport policy and short sea shipping: empirical evidence based on modal choice models', *Transport Reviews*, Vol. 29, No. 2, pp.239–259.

Romero-Hernández, M.C. (1999) 'Análisis coste-beneficio de un proyecto de inversión en infraestructura de carreteras', *Investigaciones Económicas*, Vol. 23, No. 2, pp.251–265.

Romilly, P. (2004) 'Welfare evaluation with a road capacity constraint', *Transportation Research Part A: Policy and Practice*, Vol. 38, pp.287–303.

Washington, S.P., Karlaftis, M.G. and Mannering, F.L. (2003) *Statistical and Econometric Methods for Transportation Data Analysis*, 1st ed., Chapman & Hall Books. AUTHOR PLEASE SUPPLY LOCATION.

Queries

AQ1: PLEASE SUPPLY EXPANSION FOR THE ACRONYM 'VRP'.

AQ2: PLEASE CITE 'Table 4' IN TEXT.

AQ3: PLEASE CITE 'Figures 2, 3, 4, 5', IN TEXT.

AQ4: PLEASE SUPPLY BETTER QUALITY FOR 'Figures 6, 7, 8, [illegible]0, 11'.