A PARAMETERIZED MODEL OF MULTIMODAL FREIGHT TRANSPORTATION FOR MARITIME SERVICES OPTIMIZATION

Rosa Rios Prado[(a)], Diego Crespo Pereira[(b)], Juan Manuel Bastida Sardiña[(c)], David del Rio Vilas[(d)], Nadia Rego Monteil [(e)]

[(a) (b) (d) (e)] Integrated Group for Engineering Research, University of A Coruña (Spain)
[(c) (d)] Proyfe S.L. (Spain)

[(a)]rrios@udc.es, [(b)]dcrespo@udc.es, [(c)]juanmanuel.bastida@proyfe.es, [(d)]daviddelrio@udc.es, [(e)]nadia.rego@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 for evaluating and selecting the best options in terms of profitability. This paper presents a parameterization schema of a freight transport model for the assessment of a multimodal transport service in terms of its internal rate of return (IRR). Parameterization enables the application of optimization algorithms for the maximization of profitability. In order to verify the proposed parameterization, a case study is presented consisting of the evaluation of a new maritime service for the interregional freight transport in Spain.

Keywords: logistics, freight transport, multimodal, simulation, supply chain, optimization, IRR.

1. INTRODUCTION

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

Multimodal transport is presented as a solution for the unbalanced global sharing of the 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. This was shared in 83% by road, 16% by sea and 1% by railroad.

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

In 2011 a new Transport White Paper has been published. It reinforces the need of the multimodal transport and the implementation of actions to support it. One of them is the optimization 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 in a percentage of 30% in 2030 and 50% in 2050. To do so, efficient and ecological freight corridors and investments in infrastructures have to be promoted. EU proposes to enhance the attractiveness of multimodal services for the shippers in terms of profitability. In Spain, the Strategic Infrastructures and Transport Plan supports the development of multimodal infrastructures or services. It also promotes the cooperation between all the elements of the multimodal chain, setting out the possibility that Spain could be an international logistic platform.

Therefore, the EU needs freight corridors specifically developed to ensure a high uptake of the flow of goods. Competitive, reliable and safe routes would attract the investor and also respect the environmental rules on energy efficiency and emissions. This context provides an ideal framework for the development of initiatives for the optimization of multimodal transport chains.

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

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

2. STATE OF THE ART.

From the point of view of optimization, most of transport planning problems (VRP, network design, route planning, etc.) are combinatorial optimization problems, notoriously difficult to solve. Transport models can be divided in those concerning passengers or freight. Bielli, Bielli and Rossi (2011) concluded that transport and logistics service requires the collaboration of different disciplines due to their special characteristics. They explained the need of combining data mining, forecasting methods, optimization and simulation models, heuristics, etc. in a useful decision system.

The case of Passenger Transport Modelling has been widely studied, using generally the Classical Model of the Four Stages (De Dios and Willumsen 2011). This method requires network modelling (graphical and operationally) and transport. Although this model can be adapted for the carry of goods, it often fails due to a lack of definition on policy makers' preferences (by the limited availability of data). Specifically, Kreutzberger (2008) identifies four parameters that are usually characterized, namely the cost of transported goods, transport reliability, frequency of shipments and transport time.

Unlike passenger transport, the consideration of the carried goods (transported unit and level of disaggregation) is a decision that influences the transport system design. If the study is focused on a specific sector, it may be of interest to restrict a very specific type of goods. For instance, in Gursoy (2010), only the goods in the textile sector are studied. Multimodal freight transport models are complex systems composed of different transport networks, infrastructure, different media and transport operators, which further increases the number of possible combinations. Regarding the type of merchandise, both the same unit for all modes of transport is defined in the model or other variables such as media storage and loading / unloading operations have to be included. In this work, the container has been adopted as the homogenous transport unit used for goods with high added value. This assumption has been considered convenient since containerized freight is easily transferred between transport modes and thus suitable for multimodal transport.

There is abundant literature on the field of simulation and optimization 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 strategic planning of a shipping company. The simulation is performed by solving the route planning time considering a "rolling horizon" where information is updated. In the long term, the solutions can solve strategic problems on fleet size and terms of contracts. Chou, Song and Teo (2003) raised the problem of optimizing shipping routes where there are two types of problems: the direct service and the transfer service. Mu and Dessouky (2011) presented their work to optimize the time plans for rail transport. They combine local search heuristics to find optimal feasible solutions in the short term with a heuristic that optimizes the overall total delay.

A noteworthy example in problem solving multimodal transport is the work of Yamada et al (2009). This work optimizes a particular network of multimodal transport for the exchange of goods. On the other hand, Andersen et al (2009) present an optimized 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.

Our work proposes the development of models of multimodal freight transport with a focus on simulation and optimization. Unlike the previous works outlined above, this model does not distinguish the freight by its nature but uses an aggregate unit. Another difference is that restrictions on sending terminal or fixed destination are not assumed; their choice is part of the solution of the optimization (the definition of routes) and the individual decision process of the network users. This is a computationally expensive optimization problem because of the size of the modelled networks as the number of variables and relationships between different modes listed as alternatives increase. Also, considering the economic aspect is less common as a criterion to optimize transport problems.

Some studies in Spain (Romero–Hernández 1999) in medium cities show the positive influence of improving the communication roads of the city. The investment valuation techniques that have been traditionally employed are based on static net present value (NPV static). However, the employment of his technique for the assessment of long term and complex projects is now seen as incomplete, rigid and myopic, and often leading to major deviations (Romilly 2004).

The freight transportation problem is complex in its a priori definition, and it has wide horizons for planning, implementation and operation. Extended NPV based on real options are best suited to dynamic projects with high uncertainty, as it is the case.

Real options assessment (ROA) has been successfully used in sectors like pharmaceuticals, energy and aeronautics. However, applying this methodology in the field of logistics simulation is an original and promising approach.

Although not yet accomplished, the parameterization schema and the transport model explained in this paper are the first steps in order to obtain the complete simulation model that will allow applying ROA algorithms and optimization algorithms based on typical NPV or Real Options NPV.

3. METHODOLOGY.

As it was said in introduction, this work seeks to parameterize a multimodal freight services model in order to apply optimization algorithms. The new service modelled is parameterized in terms of a set of design variables that influence the expected return from the point of view of the shipper. To do so, a GIS (geographic information system) and a transport planning software (TransCAD) have been used.

The first step of the work was the construction of the multimodal freight transport model. This work extends the model of Spanish interregional freight transport developed by Rios et al. (2011). Based on the classical four steps method, it allows the evaluation of flows absorption between road and multimodal options. It was observed that the transport characteristics (fees and times) lead to variations on the absorption of freight flows by the multimodal option.

In the second step, design variables of a new maritime transport service were defined together with the parameters for the profitability calculation. The transport model is used to forecast future multimodal flows and thus to estimate the discounted cash flow of an investment option in the designed service. The span of the simulation was 10 years. Available data were used to verify the model definition and implementation in TransCad and to demonstrate the utility of the proposed parameterization.

3.1. Multimodal Transport Model.

The classical four step model was used to develop the transport model. The four steps of the model are Trip Generation, Trip Distribution, Modal Split and Assignment. The first and second steps define the freight flows between zones (Traffic Analysis Zones, TAZ). The third one splits the flows between unimodal and multimodal transport. The last one assigns the flows to the network stretches.

In this case the TAZ chosen were groups of council clusters (with identified functional relationship between the councils) gathering population levels high enough for generating and attracting flows of goods. Figure 1 shows the TAZs of the model. Data from the National Statistics Institute (Spain) were used to obtain the freight flows between TAZs.

Figure 1: TAZs of the Model. Multimodal Options between the Spanish Atlantic and Mediterranean Shores were considered.

The method applied in the Modal Split step was logistic regression (Equations 1 and 2). The probability of multimodal transport choice (Equation 1) is modelled as a function of a relative utility measure that depends on the ratio between costs and times for both modes (Equation 2).

$$P_n(MM) = \frac{1}{1+e^{U_n}} \quad (1)$$

$$U_n = -3{,}9848 + 1{,}1606\frac{C_{nR}}{C_{nMM}} - 3{,}7944\frac{T_{nR}}{T_{nMM}} + 8{,}955\frac{C_{nR}}{C_{nMM}}\frac{T_{nR}}{T_{nMM}} \quad (2)$$

In this context, the cost term refers to the door to door cost for the user of the transport service. Thus, it will be the fare charged to the owner of the freight for the transportation of a container from the origin to the destination point depending on the mode employed. Also, the term time refers to the door to door travel time when using each mode. The time and cost calculation will be explained in more detail in the parameters definition section.

The model employs a GIS network containing the main roads of Spain. The maritime legs had to be purposely developed for this research work. This model was used to obtain the future freight flows under different conditions. The simulation has a span of 10 years, which is a common period of time when assessing the Internal Rate of Return of transport services.

3.2. Model Parameters.

The objective function is the profitability of the service (new multimodal route) of a potential shipper. The parameters are the design variables that influence this profitability, such as the ones related to intermediate stops, fees and frequency. In particular, we have considered the following variables:

- **Fare**: Value per TEU and distance. Each route has a particular fare. A condition is imposed in that this fare must be higher than the route cost; otherwise the route would generate losses. Fare affects the flow absorption by entering in the equation 2. Thus, it determines the service incomes which are calculated as the product of the freight flow by the fare applied to each container.
- **Cost:** Both fare and mode choice depend on the cost of the service, so it is important to obtain a well fitted cost function. Three possible costs are considered, depending on the link of the transport chain (Equation 3). These costs are the same used to fit the transport model. Road unit cost term is described in Table 1. Costs of the time that the truck is in movement and the time that the driver has to rest have been included (which also depend on the origin-destination distance $\boldsymbol{d_{ij}}$). On its part, inventory cost is an opportunity cost of the TEU, and depends on $\boldsymbol{d_{ij}}$ and truck speed $\boldsymbol{v}$, in kilometres and kilometres per hour respectively.

$$Costs = Cost_{Road} + Cost_{Harbour} + Cost_{Sea} \quad (3)$$

Table 1: Road Cost Functions.

Item	Function	Unit
Unit Cost	$C_{ij} = 1.221 \times d_{ij}$	€
Inventory Cost	$C_{Inventory} = 0.0764 \times 2.7483 \times \frac{d_{ij}}{v}$	€/TEU

Table 2: Harbour Cost Functions.

Port operation Cost	$C_{po} = 22{,}2925 \times GT^{0{,}8448}$	€/stop
Inventory Cost	$C_{Inventory} = 0.0764 \times T_{po}$	€/TEU

The costs on harbour are showed on Table 2. These costs depend on the gross tonnage of the ship, ***GT***, and the port operations times, T_{po}, due to the loading and unloading operations and transhipments.
The maritime costs are shown in Table 3. They are calculated following the methodology used by the Spanish Freight Road Transport Observatory (2012). They take into account the financial cost, maintenance, crew, fuel consumption and port fares. These functions depend on ***GT*** , distance between ports d_m (in miles) and ship speed ***v*** (in knots).
Income: 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 may be routes with intermediate stops, so the turnover is the sum of the goods that targets the middle and the end points.

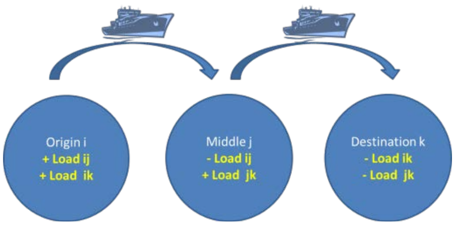

Figure 2: Example of a Route with Intermediate Stops.

Table 3: Maritime Cost Functions.

Capital	$C_{Capital} = 0.4228 \times GT$	€/day
Maintenance	$C_{Maintenance} = 0.0148 \times GT$	€/day
Crew	$C_{Crew} = 386.217 \times GT^{0.1371}$	€/day
Port Fares	$C_{Port\ Fares} = 1.521 \times \frac{GT}{100} + 53.96 \times 0.3307 \times GT^{0.8448} + 0.85 \times \frac{GT}{100} + 0.03 \times 14.4 \times 0{,}3307 \times GT^{0.8448} + 5.0759 \times GT^{0.4154}$	€/stop
Fuel	$C_{Fuel} = 0{,}1457 \times GT^{0{,}5081}$	€/miles
Inventory	$C_{Inventory} = 0.0764 \times \frac{d_m}{v}$	€/TEU

Thus, as shown in the Figure 2, for routes with stops, we should also consider the goods from the TAZ ***i*** to intermediate TAZ and goods from TAZ ***j*** to TAZ destination.
The main disadvantage of the routes with stops, are the high costs of each stop in port. The port charges, together with the time wasted between unloading and loading of goods, may contribute to discard the maritime route compared to the road alternative.

- **Intermidiate Stops**: They should be considered in solving the problem because they are associated with obtaining the shipping costs.
- **Time**: It is the time from origin to destination. In most cases this parameter is critical for the company that hires the shipping services in choosing one alternative or another. If there are intermediate stops it is necessary taking into account the load and upload times in port. The time for the road stage takes into consideration the time in movement and the time on rest. (Equation 4). d_t is the distance in kilometers between origin and destination and v_t is the speed of the truck in kilometres per hour.

$$T_{road} = 2{,}7483 \times \frac{d_t}{v_t} \quad (4)$$

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

$$T_{maritime} = \frac{d_m}{v_m} \quad (5)$$

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

$$T_{port} = N_s \times T_{po} \quad (6)$$

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

$$T_{po} = \frac{365 \times 24}{2 \times F} \quad (7).$$

- **Number of Routes**: Due to the number of ports and the geographic dispersion, it could be more profitable to have several routes to transport goods. Two routes may serve different sides of the shore and it may be goods interchange between the routes. Thus, another variable to consider is the number of routes.
- **Number of Ships**: Another possible solution would be to have more than one ship on the route, thereby minimizing the time that the

TAZ would have to wait to receive two consecutive deliveries.

$$N_B = \frac{\frac{d_m}{v_m}}{F} \quad (8)$$

Where d_m is maritime distance, v_m is ship speed and F the frequency.

3.3. Objective Function.

After defining the variables involved in the problem, the next step is to calculate the cash flow for the simulation span (10 years). Then, an economic analysis to check the profitability of the route can be performed. To achieve this end, we calculate the Internal Rate of Return (IRR) as follows:

$$\boldsymbol{Fare} = \boldsymbol{Costs} + \boldsymbol{Net\ Profit} \quad (9)$$

$$\boldsymbol{Income} = \boldsymbol{Fare} \times \boldsymbol{Freight\ Flows} \quad (10)$$

$$\boldsymbol{Profits\ Before\ Taxes} = \boldsymbol{Income} - \boldsymbol{Costs} \quad (11)$$

$$\boldsymbol{Profits\ After\ Taxes} = (\boldsymbol{Income} - \boldsymbol{Costs}) - \boldsymbol{Taxes} \quad (12)$$

$$\boldsymbol{Cash\ Flow} = \boldsymbol{Profit\ After\ Taxes} + \boldsymbol{Amortization} \quad (13)$$

$$CF_0 + \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_{10}}{(1+r)^{10}} = 0 \quad (14)$$

Where CF_j denotes Cash Flow in year j, and r is the IRR. As it was previously explained, fare is the price for the loader per TEU. It represents the total cost of moving a TEU between origin and 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 IncomeTax). The amortization 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.

3.4. Implementation and model execution

The software used to implement the transport model is TransCAD which fully integrates a Geographic Information System (GIS) and planning transport tools. It also provides a proprietary programming language, GISDK, which allows developing of customized transport planning methods by means of macros programming.

In this case, transport network data are stored in the layers of a GIS map and freight flow data in origin-destination matrices. A GISDK macro has been coded that estimates the internal rate of return for a given solution in terms of route configuration and fares. The decision variables are:

- Number of routes.
- Ports and sequence of ports in a route.
- Fares.
- Number of ships.

The macro uses as an argument the previous information. Then, it estimates the freight flow in each route stretch by means of the above presented transport model. Finally, the cash flow is estimated and the IRR calculated. The next procedure is followed for each pair of origin-destination pairs:

1. Time and cost of the road transport mode is calculated by means of equations presented before. Built-in functions allow for the calculation of the shortest path distances between pairs through the road network.
2. In order to calculate the cost and time of the multimodal option, 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.
3. Once the cost and time of each mode have been evaluated, equations 1 and 2 are employed to calculate the fraction of flow absorbed by the MM mode.

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. After that, the costs of the service for every year are calculated. The macro checks that the occupation of the ship is lower than 100%, otherwise the number of ships for the service will be accordingly increased. Once incomes and costs are known, and also the initial investment, a macro calculates the IRR.

4. CASE OF STUDY

From the model implemented in TransCAD 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.

In order to demonstrate the capabilities of analysis, a service with two routes is evaluated. The first route was aimed to link the ports of Barcelona, Valencia, Cádiz and Avilés (R1) whereas the second route linked Castellón, Cartagena, Huelva and Barcelona (R2). Table 2 presents the values of two of the parameters of the model, used to obtain the profitability of the two routes proposed.

Table 2: Data for the Model.

Fixed Data	Frequency	Fare
	50 trips/year	0.50 €/km

Table 3: Route 1 IRR Results.

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

Table 4: Route 2 IRR Results.

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

As incomes and costs depend on the number of TEUs moved in a certain route, a first step is the calculation of the TEUs moved in every stretch of the route. The number of TEUs between origin and destination is calculated applying the Mode Choice Model of the developed transportation model. It gives the probability of taking the multimodal option considering the cost and time of the freight. Figure 3 shows the percentage of occupation of the route, which informs about the extent of use of the ships in this route. For example there are two ships operating the Barcelona-Valencia route reaching an occupation between 90% and 100% during the whole timeframe.

Applying these probabilities 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 4 shows the annual multimodal freight flows in TEUs, for the first route of the case of study.

Figure3: Occupation Percentage of Route 1.

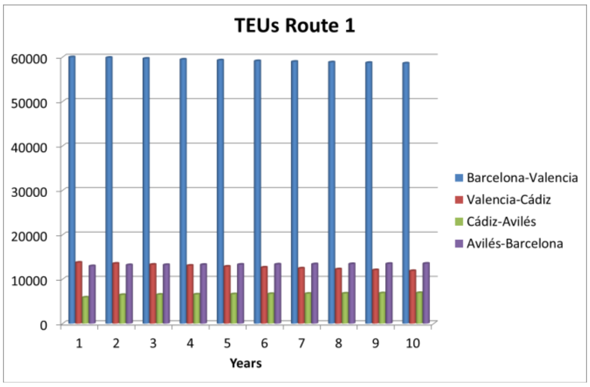

Figure 4: TEUs moved in Route 1.

For this case study we supposed that the initial investment is the cost of the ships of the service. As we are taking into account a generic approach, we disregard any financing method. There are a lot of shipping companies each with different operational set ups, so some of them might not even use external financing. In our case, we assume that the cost of investment will be borne by the shipping company.

The life time considered for the ship is twenty years, which is twice the period of time considered for the profitability assessment. Therefore the residual value of the ships is accounted as an income in the last year of the period. Figure 5 to Figure 8 show the values of Incomes, Costs and Cash flows calculated as they have been explained in point 3 of the paper.

As we can see in Figure 3, Cádiz-Avilés and Avilés-Barcelona are the routes that increase their freight flow over the years. Both routes also give the best results in terms of Cash Flow (Figure7 and Figure 8).

Tables 3 and 4 exhibit the results of applying the parameterization model to both routes R1 and R2. It is important to note that these routes are based on actual operating general purpose routes –thus, timetables, frequencies, stops and other operational parameters have not been specifically design for the optimal exploitation of the routes in terms of multimodal transference- so the IRR values may seem not good enough. But the proposed parameterization is useful to obtain the profitability of the route and the stretches that belong to it.

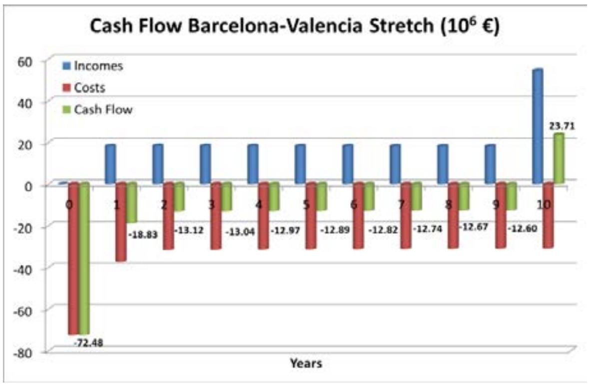

Figure 5: Cash Flow for Barcelona-Valencia.

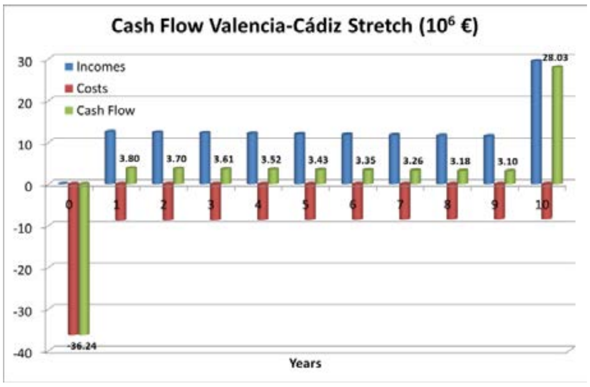

Figure 6: Cash Flow for Valencia-Cádiz.

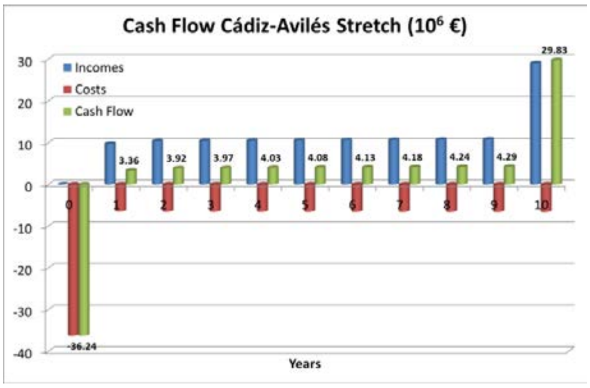

Figure 7: Cash Flow for Cádiz-Avilés.

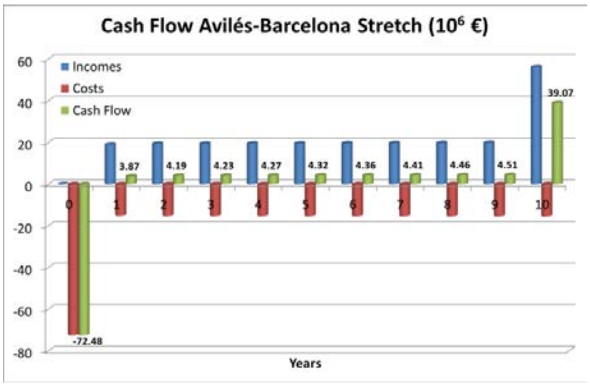

Figure 8: Cash Flow for Avilés-Barcelona.

5. CONCLUSIONS

The assessment of multimodal transport services against road transport in terms of their internal rate of return is achieved thanks to the development of a valid parameterization schema both for the multimodal transport model and for the evaluation objective function. It puts the bases of new IRR optimization algorithms, and as a result, the proposal of new interesting exploitation multimodal services. This is the first step to obtain optimized multimodal routes for freight transport which carry out the objectives of the White Paper of the Transport. The developments of the parameterization together with the transport model also allow obtaining the operation conditions that increase the freight absorption rate of the multimodal mode. So we have the possibility of implement algorithms for a double optimization, i.e., absorption rate and service profitability.

Another important point to take into account is its versatility. In spite of 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 that allow displaying GIS networks and implement some transport utilities could be used.

6. FUTURE RESEARCH

A first line of future work is focused on the improvement of optimization 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, optimization 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 parameterization, it may improve the results of the optimization. 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., Christiansen M., 2009. Service network design with management and coordination of multiple fleets, *European Journal of Operational Resarch*, Vol. 193, Issue 2, pp. 377-389

Bielli M., Bielli A., Rossi R., 2011. Trends in Models and Algorithms for Fleet Management, *Procedia Social and Behavioral Sciences*, vol. 20, pp. 4-18.

Chou, M., Song, M., Teo, C. P., 2003. Inventory-Routing Problem in Sea Freight: Direct versus Transshipment Model.

De Dios Ortúzar, J., & Willumsen, L. G., 2011. *Modelling Transport*. United Kingdom: John Wiley & Sons, Ltd.

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].

Fagerholt, K., Christiansen, M., Hvattum, L. M., Johnsen, T. A., & J.Vabo, T., 2010. A decision support methodology for strategic planning in maritime transportation. *Omega, The International Journal of Management Science* , 465-474.

Gursoy, M,2010. A method for transportation mode choice.*Scientific research and Essays V5*, 613-624.

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

Mu S. and Dessouky M., 2011. Scheduling freight trains traveling on complex networks. *Transportation Research Part B*, In Press, Corrected Proof.

Rios Prado R., Crespo Pereira D., del Rio Vilas D., 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

Romero-Hernández, M.C., 1999. Análisis coste-beneficio de un proyecto de inversión en infraestructura de carreteras; *Investigaciones Económicas*, volumen 23(2), págs. 251-265

Romilly, P., 2004. Welfare evaluation with a road capacity constraint; *Transportation Research Part A: Policy and Practice*, volumen 38, págs 287-303.

Spanish Freight Road Transport Observatory, 2012. Available from 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., & Taniguchi, E. 2009. Designing Multimodal Freight Transport Networks: A Heuristic Approach and Applications. *Transportation Science* , 129-143.

AUTHORS BIOGRAPHY

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 she is now studying for a PhD. She has also previous professional experience as an Industrial Engineer in the industrial installations sector. 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 is currently studying for a PhD. He is 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 optimization. He also has developed projects in the field of human factors affecting manufacturing processes.

Juan Manuel Bastida Sardiña obtained his MSc in Industrial Engineering in 2011. Since then, he has been working in Proyfe SL, a civil engineering privately held firm within its R&D Innovation Department. Amongst other areas and projects, he is mainly devoted to the development of logistical projects related with multimodal networks and its infrastructures.

David del Rio Vilas holds an MSc in Industrial Engineering. He is Adjunct Full Professor at the Department of Economic Analysis and Company Management of the UDC. Since 2007, he works in the GII of the UDC in industrial processes improvement projects. He also leads the R&D Department of the Spanish civil engineering company Proyfe S.L.

Nadia Rego Monteil obtained her MSc in Industrial Engineering in 2010. She works as a research engineer at the Integrated Group for Engineering Research (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 Optimization and Production Planning.