MULTIMODAL FREIGHT TRANSPORTATION: A SERVICE OPTIMIZATION ALGORITHM

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ABSTRACT

Most of the initiatives in terms of transportation promote multimodal transport, trying to decrease the road transport flows. In general a multimodal option is more efficient in terms of cost, fuel consumption and congestion than road transportation. One example of this initiative is the Transport White Paper 2011. In this paper the idea of multimodality and the actions to support it are reinforced. The optimization of the multimodal chain performance is one of these actions. This paper shows an optimization approach for the maritime service, taking into account the multimodal network. In this case the objective of the optimization is to maximize the value of the internal rate of return of the maritime service. To evaluate it, a multimodal transportation model, developed in a previous work by the research group, is used. This model, the optimization algorithm and some results will be shown in this paper.

Keywords: optimization, transportation, multimodal, Internal rate of return

1. INTRODUCTION

The current situation is the ideal framework for all the initiatives that promotes more efficient and sustainable transportation systems. Nowadays the roads are very congested: it is an important problem for transportation companies but also for the inhabitants of areas near the road, and actually for all the people. This is because this transportation mode produce high greenhouse gases emissions and its accidents or incidents have high impact over the population.

There are some initiatives in Europe that promote the use of other transportation systems in order to transfer movements of freight and passengers that usually use road transportation to other transportation systems.

For example, the European Transport White Paper (European Transport Commission, 2001) pays attention to the multimodality in order to obtain more sustainable transportation modes. Another initiative is, for example, the MARCO POLO Program. It indicates that road transportation depends on fossil fuel that produces high CO_2 emissions, and also congestion problems. Further, it underlines the need of integrating the railroad, short ship shipping, and river transportation in the transportation chain to decrease the road flows. Another project like Motorways of the sea or the improvement of the connections between ports and railroad follows the same idea.

Another White Paper (European Transport Commission, 2011) published in 2011, indicates the goal to reach, that is an absorption of the 50% from road transportation to other transportation modes. The way to obtain it is to optimize the multimodal chain in different terms (profitability, energy efficiency…). But the services that cover this have to be attractive for the shippers. To do so, these services have to be profitable.
All these reasons give an ideal framework to develop algorithms that optimize these services or the complete supply chain.

In this paper we propose an algorithm to optimize the maritime services as part of a multimodal transportation chain. This work is a continuation of a previous work presented in the HMS 2012 in Wien (Vienna) whose title is *A parameterized model of multimodal freight transportation for maritime services optimization* (R. Rios Prado, Crespo Pereira, Bastida Sardiña, del Rio Vilas, & Rego-Monteil, 2012).

Section 2 presents a brief review of optimization and simulation related with transportation. Section 3 explains the transportation model used. Section 4 shows the algorithm developed and the last section presents some results.

2. BACKGROUND

One of the tools best suited to transportation problems is simulation and optimization because it allows the establishment of systems with higher performance and/or with lower environmental effects.

The different levels of resolution and problems that the transportation presents mean that this kind of solutions are appropriated. There are some examples that we can use to illustrate this importance. In 2010 Longo (Longo, 2010) used this tool to improve the terminal operations, or Frick in 2011 (Frick, 2011) that explains the importance of simulation of a transportation network and proposes their own implementation. Also works like

Juan et al. in 2010 (Juan et al., 2010) shows how to use optimization to solve some transportation problems.

In terms of models for transportation planning there are two main groups. There are models for passengers and for freight transportation. The first ones are more developed, it means, there are more works about it. In most of them the method used is the Classical Model of the Four Stages (Ortúzar & Willumsen, 2011). This model is based on the movement of passengers between zones. These zones are called Traffic Analysis Zones, or TAZ, which are zones capable of generating and attracting movement of passengers. The four stages of the model are the following:

1. Trip generation: Trips generated in each TAZ.
2. Trip distribution: Generate trips between origin and destinations.
3. Modal split: Choose the transportation mode.
4. Traffic Assignment: Gives the links of the network used for a trip.

This model, despite being widely used for passengers' transportation, can be adapted for commodities transportation.

The difficulty to obtain a mode choice for freight transportation is the reason for fewer of these works. Decisions about transportation in companies follow complex criteria. More than a couple of variables have to be taken into account. For example Kreutzberger in 2008 (Kreutzberger, 2008) identified cost, reliability or frequency as important factors that affect the choice of mode.

In terms of optimization there are many works applied to transportation modeling, using Dynamic Programming and Operation Research techniques. Many of these works are referring to the Vehicle Routing Problem (VRP) in all its forms. Most of these papers are about a single transportation mode, meaning that they do not take into account the multimodality of the transportation.

In contrast, there are some works that search the optimization of transportation services. In 2010 Fagerholt (Fagerholt, Christiansen, Magnus Hvattum, Johnsen, & Vabø, 2010) presents a methodology for the strategic planning of a shipping company; he solves a route planning problem considering a "rolling horizon", updating information, to obtain the optimization. Another example is the work of Chou et all (Mabel Chou, n.d.) that optimizes shipping routes taking into account the two subproblems that it presents, direct and transfer services. For rail transportation we can cite the paper of Mu and Dessouky (2011) which optimizes the time plans for rail transport combining local search heuristics with heuristics that optimize the overall total delay.

It is important to mention the work of Yamada et al in 2009 (2009) where they show the optimization of a particular network of multimodal freight transportation. In 2009, Andersen et al. presents an optimized model for tactical design of service networks. It pays special attention to the effects of timing and coordination of services for improvement.

As we said before, there is an important factor that affects transportation planning. This factor is the cost, so not only infrastructure and operational configuration affect the performance of the service. The economic aspect, like fares or price policies, has to be taken into account. They are often treated separately from other design factors, as could be seen in the reviews of this kind of works made by Ortúzar and Willumsen (2011).

3. TRANSPORTATION MODEL

Before optimizing a transportation service, it is necessary to develop a transportation model that takes into account all the transportation modes available in the system. In this case the network has road and maritime links, because we want to optimize the maritime service taking into account the freight flow rates between road and the multimodality road-sea.

The transportation model developed comes from a previous work of the research group (Rosa Rios Prado, Crespo Pereira, del Rio Vilas, & Rego-Monteil, 2011) and a parameterization described in the paper of Rios (2012).

3.1. Input Data

The transportation model needs a set of information to develop the model, and also for the experimentations in order to obtain the results. The elements of this set are:

- Traffic analysis zones (TAZ). They are the zones capable of attracting and generating freight flows. In the case of our model these zones are areas of Spain. In Figure 1 you can see the TAZs of the model (the red areas). The model takes into account the Atlantic and Mediterranean areas of Spain.

Figure 1: TAZs of the model

As much in the model as in the algorithm the subscript for origin is ***i*** and for destinations ***j***.

- OD matrices. A transportation model is useful for evaluating how freight flows through the different transportation systems. The origin destination matrices (OD matrices) represent the total cargo in tons that have to be moved between each origin-destination pair. We represent the flows by $F_{t,i,j}$ where t is the period of time considered (in this case, a year).

- Cartography. A GIS contains all the links and nodes necessary to define all the transportation systems. It allows to obtain the real distances and travel times between nodes, and also the associated costs. The transportation modes are identified by the subscript ***l***.
- The fare and cost chain of each transportation system.

3.2. Network

The network of the model has to include all the transportation systems that we want to evaluate or that compete between them.

In this case we uses a GIS that represents the main roads of Spain and the maritime routes that can be used. As main roads, the roads and highways available for freight transportation are used. For maritime transportation, the model uses some regular routes available when the model was built. It also have a node layer that contain all the origin and destination points, and other singular points as the ports for the maritime routes.

The GIS is important because some elements of the model are based on the distance or the links used.

3.3. Transport model

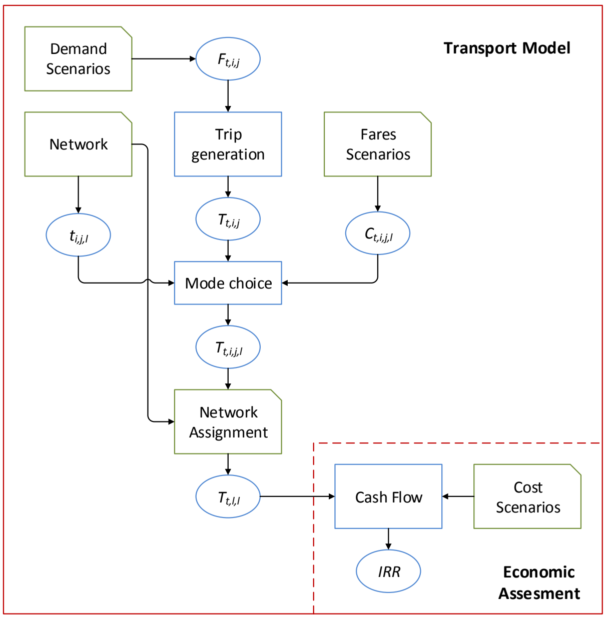

Figure 2: Transport model.

The model was developed using the Classical Four Stage Method for transportation modelling (Figure 2). In this case the OD matrices are inputs of the model, so we did not develop the first two steps. However, a modification should be made in the OD matrices for the Trip Generation Step.

- **Trip Generation**. This first step transforms the OD matrices units of tons into OD matrices of trips. We consider a standardized twenty feet container (TEU) as the transportation unit, because it is an element that can be carry by road and by sea. The TEU is a standardized unit of transportation, which represents a high intake of the global trades. This assumption simplify the model, because we do not have to take into account different handling systems due to different cargo. An average weight of the containers is used to transform tons in TEU.
- **Modal Split**. This step give us the freight flows between each OD pair by each transportation mode considered in the model. This is the most important step of the model because it gives how competitive a transportation mode is compared with the other modes considered in the model. The competitiveness could be evaluated by the freight flows that each transportation mode is capable to attract under some operational characteristics.
  There are several models developed to solve this step (Ortúzar & Willumsen, 2011), it means to predict the freight shippers choice. In this model a Multinomial Logit Model is used (MNL). It is one of the model widely used for shipper's choice.

$$P_{i,j}(l) = \frac{e^{V_{i,j,l}}}{\sum_{l \in A_L} e^{V_{i,j,l}}} \quad (1)$$

  Where:

  $P_{i,j}(l)$ Probability of the alternative ***l*** for a trip between ***i*** and ***j***.
  $V_{i,j,l}$ Utility for ***l*** travelling from ***i*** to ***j***. In this case the variables are cost and time.
  A_L Set of transportation modes. In this case road and multimodal (road-sea).
- **Network Assignment**. This step calculates the total freight flow for each link of the network. The "all or nothing" assignment method is used, because congestion effects in the network can be omitted or are not significant due to the analysis period of time considered. The freight flows are assigned by the shortest path method, minimizing the time, the cost, a generalized cost, or the length.

3.4. Parameterization

This model was developed for freight analyses but also for optimization purposes. An important aspect is to define the parameters needed for freight analysis and also for the optimization algorithm.

One of the first parameters that it is necessary to define is the **Number of Routes**. As we said before they are defined in the network.

Another parameter is the **Number of Vessels** because it was related with the capacity of the service. In our case the type of vessel is fix, as the more common vessel in the routes considered.

The **Total freight flow** ($T_{t,i,j}$) represents the total freight between origin and destination in TEUs, and using the model they have to be converted in freight flows between origin and destination for each transportation model ($T_{t,i,j,l}$). These OD matrices are obtained:

$$T_{t,i,j,l} = P_{i,j}(l) \times T_{t,i,j} \quad (2)$$

When these matrices are assigned to the network we obtain the freight flow of each link of the network, $n \in network$,($T_{t,l,n}$).

The mode choice model depends on the utility functions. The variables of these functions are **Time** ($t_{t,i,j,l}$) and **Cost** ($C_{t,i,j,l}$), because are the most important ones that affects the shippers choices (Kreutzberger, 2008)

- Road time: It take into account the travel time (function of the length and the speed) and the legal rest time of the drivers.
- Multimodal time: It has a haulage time (by road) that is calculated as it was said before. For sea links the time is a function of length and speed, but we also have to take into account the waiting times in ports.
- Road cost: The cost of road transportation comes from the data of the Freight Road Transport Observatory (Ministerio de Fomento Gobierno de España, 2012). It considers the total cost of the transportation chain by road (crew, car tires, amortization, etc.)
- Multimodal cost: For road haulage we use the same data of the observatory. For maritime option we built a cost chain similar to the road one, taking into account the costs of fare or taxes in port, port operation costs and inventory costs.

The objective is to optimize the maritime services in terms of the Internal Rate of Return (IRR). For this, we consider the **Fare** of the maritime service, because it allows to obtain the Incomes of the company.

The **Intermediate Stops** should be considered in solving the problem because they are associated with obtaining the shipping costs.

4. OPTIMIZATION ALGORITHM

After the multimodal transportation model has been built, the optimization problem could be defined. In this case the optimization search maximizes the maritime service profitability. The objective function is the Internal Rate of Return, according to the following formulas:

$$Fare = Costs + Net\ Profit \quad (3)$$

$$Income = Fare\ \times \textstyle\sum_{n \in MR} T_{t,l,n} \quad (4)$$

$$Earnings\ Before\ Taxes\ = Income - Costs \quad (5)$$

$$Earnings\ \ After\ Taxes\ = (Income - Costs) -\ Taxes \quad (6)$$

$$Cash\ Flow = Earnings\ After\ Taxes + Depreciation \quad (7)$$

$$\textstyle\sum_{t=0}^{10} \frac{CF_t}{(1+IRR)^t} = 0 \quad (8)$$

$\boldsymbol{CF}$ is Cash Flow, and $\boldsymbol{t}$ the time period. $\boldsymbol{MR}$ is the set of links of the network that belong to the maritime route considered.

In this case the tax rate is 30% of the profits (common rate of Spanish Corporate Income Taxes). A life time of the vessel of 20 years and a residual cost of the 15% are assumed.

The calculation of some parameters of the function comes from the evaluation of the multimodal transportation model, so simulation approaches are required for its calculation.

The decisions of the model are:

- The number of maritime routes
- The sequence of ports in each route
- The fares of each route. It must be greater that the cost per km.

Some variables are fixed in the model, as the characteristics of the ships of the routes, and also their number is high enough to cover all the freight flows of the maritime links. The costs and the times are calculated in the transportation model.

As the objective function shows, the optimization problem is quite complex, because its characteristics gives a combinatorial nature to the problem. The objective function has continuous decision variables (the fares), integer variables (number of routes, vessels…) and port sequences. There are different mythologies that can be applied to this kind of problems as metaheuristics (Dullaert, Maes, Vernimmen, & Witlox, 2005), hyperheuristics (Dowsland, Soubeiga, & Burke, 2007) or hybrid approaches (Mahjoub Dridi,Imed Kacem, 2004). The characteristics of the problem means that we cannot adopt some previous solutions and we had to develop our own algorithm.

The solution adopted in this case is a combination of heuristics and metaheuristics specifically developed for this problem, and that takes into account the combinatorial nature of the problem and the complexity of the objective function.

The solution uses an evolutionary algorithm, for the metaheuristics. In this case a Differential Evolution algorithm is used (Storn & Price, 1997), it gives a general and robust optimization method, and it shows good performance in problems with a low number of dimensions (Caamaño, Bellas, Becerra, & Duro, 2013).The genes include the parameter of the constructive algorithm and the route fare. The heuristics is specifically developed for the problem. The flowchart of this algorithm is shown in Figure 3.

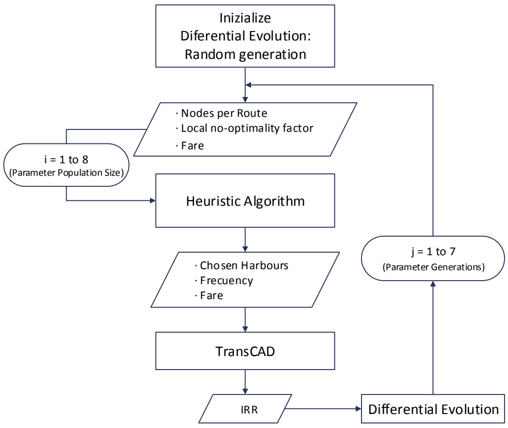

Figure 3: Optimization algorithm.

1. Initialize Differential Evolution:
   Random generation of the initial population
   Number of individuals = Population Size parameter
   Three dimension individuals
2. Evaluation of the individuals by the heuristic
3. Calculate the IRR of each individual
4. New population
5. Loop repeat

4.1. Evolutionary Algorithm.

The Differential Evolution algorithm used in the work was implemented in the Evolutionary Algorithms Framework (EAF), developed by Caamano et al (Caamano, Tedin, Paz-Lopez, & Becerra, 2010).

The parameters used in this case are the ones in the Table 1:

Table 1: Parameters settings.

Parameter	Value
Population size	8
Number of Generations	8
Parameter F	0.5
Parameter CR	0.5

The Evolutionary Algorithm is used to optimize the parameters of the heuristic. The decision variables of Evolutionary Algorithm are the parameters of the heuristic in 4.2:

- Number of nodes per route: Between 2 and 5. It have to be an integer.
- Local No-optimal Factor (***L***): Integer. It makes that a harbor has not been selected twice or more in a route.
- Fare: For each route. Its value goes from 0.3 to 0.7 euros per kilometer.

As it was said before, the first generation is a random generation. At the beginning of the execution of the search, the initialization is made. The break criterion is the number of generations. The quality function is the internal rate of return.

4.2. Heuristic Algorithm.

The Evolutionary Algorithm gives individuals with three dimensions: nodes per route, Local non-Optimality Factor and Fare.

These values feed the heuristics algorithm, and they are evaluated to obtain the ports sequence.

The flowchart of the heuristic algorithm is shown in Figure 4.

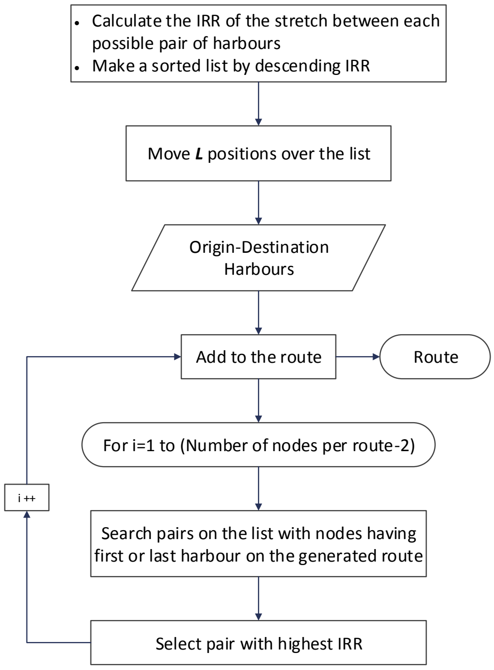

Figure 4: Heuristic algorithm.

A TransCAD macro calculates the IRR of each link between each pair of harbors. A list of this links is created and ordered by descending IRR. After that, ***L*** positions are moved over the list, giving the Origin-Destination pair of harbors. These pair of harbors are added to the route.

Now from 1 to the number of nodes per routes minus 2, the algorithm searches the link that has an end point in the origin or destination harbor previously selected. From all of them, the one with higher IRR is chosen and the other node of this link is added to the route.

These steps have to be repeated to obtain the predetermined number of routes.

When the sequence with all the ports is obtained, the IRR can be estimated. Then it is sent back to de Differential Evolution for further exploration.

5. CASE OF STUDY.

Two scenarios are proposed to evaluate the effectiveness of the optimization mixed algorithm. These scenarios are a problem with a single route and the second one is a scenario of two routes. Both scenarios are represented in the Figure 5.

Figure 5: Maritime routes for the case of study.

In this evaluation some assumptions are made. One of them is the frequency of the vessels, we considered a travel each week, 50 travels per year. This frequency minimize the number of vessels, but the algorithm checks if they are enough, if it isn't the algorithm increases it.

Table 2: Scenario 1.

Decision Variables (Genetic Algorithm)		
Number of ports in a route		4
Non-Local Optimality Factor		3
Fare per Route		0.67 €/Km
Decision Variables (Optimization Problem)		
Routes Solution		Valencia-Barcelona-Marín-Cartagena
Frequency		50
Fares		0.67 €/Km
IRR	VAL-BCN	9.54%
	BCN-MAR	35.34%
	MAR-CART	30.67%
	CART-VAL	-2.72%
IRR Overall		18.12%
Computation Time		40 minutes

Table 3: Scenario 2.

Decision Variables (Genetic Algorithm)		
Number of ports in a route	5	
Non-Local Optimality Factor	4	
Fare per Route	0.57 €/Km	0.62 €/Km
Decision Variables (Optimization Problem)		
Routes Solution	Huelva-Barcelona-Cartagena	
	Cadiz-Barcelona-Marín	
Frequency	50	
	50	
Fares	0.57 €/Km	
	0.62 €/Km	
IRR	HUELV-BCN	20.85%
	BCN-CART	-2.97%
	CART-HUELV	12.83%
	CAD-BCN	13.82%
	BCN-MAR	4.47%
	MAR-CAD	1.89%
IRR Overall		8.48%
Computation Time		3 hours 30 minutes
Absorption Rate		6.40%

As the tables show, the algorithm is capable to obtain good solutions in terms of profitability of the services.

REFERENCES

Caamano, P., Tedin, R., Paz-Lopez, A., & Becerra, J. A. (2010). JEAF: A Java Evolutionary Algorithm Framework. In *2010 IEEE Congress on Evolutionary Computation (CEC)* (pp. 1–8). IEEE.

Caamaño, P., Bellas, F., Becerra, J. A., & Duro, R. J. (2013). Evolutionary algorithm characterization in real parameter optimization problems. *Applied Soft Computing*, *13*(4), 1902–1921. doi:10.1016/j.asoc.2013.01.002

Dowsland, K. A., Soubeiga, E., & Burke, E. (2007). A simulated annealing based hyperheuristic for determining shipper sizes for storage and transportation. *European Journal of Operational Research*, *179*(3), 759–774. doi:10.1016/j.ejor.2005.03.058

Dullaert, W., Maes, B., Vernimmen, B., & Witlox, F. (2005). An evolutionary algorithm for order splitting with multiple transport alternatives. *Expert Systems with Applications*, *28*(2), 201–208. doi:10.1016/j.eswa.2004.10.002

European Transport Commission. (2001). White Paper: European transport policy for 2010. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0144:FIN:EN:PDF

European Transport Commission. (2011). White paper 2011. Retrieved from http://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm

Fagerholt, K., Christiansen, M., Magnus Hvattum, L., Johnsen, T. A. V., & Vabø, T. J. (2010). A decision support methodology for strategic planning in maritime transportation. *Omega*, *38*(6), 465–474. doi:10.1016/j.omega.2009.12.003

Frick, R. (2011). Simulation of transportation networks. In Society for Modeling & Simulation International, Vista, CA (Ed.), *Proceedings of the 2011 Summer Computer Simulation Conference* (pp. 188–193). The Hague, Netherlands. Retrieved from http://dl.acm.org/citation.cfm?id=2348196.2348222

Juan, A. A., Faulin, J., Jorba, J., Riera, D., Masip, D., & 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*, *62*(6), 1085–1097. doi:10.1057/jors.2010.29

Kreutzberger, E. D. (2008). Distance and time in intermodal goods transport networks in Europe: A generic approach. *Transportation Research Part A: Policy and Practice*, *42*(7), 973–993. doi:10.1016/j.tra.2008.01.012

Longo, F. (2010). Design and integration of the containers inspection activities in the container terminal operations. *International Journal of Production Economics*, *125*(2), 272–283. doi:10.1016/j.ijpe.2010.01.026

Mabel Chou, M. S. C. T. (n.d.). Inventory-Routing Problem in Sea Freight: Direct versus Transshipment Model. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.123.478

Mahjoub Dridi,Imed Kacem. (2004). A hybrid approach for scheduling transportation networks. *Int. J. Appl. Math. Comput. Sci*, *14*, 397 – 409. Retrieved from http://www.researchgate.net/publication/228920423_A_hybrid_approach_for_scheduling_transportation_networks

Ministerio de Fomento Gobierno de España. (2012). Observatorios del transporte de mercancías por carretera. Retrieved from http://www.fomento.gob.es/mfom/lang_castellano/direcciones_generales/transporte_por_carretera/servicios_transportista/observatorio_costes/observatorios.htm

Mu, S., & Dessouky, M. (2011). Scheduling freight trains traveling on complex networks. *Transportation Research Part B: Methodological*, *45*(7), 1103–1123. doi:10.1016/j.trb.2011.05.021

Ortúzar, J., & Willumsen, L. G. (2011). *Modelling Transport*. (John Wiley&sons, Ed.) (4th ed.). Chichester, West Sussex.

Rios Prado, R., Crespo Pereira, D., Bastida Sardiña, J. M., del Rio Vilas, D., & Rego-Monteil, N. (2012). A Parameterized Model of Multimodal Freight Transportation for Maritime Services Optimization. In *The 14th International Conference on Harbor Maritime & Multimodal Modelling and Simulation* (pp. 157–164).

Rios Prado, R., Crespo Pereira, D., del Rio Vilas, D., & Rego-Monteil, N. (2011). GLOBALOG: A Simulation Case of Freight Multimodal Transportation. In *The 13th International Conference on Harbor, Maritime and Multimodal Logistics Modelling and Simulation Proceedings* (pp. 170–178).

Storn, R., & Price, K. (1997). Differential evolution - A simple and efficient heuristic for global optimization over continuous spaces. *Journal of Global Optimization*, *11*(4), 341–359. doi:10.1023/A:1008202821328

Yamada, T., Russ, B. F., Castro, J., & Taniguchi, E. (2009). Designing Multimodal Freight Transport Networks: A Heuristic Approach and Applications. *Transportation Science*, *43*(2), 129–143. doi:10.1287/trsc.1080.0250

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