MULTIMODAL FREIGHT TRANSPORT MODEL FOR INFRASTRUCTURE ANALYSIS

Rosa Rios-Prado[a], Diego Crespo-Pereira[b], Alejandro García-Del-Valle[c]

[a],[b],[c]Universidade da Coruña

[a]rosa.rios@udc.es, [b]diego.crespo@udc.es, [c]agvalle@udc.es

ABSTRACT
Nowadays the improvement in transport infrastructures involves big projects with important investments. If a correct analysis of this new infrastructure is not made, the return on these investments will be affected and a significant increase in costs may occur. In this paper a complete conceptual model is proposed in order to analyse a new service or infrastructure and to establish the conditions to make it profitable. This model allows to obtain the use that the freight flows do of a transport system, taking into account different levels of resolution, like long and short distance travels. The variables of the model allow to make the analysis of the system from different points of view: flows, times, costs, etc. The model also takes into account the multimodality of the system, due to the importance that this characteristic has in the development of new infrastructures.

Keywords: Transportation, Modelling, Simulation, Freight, Multimodal

1. INTRODUCTION
Transportation is one of the most important activities that takes place every day and has great importance in the economy of a region. Taking into account the data of the Spanish Development Ministry (Fomento 2014), the transportation represents an average value of the 4% of the GDP (for 2000 to 2009). And in the case of the United States (US-DOT, 2015) this value increases a 10% (on average from 1980 to 2013). So improvements in the transportation system will have important effects in the economy.
But the construction of new infrastructure is also more important when we are talking about developing countries, not only by the great investments but also for the high number of existing initiatives because of the lack of them or bad conditions of the transport system. So any initiative that helps the governments to analyse a new infrastructure or prioritize the investments in order to make a better use of the available budget, will be of great value.
An important tool for transport system analysis is simulation based transport modelling. A transport model is a tool for planning a transportation system from different points of view. It is a representation of the real transport system, taking into account the geographical scale of the model and the level of resolution that this scale needs to be faithful with the reality. Using the transport model to simulate different scenarios we can forecast the future situations of the services and infrastructures.
In most of the cases a transport model is developed using the classical four step model (Ortúzar and Willumsen 2011). This steps are:

1. Trip generation: It gives the generated and demanded freight in the different zones considered in the model.
2. Trip distribution: Gives the freight flows between origin-destination pairs in base of the data of the previous step. It gives the origin destination (OD) matrices of freight flows.
3. Mode choice: It shares the OD flows between the transport alternatives of the model, giving a OD flow matrix for each one of the alternatives.
4. Network assignment: Obtain the use of the network, giving the route of each one of the OD flows.

These steps allow to obtain, for the present and the future, the generated and demanded freight of different zones and how these flows are distributed between these zones. These values provide the use of the different transport modes and the freight volumes of each arc and node of the system, or the vehicle flows.
Taking this theoretical definition as a base, a complete transport model for freight transport will be presented in this paper. But some special characteristics have to be taken into account. The first one is the geographical level of the model. The model has to be capable to consider different freight flows; that is, flows of different nature like the importation/exportation flows or the flows related to the internal consume. For this reason, the model should be able to manage a high distance variability.
Another characteristic of the transport system that the model has to consider is the transport multimodality. This is because most initiatives in the development of new infrastructures and transport policies establish that the multimodality is the main characteristic a sustainable transport system should have in the long term. For example the White Paper (European Transport Commission 2011) indicates that the main characteristics of a quality service are: attractive frequencies, easy

access, reliability of the transport and the integration of the ***intermodality***. Another example of the importance that governments give to intermodal transport is the Intermodal Transportation Infrastructure Strategic Plan of Colombia (Ministry of Transport of Colombia & EPYPSA, 2013). It indicates that the government has to guide the transportation sector towards intermodal models of higher efficiency and sustainability in the middle and long term. In the case of Spain some studies for intermodal terminals or logistic platforms are cofounded by the European Commission (European Transport Commission 2015). In South America the Inter-American Development Bank promotes some projects to develop the transport modes that are an alternative to road transport, using intermodal routes. An example is the Central Bioceanic Railway Corridor (IIRSA, 2015). This railway corridor will cross South America from an Atlantic port (Santos) to a Pacific port (Ilo, Arica…).
In this paper, a complete transportation model is presented. The architecture of this model is flexible and configurable, because not all the steps defined in the model have to be used in all the cases. It depends on the geographical level and the objectives of the project. First, and introduction of previous European models will be presented. After that, the complete model will be showed. In section 4 some cases of study will be presented. The paper finishes with some conclusions and future lines.

2. PREVIOUS TRANSPORT MODEL IN EUROPE.

A significant number of transportation models were developed in Europe in the last years. Some of them are showed in Table **1**.

Table 1: European transportation models (de Jong et al. 2013)

Model	Area	Step	Modes
SMILE +	Holland	1,2,3,4	a-f
MODEV	France	1,2,4	a,b,c
BVWP	Germany	1,2,4	a-e
Transtools	Europe	1,2,3,4	a,b,c,d
Worldnet	Europe (focusing on traffic with no European countries)		a-e
Norway	Norway	1,2,4	a,b,d,e
Samgods	Sweden	1,2,4	a,b,d,e
Mobility Masterplan Flanders	Flanders and Brussels	1,2,4	a-e
LOGIS	France	1,2,4	a,b,c
Basgoed	Holland	1,2,4	a,b,c

(1) Generation and Distribution.
(2) Mode Choice
(3) Logistics.
(4) Assignment.

(a) Road.
(b) Railway.
(c) Internal waterway.
(d) Sea.
(e) Air.
(f) Ducts.

As it can be seen, all of them use the theoretical basis of the four step model. So it could be considered a good basis for the development of a complete transportation model, but taking into account the limitations encountered in the previous models. The four step model has been developed for transport of passengers: this explains why there are a high number of papers in this field. There are also some works that use these steps to develop freight transport models, but taking into account some changes regarding to the characteristics of the freight transport. These particular characteristics are:

- Freight transport has a high number of decision agent compared with the passengers one. In the second case is the passenger the one that choose between a set of options, but in freight transport shippers, carriers… can have different decisions for a service or a route.
- The number of transport alternatives usually is higher in freight transport (road, train, maritime… and different vehicles in each one of the alternatives).
- Also there is more variability in the unit of transport or size of the shipment in freight transport.

The development of the complete conceptual model for freight transport has to consider all these elements. But there are also other elements that have to be taken into account, derivate from the study of some previous works. For the Distribution step, most of the previous works use the Gravitational model (Tavasszy 1994) (Fosgerau 1996), regardless of the geographical level considered in the model. When the model considers different types of flows this model could not work in a good way. For example, if the model considers importation/exportation flows between countries with very different economic systems, the calibration of the gravitational model is very complicated.
In the case of the Mode Choice step, the most used methods are the Logit ones (ETIS 2014). These models are robust, and provide good solutions not only in transport model but in other areas as marketing or social sciences. A limitation of the previous works is the number of variables considered in the model (de Jong et al. 2013). The introduction of new variables represents a good opportunity to consider in the development of the model.
Holguín-Veras (2011) identified that the mode choice depends on the shipment; this is an element that most of the projects does not take into account. It is very important to introduce this interaction as a new step in the model.
Another limitation of these kind of models, is the way in which congestion is considered. As SteadieSeifi et al (2014) found, the importance of congestion for freight transport is in the nodes of the network, especially of long distance. Special nodes as Customs, tolls, train terminals, ports… are important elements capable to increase the travel times because of their congestion. The

congestion is related with their capacities and the flows that can make use of them. Most of the studies uses queuing models to consider the delay due to the congestion in nodes, (Tan et al. 2015), but they do not consider the interaction between the transport mode (that calculate the freight flows) and the delays in the node.
All of this leads to set out a complete transportation model, for multimodal freight transport, that allows the assessment of infrastructures and services. This model takes into account different geographical levels, and different freight flows. It is configurable and flexible, because not all the problems need the same steps or calculations. The model considers more variables and it lets to introduce new ones depending on the problem to solve. It also takes into account the limitations in the consideration of congestion and the relation between the freight flows and the size of the shipment

3. MULTI-STEP TRANSPORT MODEL.

The great investments that a new infrastructure needs gives importance to all the tools that makes easier or give support to the decision maker. These decisions could be about infrastructure or the services that will use this infrastructure. Even these tools help in the development of transportation policy design.
A transportation system is a complex network with complicated relationship between the different elements of the system. The process for planning usually is a hierarchical process (Bussieck el al, 1997).
The network that support all these infrastructures have to be perfectly defined. Horn (2003) identified that most of the studies follow the next steps to define a complete and characterized network:

a) Identify the most important nodes, as origin, destinations, intermodal nodes etc.
b) Establish the transportation modes of the systems and the arcs and nodes of the network that each mode can use. Also if some services have fixed routes or arcs.
c) The time and cost are two important variables of the system. For a service this values are established, for other routes it is necessary to build or identify a time and cost chain.
d) Time and cost are not only important on the arcs of the system. Some of the nodes of the system are intermodal nodes, so it is necessary to identify the penalties in terms of cost and time in transfer processes.
e) Limitations of the system like arcs that cannot be used by some modes. And requirements and preferences.

The transportation system belongs to an environment, and it is not isolated of it, there are relationships between them and changes in one of them affect to the other and vice versa. For example, the changes in the socioeconomic characteristics have influence in the demand and therefore in the transport flows. In the other direction changes in the network could affect the economic and social environment, improving the communication of some areas and helping the development of these areas. It also can improve the external or internal trade of the country because of the improving of the transport routes.
Taking all these things into account and the uses searched, a methodology for the construction of freight transportation models will be presented in the paper.
The characteristics of the methodology are:

- Adaptable to the data available, the geographic level and the objectives of the analysis.
- Oriented to the national and international levels, not regional.
- Take into account the congestions on the nodes.
- Influence of the shipping size.

The projects analysed before showed that theoretical basis of the Four Step Model (Ortúzar and Willumsen 2011) is useful for transportation planning models, so it will be the basis of this conceptual model.
Figure **1** represents all the steps and methods considered in the multimodal freight transport model that will be presented in the paper. As it was said before, it follows the Classical four step model theoretical basis, but taking into account that is a freight model, that have to consider high variability in the distance of the shipments, and also the limitations funded in previous studies.

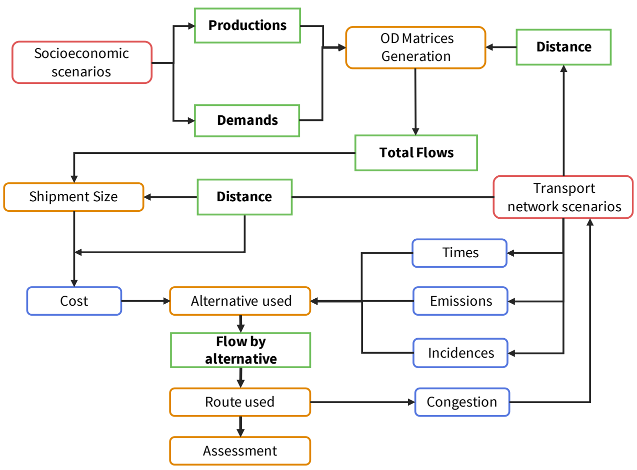

Figure 1: Complete conceptual transport model.

3.1. General elements of the model.

The model developed with the methodology must be useful for systems with high variability in the distance, for different types of cargo and different periods of analysis (not all of them with the same length). So there a set of elements which must be established or defined, depending on the problem to solve.
First of all, the **objectives** of the study must be set. They let us identify the results that the model searches and establish the steps and calculations of the model that must be used. Another of the elements are the **zones** of the study (Traffic analysis zones, TAZ). All the possible

origin and destination nodes of freight flows. These define the geographical level of the model and transport system. The relationship between transport system and environment make necessary to know the **socioeconomic characteristics** and they present and forecasted value. They are the basis of the econometric models that give the production and consumption flows, origin of the freight flows. Also these values are useful to estimate another variables or parameters of the model. The transport system has two main elements: **transport alternatives** and **transport network**. First one is all the modes or modes combination available in the system. The second one are the physical infrastructure or routes that the modes use in their trips. Both have to be characterized in the present but also in the future, because of possible changes in infrastructures or services. All these things allow to define the model to obtain the main result that is the **freight flows** over the network. Joining the freight flows the model gives another skimming results, like travel cost, travel time, distance, etc. So some parts of the complete model must be the **assessment components**, that are oriented to the different wanted analysis like emissions, economic, profitability, social, etc.

3.2. Steps of the model.

The methodology to define the transport model is based in the classical Four Step Model, but with the adaptations that the freight transport requires. This methodology is widely used for passenger transport, but there are less studies for freight transport. In these studies, the analysts use the four step model but with adaptations. It is due to the differences between both cases. In freight case there are a great number of decision maker (carrier, shipping company, user…) compared with passengers (passenger). Other difference is that freight transport usually has a high number of transport alternatives. And also there is more variability in the shipping size.
The study of previous model gives some limitations, explained in section 2:

- Use of the gravity model for distribution, independently of the geographic level.
- Logit model in most of the cases for mode choice. These models usually use time and cost as variables of the model, so it is important take into account more variables.
- The interaction between mode and route choice and shipping size is note taking into account in most of them.
- For freight transport the effects of the congestion are more important in nodes that in links, where is taking into account in most of the cases.

The steps of the model take all the characteristics and limitations in order to give answer to the requirements of the analysts.
The model presented is a model for freight transportation using multimodal systems, in order to assess infrastructures or design transport policies. The model is flexible and configurable, it means, not all the steps of the model have to be used in all the cases. The steps used depend on the geographical level of the problem, the results that the model searches, or the data available. Some characteristics of the model related with the limitations of previous models are that the model considers the congestion in the intermodal nodes, it considers a high number of variables and takes into account the shipment size and its relation with the mode choice and network assignment.
Figure **1** represents in a general way all the steps of the model. As we use as basis of the methodology the four step model, it has the four main steps of the model, but also the steps that allow to take into account the limitations or opportunities identified in the previous studies.
The model has some requirements. First one are the socioeconomic aspects. They have influence in the transport system and vice versa. Another one is the network that represents all the infrastructure that the transport modes uses. Not only physical infrastructure but routes as maritime routes. Also all the transportation modes which make use of the network must be established.

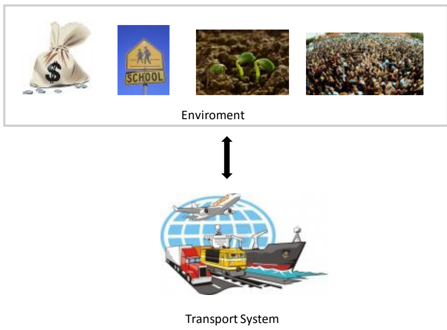

Figure 2: Bidirectional relationship between transport system and environment

Some restrictions in terms of links of the network (for some alternatives) or regulations must be considered in order to define the real network for each alternatives or the value of the parameters or variables used in the model.
It is also important establish the aims of the study and the geographical area, because they define some of the steps that must be used, or not.
The main results of the model are how the freight choose among the transport alternatives in the system, the freight flows over the network and another supporting results as travel cost or travel time. All of them allow to make differ analysis under diverse points of view (economic, environment, GHG emissions…).
The construction of the model begins obtaining **freight production and consumptions**, in the origin and destination nodes. When the methodology is used to build a transport model, we have to choose the points that generate or consume freight. These are the origin and destination nodes. Econometric models give the total

amount of freight by means of the social and economic variables of the environment. Usually regression and time series methods are used, but also input-output methods could be used.
Once the total amount of freight is defined, it is necessary to share it into **Origin-Destination (OD) pairs**. It means, share the productions and consumptions in the nodes making OD freight flows. In the methodology explained in this paper, the variability of the travel distances in the model is considered. Trade relationships between countries or regions have different nature. For example, the importation and exportation relations are very different taking into account an origin country and all the possible destination countries, and it is usually related with long distance. By other way the trade relations between regions in the same economic area are more stable.
It means that the model has to consider methods to share these freight flows which take into account this different nature of the trade relationships. For example, a system that share the production and consumptions using partition coefficients estimated using historical data, works in a good way to build the OD matrices when there are very different relationships among the areas of the study. In other way the gravity model works better when these relations are more stables. Depending of the model and its geographic level could be necessary apply one of the models or both of them.
Once the total OD matrices of freight flows are obtained is necessary to know the way these flows use the different transport alternatives existing in the model, it means **freight flows for each alternative.** In most of the cases logit models are used. But there is a limitation in most of the studies and it is that the relation between the size of the shipment and the mode choice it is not presented. The solution presented in this paper is the following. The cost of a travel usually is one of the parameters that some user takes into account to decide which alternative should be used for a shipment and assess its viability (Kreutzberger 2008). So the methodology implements a step to do that. In this step the size of the shipment is calculated, using formulas of economic order quantity, regression models, etc. The **size of the shipment** allows to obtain in a more accurate way the real cost of the travel, because it makes possible to define the vehicle and to handle the cost of the shipment.
As it was said before, the cost is one of the most important parameters for mode choice, so the cost is the element that **relates the shipment size and the mode choice**, that is one of the limitations detected in previous studies.
The choice between alternatives using mode choice models gives the OD freight flows for each transportation alternative in the model. Logit models are widely used, but there is another method like minimize a generalized cost. In previous studies, it could be seen that the number of variables used to make the choice are minimal. The proposal methodology takes into account an important number of parameters, which could be used or not, like travel cost and time, distance, GHG emissions or incident probabilities. The higher the number of well-defined explanatory variables, the better the establishment of mode choice.
Last main step is **assign the freight flows to the network**. The way that the route for each OD pair is calculated depends on the result searches: generalized cost minimization, short path methods…An improvement of the classical studies is that the congestion is taken into account in the nodes of the system, not in the links. Due to the capacity of the nodes (ports, train terminals, customs…) and the freight flow that try to use it, it is possible that delays may occur in those nodes.
This model is useful for macro models, where long distances and high periods of time are evaluated. It makes that travel times can be of days or weeks compared with travel times of hours in meso and micro models. So the problems that a model for urban transport or pick and delivery transport have with the congestions of roads and streets are not representative in the macro models. Nevertheless, the **congestion in the intermodal nodes**, as a congested port or a custom with waiting times of weeks, has important effects on the total travel time. This is the reason why it is important the node congestion. In most of the studies of delay times in intermodal node the time is obtained by queueing theory, so in function of the freight and the capacity of the nodes, the total time could be obtained.

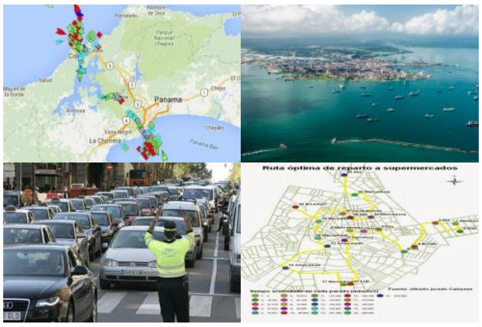

Figure 3: Congestion: Nodes vs Links.

3.3. Model results for infrastructure analysis.
The main results of the model are the freight flows in arcs and nodes of the network. They are obtained using simulation of some scenarios and they allow to know the future use of the infrastructure under different conditions. It means, if a new infrastructure will be used, if an infrastructure could have congestion problems, define the characteristics of this infrastructure, the operational service conditions, etc.
But the model gives another results like travel times, travel cost or travel emissions. They allow analysis the infrastructure for another points of view, like economic assessment, GHG emissions or logistics times.
The mode choice gives the total among of freight for each transportation mode, so it gives a measure of the rate of use of all the modes in the system.
As the model uses the support of a SIG system, where information about population, regions, etc, is present, the model gives some secondary results as the population

affected by an infrastructure or services or distances to the infrastructure.

4. CASES OF STUDY.

The methodology described in the paper was used in two real projects. Both projects are developed in countries of South America: Bolivia and Brazil. They search different aims. The case of Bolivia searched the assessment of a new railway infrastructure that cross the continent from the port of Santos in Brazil to the Ilo port in Peru. The model of Brazil allows to prioritize a set of projects related with logistics and transportation infrastructures.
The aims of both projects and the data available makes that each one of the models uses different steps of the methodology.

4.1. Bolivia Transportation Model.

An international model to assess a railway corridor between Pacific and Atlantic coasts was developed. The aim of the study was establishing if the railway corridor will be profitable, under which condition it is profitable and also the characteristics of the infrastructure. The purpose of the model was obtaining the freight flows in each link and node of the transport system. It also allows to obtain another secondary results as travel cost and time.

The steps of the methodology used in the model are showed in Figure **4**.

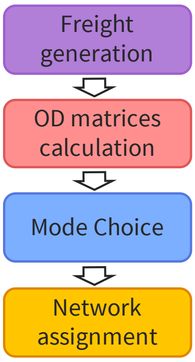

Figure 4: Steps of the Bolivian Model.

The productions and demands of each one of the origin and destination nodes considered was build using socioeconomic data, importations and exportation and some more sources.
The OD matrices were built using two methods. For import export flows, a method that share the productions and demands using coefficients based on historical data. Inside the country, gravity methods were used. The use of both methods allows to take into account the different nature of the trade relationships.
Once the OD matrices were built the step to obtain the size of shipment is not necessary, because the units that the analysts need are physic units. The mode choice model, a logit model, was calibrated using cost and time variables, based on physical units.

The mode choice gave the total freight flow that will use each one of the transportation modes. An all or nothing assignment was made to see the total freight that use each link and node.
As the model was built for simulation, some scenarios of speed, cost and times in nodes were evaluated to obtain the optimal characteristics of the system.
So the methodology allows to assess the new infrastructure.

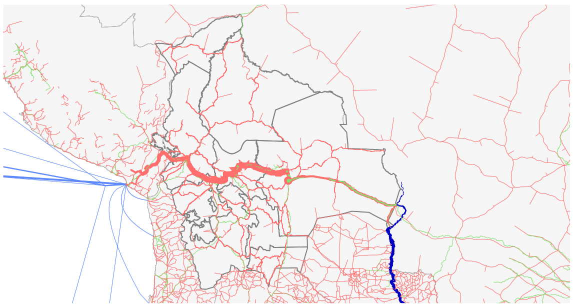

Figure 5: Network assignment, flows results.

In the case of Brazil, the aim of the study was to prioritize a set of projects (logistics and transportation projects). To do that, a multi-criterion matrix was built, where some of the variables used are results of the transportation model.

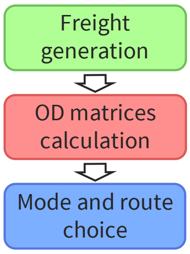

Figure 6: Steps of the Brazilian Model.

In this case the geographical area of the model was the north east region of Brazil.
The OD matrices come from input-output data of the Institute of Statistics of Brazil, using as in the case of Bolivia a mixed system of coefficients and gravity model to transform these data in the OD matrices. In this case a joining choice of mode and route was made. To do that, a generalized cost build with the travel cost and the cost of the travel time, was minimized. The congestion was considered as penalized time in the nodes.
The results of the model were the flows in links and nodes, and also another elements as affected population or saving transport time and cost.
All these elements are part of the multi-criterion matrix, that in function of the points given to each project for the variables prioritize them.
The methodology was useful to establish transport and investment policies.

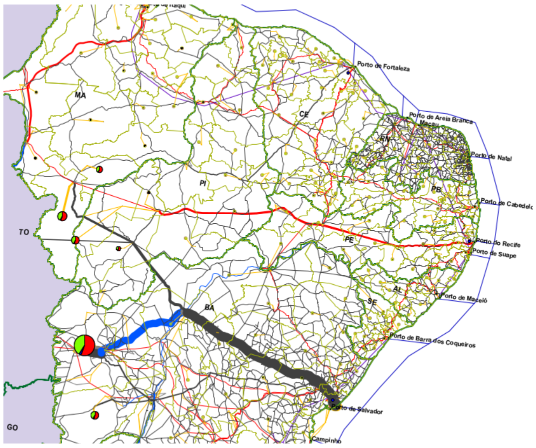

Figure 7: Flows in the system.

5. CONCLUSIONS.

This methodology allows to build complete models to assess infrastructure and services and define policies in terms of transportation or investments.

It is highly configurable, only is necessary use the step that are consistent with the data available and the aims of the model.

The methodology takes into account the variability of the trade relations between zones, and it propose a mixed model (coefficients and gravity model). Also implement the relation between shipment size and mode choice by the step of size shipment calculation and the calculation of the cost of the travel.

The congestion in the nodes is taking into account and is related with the mode choice.

As it was explained the methodology was used to develop the transport model for two real projects. It allows to verify the utility of the model. In the case of Boliva, the assessment of a new infrastructure and in the case of Brazil, it was a tool decision support to choose better investments.

REFERENCES

Bussieck, M. R., T. Winter, and U. T. Zimmermann. 1997. “Discrete Optimization in Public Rail Transport.” *Mathematical Programming* 79 (1-3). ELSEVIER SCIENCE BV: 415–44. doi:10.1007/BF02614327.

de Jong, Gerard, Inge Vierth, Lori Tavasszy, and Moshe Ben-Akiva. 2013. “Recent Developments in National and International Freight Transport Models within Europe.” *Transportation* 40 (2): 347–71. doi:10.1007/s11116-012-9422-9.

“ETIS and TRANS-TOOLS v1.” 2014. Accessed September 25. http://www.slideserve.com/pillan/etis-and-trans-tools-v1-freight-demand.

European Transport Commission. 2011. “White Paper 2011.” http://ec.europa.eu/transport/themes/strategies/2011_white_paper_en.htm.

———. 2015. “Financiación Para Mejorar Las Redes de Transporte Españolas.” http://ec.europa.eu/spain/actualidad-y-prensa/noticias/transportes/conectar-europa-beneficiarios_es.htm.

Fomento, Ministerio D E. 2014. *Evolución de Los Indicadores Económicos Y Sociales Del Transporte Por Carretera*. http://www.fomento.gob.es/NR/rdonlyres/3784CAC4-866C-4789-BAD0-DE6BDB89A7CC/127674/IndicadoresEconomicos_.pdf.

Fosgerau, M. 1996. “FREIGHT TRAFFIC ON THE STOREBAELT FIXED LINK.” In *TRANSPORTATION PLANNING METHODS. PROCEEDINGS OF SEMINAR E HELD AT THE PTRC EUROPEAN TRANSPORT FORUM, BRUNEL UNIVERSITY, ENGLAND 2-6 SEPTEMBER 1996. VOLUME P404-2*. http://trid.trb.org/view.aspx?id=575156.

Holguín-Veras, Jose, Ning Xu, Gerard de Jong, and Hedi Maurer. 2011. “An Experimental Economics Investigation of Shipper-Carrier Interactions in the Choice of Mode and Shipment Size in Freight Transport.” *Networks and Spatial Economics* 11 (3): 509–32. doi:10.1007/s11067-009-9107-x.

Horn, Mark E. T. 2003. “An Extended Model and Procedural Framework for Planning Multi-Modal Passenger Journeys.” *Transportation Research Part B: Methodological* 37 (7): 641–60. http://ideas.repec.org/a/eee/transb/v37y2003i7p641-660.html.

IIRSA. 2015. “Project Sheet: Central Bioceanic Railway Corridor.” Accessed December 10. http://www.iirsa.org/proyectos/detalle_proyecto.aspx?h=1351.

Kreutzberger, Ekki D. 2008. “Distance and Time in Intermodal Goods Transport Networks in Europe: A Generic Approach.” *Transportation Research Part A: Policy and Practice* 42 (7): 973–93. doi:10.1016/j.tra.2008.01.012.

Ministry of transport of Colombia, and EPYPSA. 2013. “Plan Estratégico de Infraestructura Intermodal de Transporte.” https://www.mintransporte.gov.co/Documentos/documentos_del_ministerio/PEIIT.

Ortúzar, J, and L. G Willumsen. 2011. *Modelling Transport*. Edited by John Wiley&sons. 4th ed. Chichester, West Sussex.

SteadieSeifi, M., N.P. Dellaert, W. Nuijten, T. Van Woensel, and R. Raoufi. 2014. “Multimodal Freight Transportation Planning: A Literature Review.” *European Journal of Operational Research* 233 (1): 1–15. doi:10.1016/j.ejor.2013.06.055.

Tan, Zhijia, Wan Li, Xiaoning Zhang, and Hai Yang. 2015. “Service Charge and Capacity Selection of an Inland River Port with Location-Dependent Shipping Cost and Service Congestion.” *Transportation Research Part E: Logistics and Transportation Review* 76 (April): 13–33. doi:10.1016/j.tre.2015.01.009.

Tavasszy, Lorant A. 1994. *Characteristics and Capabilities of Dutch Freight Transportation System Models*. Leiden: RAND Corporation. http://www.rand.org/pubs/monograph_reports/MR382.html.

United States Department of Transportation. 2015. "National Transportation Statistics." *Bureau of Transportation Statistics*. http://www.rita.dot.gov/.

AUTHORS BIOGRAPHY

Rosa Rios Prado, PhD, MSc Industrial Engineer. Rosa is Adjunct Professor of the Department of Economic Analysis and Company Management of the UDC as well as a research engineer in the GII of the UDC. Rosa is mainly devoted to the development of transportation and logistics models for the assessment of multimodal networks and infrastructures.

Diego Crespo Pereira, PhD, MSc Industrial Engineer. Diego is Assistant Professor of the Department of Economic Analysis and Company Management of the UDC. He also works in the Integrated Group for Engineering Research (GII) of the UDC as a research engineer and project manager. He is mainly involved in the development and coordination of R&D projects related to industrial and logistic processes optimization.

Alejandro Garcia del Valle is Full Professor 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 optimization of industrial, logistical and service systems.