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What Modelling Approach for the Time-space Consideration in Modal Choice Analysis of a Sustainable Alternative Mode?

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Abstract: This article aimed to detect space-time consideration in currently methods and model used in modal choice between Motorways of the Sea (MoS) in competition with other terrestrial mode. In reference to the existent literature in modal choice model and time geography theory, the spatial model developed in this work includes in its first part an evaluation of the spatial potential that represent the fundamental factors in international freight exchange. The second part regards the modal choice with an aggregate binomial logit model which generalized cost equation to the internalizing marginal external cost expressing the environmental impacts of freight traffic. The originality and effectiveness of this model is to enhance the existing prospect models in spatial interactions and space-time consideration in their methodology. The expected results shall specify the spatial changes of the main systems in the organization and restructuration of transport flow at a long time horizon. Measurement of spatial accessibility of the offered services by road and MoS modes and, the reduction in environmental impacts will be studied in a spatio-temporal dimension.

Key words: sustainable transport; motorway of the sea; road; modal choice; spatial model
JEL code: F1

1. Introduction

Prospected the territorial future by flow analysis in multimodal freight transport, at a short and long term, is a delicate work. Methods and models for forecasting the supply and the demand for freight transportation attempt to solve this challenge by studying the evolution of transport flows and their projection in the near and mean term. This work seeks to highlight the geographical aspects of international freight trade discussed differently in the existing literature. The architecture of the proposed spatial model seeks to emerge individual behaviour in modal choice based on spatial structures of logistics systems, production, consumption, transport and the environment. Territorial agent ceases to be simplifying in their movement to travelling trip with a certain quantity of goods from a point to another one. They are strongly linked to the spatial and time dimensions in their travels. Quantities transported individually give way to a more representative value of the spatial unit of individual's membership, obtained by complex interactions and interrelationships between the described systems. The transportation space changes according to internal and external dynamics which characterized those individual's communities. The spatial model includes a part of the generation-distribution of flows and another part of modal choice based on

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transportation costs and value of time. The territorial potentials evaluated for each territorial community is connected to the binomial logit model of modal choice by a time-space relationships through complex interactions which exist between empirical and stochastic variables.

1.1 Model in Freight Transportation Modal Choice

Econometric and network model: In this model, network is represented by nodes and arcs selected according to their role played in the entire supply chain structuration. They are useful to determine the shortest paths through transport costs implementation in the network. Behaviour of users depends on the offered services by each mode. Transport network are modeled through transport costs and time values. *Some models consider the transport network as a continuous network, others models are based on the graph theory with a complex discontinuous network articulated by nodes and arcs, and finally, the last category include network only as an illustrative vector of flow.* Febbrero et al. (2010) compare the competitiveness of MoS versus road transport mode by Advantages-Cost-Analysis (ACA). The multimodal transportation network is drawn as a graph defined by the main nodes linked by arcs. Mange (2006) develops a Cost-Benefit-Analysis (CBA) by introducing cost function from the origin and destination of the flow. These costs provide a balance between the supply and demand of transport with a variable integration of socio-economic and environmental context. Jiang (1998) distinguishes the equilibrium networks, the equilibrium spatial price model and generalized spatial price model. Martell (2010) in its DETCCM model defines equivalent distances for the selection of multimodal chains from exhaustive combinatorial paths between the nodes of different transport networks and services provided by modes. Fusco et al. (2012) apply a CBA model on the entirely network. Paulauskas and Bentzen (2008) developed an aggregated model that shows the possibility of integration of MoS throughout the supply logistics chain and transportation. Russo and Cartisano (2003) build a graph of **intermodal transport** based on the three main phases of transportation: sea trip, intermodal operations and port pre and post delivery by road. The graph is evaluated by allocating costs on the arcs that give the cost of routes and flows on the arcs which give flows on the observed routes. Modelling the supply of transport in loading and unloading terminalists operations leads to different results depending on the types of vehicles loaded or unloaded in their storage on board the ship (Table 1).

Event and planning models: Modelling modal choice between road and intermodal transport has progressed toward simulation based on the individual behaviour in the profits and utility maximization in the proposed transportation mode. Behaviours simulated distinguish spatially three types of models: the simulation of events occurred in the port areas and their impact on the entire intermodal chain, planning models and spatial organization of the port hinterland and simulation of movements and flows on the network. In aggregate models the behaviour of actors are simulated by an individual average value that represented a spatially delimited community. Their advantages are lied in the fact that these models are best suited to study the behaviour of a group or community, but lose the quality of individual's behaviour necessary to simulate the reality of freight transport. This challenge is solved by the disaggregated models, where movement is really observed on agents in their behaviours and relationships with other agents. Conversely, these models are losing importance to understand the fundamentals factors of the entirely community exchange.

A fundamental difference between the three models is on the step of variables observation in their dynamics and interactions. According to the road and intermodal networks morphology, simulations seek to explain how a change in transport can reach a goal or, what are the impacts from a variable change throughout the whole transport chain. Microscopic simulations on MoS involve essentially three steps: the arrival and departure time of ships in port management and port services, loading and unloading vehicles on the port terminals and the relation between flow and hinterland structures. The model proposed by Vitetta and Assumma (2006) for the simulation of loading and unloading operations in ports and logistics space show the role played by the introduction of new service of a combined rail-road intermodal transport on the entirely chain. Baindur and Viegas (2011) also demonstrate the positive impact of the ecobonus and the increased services frequency of intermodal transport on modal choice. Rich et al. (2009) applied a nested logit model to determined OD (Origin-Destination) pairs of flows. Their model has a territorial input with aggregated empirical data. Modal choice depends on the utilities of time and transportation costs by mode that depends on the quantity and type of transported product. Casaca and Marlow (2005) realized an empirical analysis on the competitively factors of Short Sea Shipping (SSS) in the entire intermodal transport chain. Feo et al. (2011) apply a mixed logit model on the intermodal transport flow involving Spanish regions with others European countries. Bergantino and Bolis (2003) develop a Tobit model with a profits maximization of the users in their modal choice. Mesa and Gomez (2008) estimate transport demand by comparing the results of a binomial logit model and mixed logit model based on probable utility of the users on the available modes.

Table 1 Relevant Factors in Modal Choice Models: Road and Motorway of the Sea Transports

Models classification	Authors and years	Methods and approach used	Relevant factors identified
Network models	Mange, 2006, Paulauskas and Bentzen, 2008	Transport cost is implemented in the network. -Adjustment between demand and supply transportation offers.	External cost impact on motorway-of-the-sea increasing market. Cost and reliability offer an opportunity in supply chain of logistics integration.
	Febbrero et al., 2010, Russo and Cartisano, 2003.	Djikistra algorithm are used to build the network. Supply model detailed the sub-system in intermodal transport.	Shortest path determined modal competitivity.
	Fusco et Al. 2012	Cost-Benefit Analysis.	Cost and value of time are the most important factors.
Empirical analysis	Casaca and Marlow, 2005	Statistical analysis of data collected by enquiry near maritime and intermodal (logistic).	Short Sea Shipping competitivity depend on the integration level in the multimodal supply chain and logistic
Simulation model (Logit, Tobit or Probit model)	Mesa and Gomez, 2008, Feo et al., 2011	Binomial logit and mixed model are used to evaluate transport demand. Modal choice of users depends on the utilities by mode. (Mixed logit model)	Transport cost and value of time is relevant factor. Frequency and reliability records high value than cost and travel time.
	Rich et al., 2009	Nested logit model are used to split the market of five transportation modes.	Cost and travel time shows decreasing elasticities compare to others studies
	Baindur and Viegas, 2011	Nested logit model are used in individual desagregate modal choice	Gouvernment support with Ecobonus increase motorway of the sea market.
	Bergantino and Bolis, 2003	Tobit model based on the users profit maximisation.	Location factors and products are determinant in modal choice

Source: NDAYISHIMIYE.

In the case of modal choice between two or more transportation modes, the choice depends on the utility that users assign on the selected mode than other. The utility function uses the price of the offered services, the quantity of goods to be moved and the unknown qualitative parameters obtained by the stated preference enquiry of different users. Individual's modal choice is determined by both the explanatory parameters and random utility. Bonnel (2006) defines the probabilistic formulation of random utility difficult to measure with the only deterministic approach:

$$Uin = Vin + \varepsilon in = f(Xin) + \varepsilon in$$

εin is a random utility term and Xin a vector explanatory parameter of the utility of alternative mode i for an agent *n* (Vin is the deterministic part of the model).

$$P \langle i/Cn \rangle = P((Vin - Vjn) \geq (\varepsilon jn - \varepsilon in)) \text{ for all } j \neq i / Cn$$ (Bonnel, 2006, p. 249)

j and *i* are the modal alternatives for an individual *n*, *Cn* all alternatives modes, *Vn* the deterministic part of the modal choice and *εn* part determined by the random utility function.

Modeling the behaviour of actors in their choice is made based on logit or tobit models using an exponential or logarithmic function. Logit models approaches are disaggregated in individual behaviour choices. The probability of choosing a transportation mode for an individual is equal to 1 or 0. The individual is not an average person as in the case of aggregate logit models. In this last case, the probability of modal choice is obtained by averaging the probabilities of choosing alternative i by all individuals belonging in the population N. (Bonnel, 2006) Disaggregate logit model examines a real person who makes a journey on the network by the choice made on the destination and the used transport mode, according to the information and knowledge he has. The value of time and transport costs are introduced in the logit model in the way that incorporate deterministic and stochastic factors expressed by an exponential or logarithmic function. Russo and Chila (2009) simulate using a multinomial logit model the impact of changes in intermodal transport speeds on the travel time reduction and the probability increasing in MoS market compared to road transport. Mangan et al. (2002) assessed the selection of docking ports of ferry from on the Britain and Ireland large with a holistic model (process-oriented model). Sauri et al. (2011) analyze how the ports agents respond to terminal operational disruptions by reducing time of loading and unloading and port transit time in general. In the same direction, Mazzarino (2004) in his process-oriented model attempts to determine the selection criteria for port users located on the logistics supply chain. Criteria are hierachised according to their importance in the quality of services sought and logistical requirements of the latest distributions of the intermodal chain.

1.2 Modal Choice in Stated Preference Method and Empirical Data

Data are collected from different existing sources and literature. Another part of the data are generally obtained by survey conduct on the carriers, chargers, port operators and others agents involved in the supply transportation chain and logistic. The latest part of data is useful for understanding the individual’s reasons for modal choice impossible to define by the only analysis of empirical data.

2. International Trade, Space and Territorial Potential

2.1 Territorial Potential in International Trade

2.1.1 Main Spatial Systems in International Transportation of Goods

Demand and supply transportation in the distribution and aggregated model is globally expressed on delimited community. Industrial needs and population consumption are gathered together in the single demand per community. The quantity of goods produced and consumed in a community are the foundation of the consumers theory. This theory establishes links with a utility function between consumption level of an individual’s income and the supply of products on the market. International freight demand is evaluated from activities and population consumption. These include urban centers, industrial units, logistics business and all others activities. Demand cannot well understand out of the population in its distribution in urban centers or in its disparity across the studied territory and its ability to consume goods and products. Our study area of trade in goods involved south of France and north Italy regions. Transport demands depend on intrinsic population attributes such as income, industrial employment rate and the general rate of employment. Productive industrial system and spatial location of consumption zones are daily connected by physical and informational flows. The logistics and warehousing system play an organizer and structural role of industrial goods flow toward it final destination. The spatial location of these three main systems of freight transportation flow lead to understand the operational distribution areas in international good exchange.

Productive industries or transport profiles can be studied in specific cases according to their membership with the warehousing services needed. The port area becomes an attractive area that offer a spatial interpretation of flow distribution from or toward the storage areas linked to the productive industries units. New strategies developed by industrial companies increase the logistics markets and reduce the storage space within the production sites. The size of storage areas has been greatly reduced in industrial production and business areas. Warehousing and storage products tasks are actually assigned to specialized external providers. Thereby, the number of warehouses has decrease whereas their size has increases. This new organization of logistics activities aim for an extension of the number of industrial and population served within a wide area. All described systems are embedded in a dynamic environment defined by numerous spatial interactions.

2.1.2 Concepts and Methodology of Territorial Potential Measurement

Modeling international freight transport should not be done without integrate space. The space appears in the supply and demand transportation model as multidimensional space composed by several units gathered together by their proximity relationships and interrelationships. It is a space of location and spatial distribution of different units. Logistics areas, for example, have a location aspect and a spatial appropriation of production units in their organic connection with storage areas.

This area is composed by nodes and major places that structure and organize activities related to international freight transport. A network space that establishes connections by arcs between these nodes through numerous freight flows. Transportation models incorporate differently spatio-temporal dimension. The data quality reflects at once the level of space consideration. Some models emphasize on transport costs and travel time and other models are more or less qualitative rather than quantitative. Through space analysis we differentiate models and we introduce a relevance quality of the geographical reading of transport phenomena. Given the complexity and multisectoral explanatory elements of international freight transport, we wanted to establish a synthetic value which defines for each spatial unit its potential for trade with other territories. A value that could better expressed space forces which interact each other and generate the transport flows. This force consists of an internal and external capacity depending on the level of trade and interactional relationships considered. The internal potential expresses the internal dynamism of production, consumption and logistics activities factors. We postulate that the production of department n, depends on its internal consumption and consumption of others departments which belong to its territory N (either south of France or north Italy regions) (Table 2).

The internal potential (3) is obtained by the interaction between the warehousing and logistic system with production and consumption systems (2). At an international scale, the external potential (6) expresses the capacity of inter-departmental trade between different countries. It is an ability of a given territory, at the time t, to satisfy his needs or supply other territories in products. Counter to internal potential, this potential is measured independently of internal interaction factors to the territories belonging to each department N, but rather on the territories N'. The global potential is the result of the interaction between the internal and the external force, depending on the internal level of relationship for each department (7).

Table 2 Internal and External Potential in Goods Transportation

System and spatial interaction	Spatial indicator of the internal potential	Prod. xi	Conso. yj	Logi. xi
(1) Production and consumption. (2) Individual production impact on subregional units. (3) Logistic system role in production and consumption systems.	n . j = $\frac{1}{N} \sum_j \text{prod.}i \times \text{Conso.}j$ (1) X prod.i= $\frac{1}{n} \sum i \sum_j n.j \times \text{prod.}i$ (2) P.I.i = $\frac{1}{N} \sum_{i=0}^{n} \frac{\text{X prod. i}}{\text{logi. i}}$ (3)			
System and spatial interaction	Spatial indicator of the external potential	Imp.-Exp.xi	Imp.-Exp.yj	Transp. i,j
(4) Import and export value (or quantity) by mode of all units. (5) Transport as an impulsion to the external trade.	n . j= $\frac{1}{N'} \sum_j \text{Imp.}i\,[1] \times \text{Imp.}j\,[2]$ (4) Ou Exp. i [1 et 2] P.E.I(E)i=$\frac{1}{N'} \sum_{i=0}^{n} n.j \times \text{transp. i}$ (5)			
(6) Interaction between internal and external potential in international trade.	Potentiel Global à l'import ou à l'export P.G.I (Ei)=$\frac{1}{N+N'} \sum \frac{(\text{P.I.i} + \text{P.E.I. (Ei)})}{\text{P.I.i}}$ (6)			

Source: NDAYISHIMIYE.

2.2 Internal, External and Global Potentials

2.2.1 Territorial Potentials

Figure 1a, 1b and 1c represent internal, external and global potential in external trade relations between south of France and north of Italy in 2004 and 2009. In France, the internal potential are high in the Rhône-Alpes and its surroundings regions as well as the coastal regions. A north-south axis connects the two major areas of internal trade. This pattern reinforces the level of external trade and provides the import-export in global potentials centered on some specific regions. In Italy, the Turin-Milan axis toward eastern European countries is confirmed and dominates in internal exchange of goods. A balance is achieved by a new dynamic areas located in direction of Piacenza-Bologna to Cuneo. In both cases, the port areas stand out in their location relatively to large zones of external trade transport.

2.2.2 Parametrical Interpretation of Department Potential

Table 3 gives the multiple determination coefficient (r) used for showing the correlation between the truly importation and exportation values and the potential indicator. Multiple linear correlation coefficients are in 80% cases 0.830 very close to 1. These results justified a greater dependence relation between importation and exportation values and the global potential indicator. The low value of Global potential registered (between 0.609 and 0.718) depend up on the irregular interaction between the selected variables in the period of 2005 and 2006 for the global potential of importation (in south of France) and 2005 (in north of Italy in both importation and exportation global potential indicator). At a 95% of confidence level, the all studied area are characterized by a validate global potential.

The linear regression confirms this dependence explained by the potential for the 77 observed departments. The potentials are thus useful in the generation and spatial distribution step of transport flows modelling. The calibration of the model using the potential parameters to the origin and destination of the flow introduces spatial and socio-economic constraints in the model. This potential is then correlated with environmental factors and the impact of transport in territorial dynamic evolution.

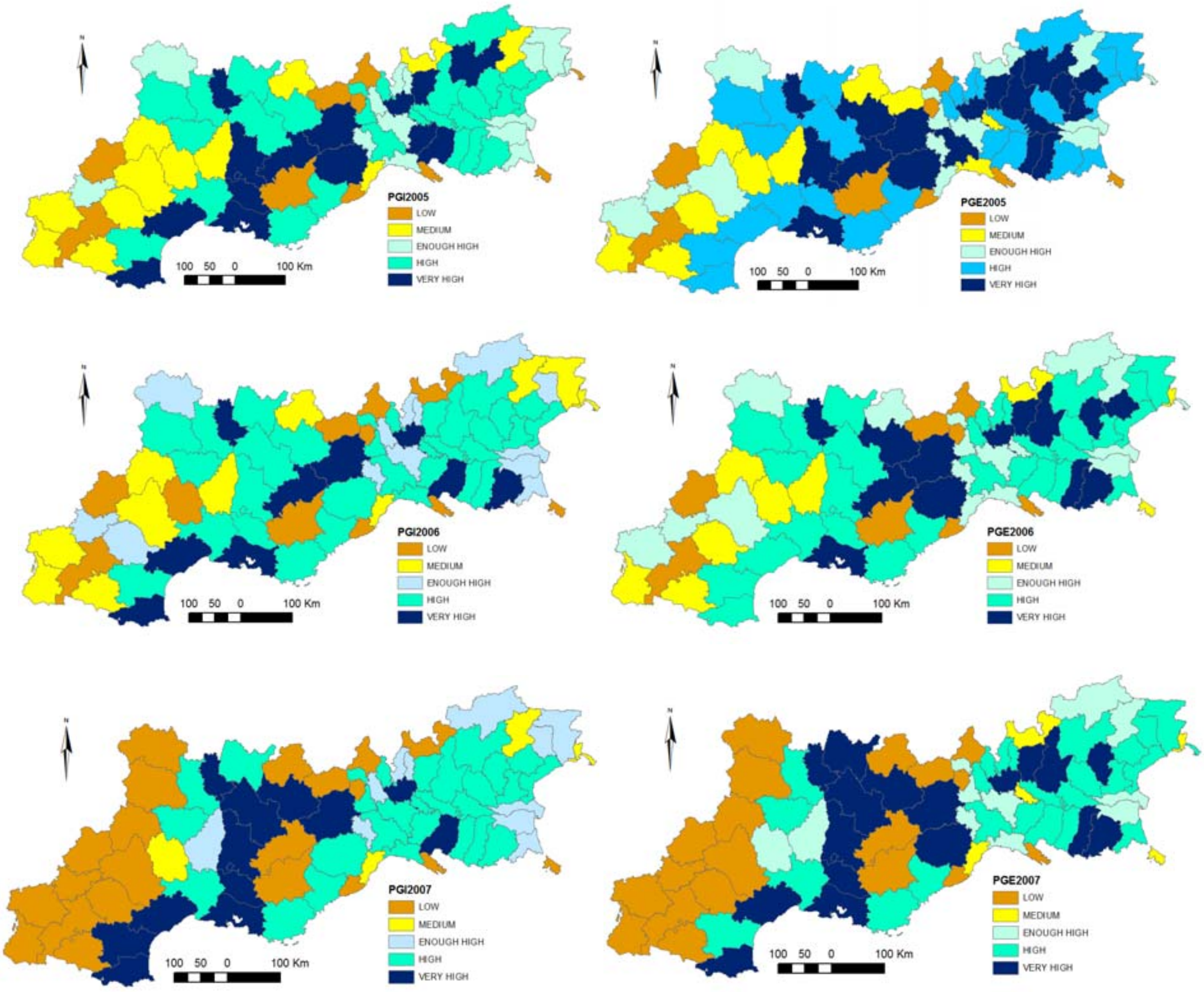

Figure 1 Global Potential in Importation (PGI) and Exportation (PGE) between 2005 and 2007 (Ndayishimiye, UMR CNRS 7300 ESPACE NICE)

Table 3 Validation with Linear Regression Coefficient of the Global Potential in Importation and Exportation

Years	Potential type	Multiple determination coefficient (r) south of France	Multiple determination coefficient (r) north of Italy	Multiple determination coefficient (r) all zones
2005	P.G.I	0.695	0.718	0.694
2006	P.G.I	0.710	0.984	0.717
2007	P.G.I	0.911	0.991	0.915
2005	P.G.E	0.831	0.609	0.813
2006	P.G.E	0.868	0.942	0.854
2007	P.G.E	0.809	0.963	0.843

Note: P.G.E Export Global Potential indicator for n year; P.G.I Import Global Potential indicator for n year.
Source: NDAYISHIMIYE

The explained potential are part of the spatial interactions of a general model of modal choice. Their variation is nevertheless correlated with the explanatory factors of transportation costs, necessary to make a delivery of goods from one territory to another. The potential model in external trade is completed by the introduction of monetary and temporal distances according to market shares of transportation studied modes. The generalized transport costs and spatial potential interact in explaining spatial modal choice. By an internalization of those marginal external costs, the potential model introduces a dimension of sustainability in freight transportation modelling. Distances estimated by each mode of transport will be assessed taking into account the potential for each territory.

3. Internalization of External Marginal Costs in the Generalized Transportation Cost

3.1 Generalized Cost and Internal Cost Currently Used

3.1.1 Transportation Cost and Value of Time Function

The function of modal choice between road and MoS proposed in this work depends on the utility of carriers and shippers in the services offered by the available modes. Generalized cost corresponds to the individual perception of cost or travel time which affects their choice process. Bonnel (2006) gives a general formula for evaluating the generalized transportation cost:

$$Cg = P + (\sum \alpha i\ Ti) * Vt \quad \text{(Bonnel, 2006)}$$

Cg is the generalised cost;

P is the price to be paid;

Ti is the required time to travel a certain distance;

Vt is the individual assigned value in travel time;

αi is a weighted coefficient of the elementary time *Ti*.

This formula is simplified compared to the formula used in freight transport. The essential parts to remember are the travel time Ti, which is the sum of time that the user passes between an origin and a destination and the value *Vt*, representing the random value that consumers attribute on the time *Ti*. Supply transportation model distinguishes the deterministic and the random part that emanate from the individuals judgments value. The generalized transport cost of mode 1 (T^1 ij) is obtained by adding the costs of the main travel steps (in discontinuous model) or by calculating an average cost per distance unit (in continuous models). Modal shift from road to the proposed alternative is based on modal services offered expressed by cost. Modal choice is determined by optimal routes on different OD pairs of transport. Generalized cost function that we use incorporates marginal external costs related to environmental factors. Damage and impact of freight transport on people and on the natural environment are also involved in the generalized cost calculation.

$$T^1\,ij = \sum e^{-b\,Cg\,1\,ij} \qquad (1)$$

$$P\,(1) = \frac{T1\,ij}{T\quad ij} = \frac{e^{-b\,Cg\,1\,ij}}{\sum e^{-b\,Cg\,k\,ij}} \qquad (2)$$

T^1 ij is the generalized cost of mode 1 between zones i and j (1). This cost includes all internal and external costs which will be discussed in detail in the following paragraphs. P (1) is the probability of choosing mode 1 expressed in the binomial logit model, between mode 1 and all existing modes k (MoS in this case) on the OD pairs between i and j zones.

$$Kij = -\frac{1}{\lambda}\log \sum_k e^{-\lambda\,Cg\,k\,ij} \qquad (3)$$

Kij is obtained with a logarithmic function with $b \leq \lambda$.

Kij is the generalized composite cost of all modes k evaluated by a logarithmic function with a scaling parameter λ. The generalized cost of road and MoS transportation is the sum between the internal or fixed costs and marginal external costs.

3.1.2 Internal Cost in Road and MoS Transportation Modes

Internal transport costs include costs paid by carriers or shippers to make a path between an origin and a destination. The main raised cost concern (Table 4):

Energy and fuel consumption: Fuel costs depend on the loading rate of vehicles, speed, traveled distance and the type of vehicle used. Consumptions are first evaluated according to travel costs paid by unit costs and, secondly brought back to the unitary cost distances expressed in tonne-kilometers. The average consumption of diesel is ranged from 0.30-0.35 l/km at an average speed between 50 and 90/100 km/hour (Janic & Vleugel, 2012).

The salary costs of drivers: These costs are assessed differently depending on whether road or MoS transport. The salary is recorded on the number of hours of driving up from an OD pairs of the route. This time also includes the time of rest which is about 45 minutes every 4h 30 minutes driving. Transport by MoS takes into account the maritime route in the case of an accompanied vehicle with its driver. The time becomes the driving time on road before and after the sea trip in addition to the time spent on board the ship. Unaccompanied transport is desirable and profitable to save hours spent on the sea trip. The general cost is acquired on the total time of travel for hours paid according to the driver’s payment schedule;

Vehicles maintenance and reparation: The maintenance and servicing of reparation are measured on the cost of servicing and maintenance in good working condition of the vehicle and, the cost of tire wear. Febbraro et al. (2010) obtained costs of €0.25/km, respectively €0.072/km and €0.13/km for repairs, maintenance and tire wear.

Taxes costs of road transport: The various taxes and fees paid by carriers are evaluated differently by modes. Road charging is related to road fees and infrastructure costs that are directly collected on trips. The loading and unloading operations also have a cost depending on the type of product and the quantities of goods. Modal choice depends not only on the quantitative aspects of profits and gains of transportation but also on the preferential selection criteria very decisive in modal choice. Each variable is then tested according to the preferences expressed by users. The tests are done to check how many times or how many additional costs that a user is willing to pay for the change of a given attribute. For example, it is a question of monetary values corresponding to a reduction or an increase in attribute values. One hour of travel time reduction is equivalent to 0.44 Euro per on transported tonne of good, and, 1% reduction in the level of reliability involves financial compensation of 3 euro per tonne according to Bergantino and Bolis (2004) results.

Table 4 Summary of Internal Costs Existant in Different Literature

Transport costs	Road costs	MoS costs	Authors and studies
Mean internal cost	€0.81/hour/tonn	€300/Truck/trip €500/Truck/trip	Bolis & Maggi, 2003; Reffet et al., 2008.
Maintenance and exploitation cost	1.13, 1.008, 0.17(F.F Vehicle/km)	-	Jeanrenaud, 1988; Brossier, 1992; E. Quinet, 1992.
Road payment or fees	1.16, 0.680, 0.70 ((FF for Vehicle/km)	-	Jeanrenaud, 1988; Brossier, 1992; E. Quinet, 1992.

Source: See authors in this table.

Discrete variables most commonly used in state preference methodology are the value of time and transport costs, frequency in departures and arrivals and reliability of modal services.

3.2 Internalization of External Marginal Cost in the Generalized Transport Cost

3.2.1 External Marginal Costs

External marginal cost is part of the costs that are not accounted for in the costs of transport companies. They are very useful for modal shift and emissions impacts reduction of road transport. They are assessed by the following socio-environmental impacts (Table 5):

Congestion cost assessment: Slower, long line of vehicle for overcoming an obstacle, sudden stops, etc., cause overtime costs for carriers and shippers. These times are estimated based on excess time exceeded over time made in normal traffic conditions. The congestion costs are calculated by the speeds recorded during peak and hollow hours, by the number of vehicles and traffic flows on these statements of the transportation axis. A relationship between the flow, identified traffic time and traffic speeds is then established. These times are then converted in monetary costs form lost by users.

Noise disturbance: Jourquin (2004) offers two methods of assessing costs related to noise. The first approach is to estimate a statistical analysis of rents paid with different housing characteristics from exposure to noise. The second approach is to analyse statistically the same rents paid to expenditure aimed at reducing the perceived noise. As with other types of problems caused by freight transport, the amounts are then evaluated by the observed traffic flows (expressed in tonne-kilometers).

Accidents and incidents costs: Methodologies of assessing external costs of road accidents use the numbers of accidents reported on the traffic on different paths in accordance with the traffic flow of goods recorded in the same period (expressed in tonne-kilometers). Accidents are first estimated in monetary value according to the damage, injuries and deaths costs. These costs are then weighted to the traffic flows.

Table 5 Summary of External Costs in the Existent Literature

External costs	Road costs	MoS costs	Authors and studies
Air pollution	€8.4/1,000t-km, 18.2 mECU/t-km, €4.70/Veh.km, €0.0089/tkm	5.4€/1,000tkm, 9,8mECU/t-km (sea river), 0.0056€/tkm	Essen et al., 2011; Jourquin, 2004; Janic & Veuglel, 2012, Wolf et al., 2010
Congestion	€31.13/1,000t-km, 23 mECU/t-km, €0.17/Veh.km, €0.0113/tkm	-	Essen et al., 2011; Jourquin, 2004; Janic & Veuglel, 2012, Wolf et al., 2010
Noise	€2.5/1,000t-km, 6.6 mECU/t-km, €0.18/Veh.km, €0.0028/tkm	-	Essen et al., 2011; Jourquin, 2004; Janic & Veuglel, 2012; Wolf et al., 2010
Incident/Accident	€17/1,000tkm, 12.95mECU/t-km, €0.30/Veh.km, €0.0043/tkm	-	Essen et al., 2011; Jourquin, 2004; Janic & Veuglel, 2012; Wolf et al., 2010
Infrastructures	€0.0043/tkm	€0.0034/tkm	Wolf et al., 2010
Others external costs	3.1€/1,000tkm, 51.043 mECU/Charged Veh./km and, 0.0415 for unloaded veh., €0.0043/tkm infrastructure cost	€0.9/1,000tkm, €0.0034/tkm for infrastructure cost	Essen et al., 2011; Jourquin, 2004; Janic & Veuglel, 2012; Wolf et al., 2010

Source: See authors in this table

Air pollution: Air pollutant most harmful and most studied in freight transport are micro-particles (PM10), carbon monoxide emission (CO), nitrogen oxides (NOx), sulfur dioxide (SO_2), and VOC (Volatile Organic Concentration). The methods developed are designed to measure the effects of pollutants on the number of deaths related to their concentration in the atmosphere as well as the deterioration of the ozone layer. Impacts on the natural environment are also taken into account. Quantification of pollutant emissions per vehicle per tonne of cargo carried per kilometer, is established according to the quantity of fuel consumed, speeds, types of vehicles and average emissions per pollutant. "The health effects are then obtained by applying the mortality rate appropriate to the concentration of the pollutants multiplying by the concerned population" (Jourquin, 2004). Cost estimates for pollutants are obtained by multiplying the mortality rate, the estimated value of life and the total quantities emitted by pollutant.

3.2.2 Impacts of External Marginal Cost in Modal Shift Model

The experience of the Italian ecobonus is the most commonly cited in the impact assessment of the marginal external costs. But the real impact of modal shift is perceived differently according to the logic of the actors and especially the daily lives of people and communities subject to the pressure of traffic flows. Spatially, the impact of modal shift towards alternative mode raises new questions about the future of freight transportation and the really reductions of the actually produced emissions of greenhouse gasses and other road traffic impacts.

Environmental impacts are directly measured around the main freight corridors. Structural changes in infrastructure and transport chains are aiming to reduce these impacts on areas highly affected by road freight traffic. Baindur and Viegas (2011) demonstrate the positive impact of increased ecobonus and services of intermodal transport in modal choice. In an approach to interregional transport, micro-simulations give a 12% growth markets of MoS by granting financial compensation on the external costs avoided by taking the waterway, and 26% of markets MoS providing by a daily services. Jourquin (2004) reaches a reduction in road transport of 71% to 54% in favor of rail transport (16% to 21%) and inland waterway (from 13% to 24%) in his study of the internalization of the marginal external costs of Belgian territory. Mange (2006) in his econometric model shows the gains and benefits costs of alternative mode to road transport by integrating in internal transport costs the environmental factors.

4. Discussion on the Space-time Inclusion in Retrospective, Prospective and Geoprospective Vision

4.1 Space and Time Theories in Geographical Studied

4.1.1 Space and Time in the Time Geography Theories

This work emphasizes on time-space in the relation between transportation and territories. Time geography theories serve as a reference in individual's movement studies in time and space. Chardonnel (2005) distinguishes two approaches in time geography theories: Approach that focus on the organization and development of space systems and an approach that locates the individual in his travels in space. In spatial models, the integration of time is done through the evolution of space systems to explain a given phenomenon over time. Time is a dimension that distinguishes changes and upheavals in accordance to the rhythm of systems evolution. The second approach is based on individuals who move. Here, time plays a central role on location of individuals during their travels.

The time geography studies the possible fields in the movement of an individual by taking as basic criteria all the motivations of travel and movement attributes. An individual is described by its unique characteristics which contribute to its displacement (standard of living, socio-economic status, location of settlements, etc.) He moves between activities locations and stays according to duration of its activities. Between different activities a journey time is necessary to overcome the obstacles that arise when moving from one place to another place. The movement space is represented in a prism in the three dimensions (one for time and two for space). Thus, time geography provides an opening field to many applications that involve the human, material or immaterial individual's movement. Chi G. et al. (2013) apply the time geography in the assessment of changes in spatial accessibility as a result of gasoline prices variations. The price of gasoline is taken as the main constraint of individual’s movement. Road safety depends on factors that are related to the type of conduct and drivers status. Thus, driving distances are reduced, the trajectories of individuals become increasingly reflected in time and space, according to the primary needs. Their profiles depend on the types of conduct and recorded frequency in road accidents (age, sex and ethnicity). Neutens et al. (2012) examine the variation of the spatial accessibility of individuals to various public services through space and time. Accessibility in space-time is measured on individuals with different characteristics and localized differently in the space. Individual profiles, the spatial proximity relative to services, socio-economic levels are the main explanatory factors that influence the variation to public services accessibility. The logic of time geography consideration in time and space led us to an application in international freight transportation. One area that involves several methods and models for forecasting and foresight but where space and time raised many question related to authors interpretation.

4.1.2 Space and Time Relation and Sustainable Freight Transportation

Spatial description of objects in their territory: Approaches of modelling freight transportation are first distinguished by the description of geographic objects in their space. Between a human, material or immaterial and aggregate average individual objects, several approaches try to threat the complexity of freight transportation by defining the individual movements within its territory and others nearest or remote territories. T. Hägerstrand (1970) defines the time geography as “an approach that explores the relationship between organizational elements of space systems at an aggregate level and the situation of individuals at a local level” in Chardonnel and Thévenin (2012). We understand hereby the duality of the individual movements between the single object and the aggregate object or spatial units.

Our individual is first of all apprehended as spatial unit (department or province), before being detailed by individual transport flows by the vehicle, transportation and logistics companies under disaggregated level. The disaggregated individual belongs to a well-defined space that interacts with other territories. Spaces of individual’s activities are described by many spatial systems. These spaces are possible fields of individual’s activities and behaviours adopted in the choice of destination and transport mode. Each spatial unit is distinguished from neighbouring and remote units by a set of space systems that motivate individuals in their movements. Till the spatial object notion, we pass to the definition of the space system. The time geography describes the required activities as prisms with a null surface between which flexibility is possible depending on the size of the prism, the available of time interval, the distance between the locations of activities and capacities of travel (speed mode of transport) Charles Raux cited in Banos et al. (2005). Required activities comprise the various systems in the interactions and interrelationships that lead individual’s choices. These systems are described in detail in the following paragraphs of this work through the main explanatory and random variables in international freight transport (Table 6, (1)).

Movements and individual’s activities in the space are measured by time-distances: Transport are organized and structured according to spatial structures seeking a large decrease in transport costs and gain in spatial competitively. The generalized and integrated cost extends the evaluation of internal transport costs to the environment through the marginal external cost. Consequently, transportation costs are both the attributes of individuals and territories to travel from one place to another (Table 6, (3)). The time taken by individuals is not a continuous time in space. This is a time varies according to the roughness and the topology of the transport networks. The individual is constrained by several socio-economic and organizational in this space. The time geography identifies spatio-temporal constraints that enameled the individual trajectories to leave a place to another one. Some attributes are directly related to individuals. Others are related to the traveled space. And others are external constraints but which play a role in their travel time. These are the capability, conjunction and powered constraints (Chardonnel, 2005). We introduce in time of transport, environmental pollution and nuisances related to the transport flow, as one of the spatial and external constraint (Table 6, (2)).

Table 6 Main Spatial Interaction Studied in the Relation between Space and Time

Geographical aspects	Observations of the model	Systems and spatial interaction
Space (1)	The investigation involves chargers and carriers in their activities. Spatial data are gathered in the departmental level.	Production and consumption of all units. Individual production impact on subregional units. Logistic system role in production and consumption systems.
	Every department interact with others departments through several described systems.	Import and export value (or quantity) by mode of all units. Transport as an impulsion to the external trade.
	The local and subregional interaction represents an internal possibility to understand international exchange.	Interaction between internal and external potential in international trade.
Time (2)	Cost function takes into account several attributes by mode. OD pair matrices offer an opportunity to constraints integration.	The time and cost function integrate external cost in the generalised cost calculation.
Space-Time (3)	Individual and spatial units served for modal and territorial comparison. Space and time described well those two individuals in an aggregate or disaggregate form.	Results: Location factor and evolution of logistics systems. Spatial accessibility of population and production system offer by studied transport mode. Sustainability measurement in modal split.

Source: NDAYISHIMIYE

4.2 Spatial Impacts and Restructuration of the Global Supply Chain

4.2.1 Spatialized Attributes and Interaction in Modal Choice Model

Reorganization and restructuring of the logistics system testify the direction of development activities related to international transport. The factor of location in time and space logistics units confirms the evolution and dynamics played at the surrounding territories. According to its weight, logistics space can serve the territory in which it operates, or even territories to its proximity according to transport cost and the opportunity to find the desired services. Their location in relation to the production and consumption units is an important issue to understand the spatial interactions that explain the freight flow dynamics. The model aims to analyze the evolutions of logistics spaces in the restructuration of trade and transport activities. This model adds the factors of sustainability of transport with modal shift from road to MoS modes. Briefly, the main systems of this model are industrial production system, the consumption system, logistics and storage system, transportation system, environmental system and the organization and planning system of all the supply chain. The selected variables for each system are spatialized variables and in their multiple interactions.

4.2.2 Spatial Accessibility of Population and Industrials Sites in International Transport

To introduce time-space offer us a possibility of a forecasting transportation flow in the middle and long term horizon. Time and space in international flows models open a field of possibilities to the representations and to cartography in three dimension the spatial accessibility offered to spatial units of production and consumption of goods, from logistic and storage services. The spatial accessibility is reflected in terms of socio-economic and environmental profitability. The projected time of the territorial futures are emerging dynamics and spatial restructuring from the new infrastructure introduced in the existing network. Other effects such as spatial integration of environmental factors on the reduction of pollutant and disturbance caused by traffic of heavy vehicles and, the effects of changes in socio-economic production activities and related flow, are expected in the model.

5. Conclusion

The present work is a time-space analysis in international freight transport modeling in the modal choice between road and MoS modes. Our results intended to build a coherent conceptual framework which could be very fundamental to a real consideration of space and time dimension in international freight transport modeling. Territorial potential defined by multiple and complex spatial relationships and interactions of the main international transport systems, is the most innovative aspect in this modal choice spatial model. The main systems interact and emerge the essential foundation for understanding the values of foreign trade of each territorial unit. The cost function and the values of the transit time of the binomial logit model constitute the modal choice step between road and the MoS modes. A dimension of sustainability is introduced into the transport system by an internalization of marginal external costs in the function of generalized cost. This environmental aspect reinforces the idea of modal shift and, taking into account the spatial modeling to predict and project the territorial futures.

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