A Study of Transportation Disruption Causes and Costs in Containerized Maritime Transportation

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ABSTRACT

This research focuses on estimating and understanding the costs and causes of transportation related supply chain disruptions. In-depth interviews with logistics managers were undertaken to investigate how companies perceive transportation related supply chain disruptions and what they are doing to respond and address them. Stated choice experiments were designed to estimate the cost of disruptions for containers in international maritime trade. The results of the discrete choice models indicate that disruption costs are several times larger than traditional values of freight travel time and reliability.

KEYWORDS: Supply Chain Disruptions, Containerized Maritime Transport, Value of Time and Reliability

1. INTRODUCTION

International trade is an increasingly vital component of the global economy. Trade flows, exports and imports, relative to GDP continue to grow worldwide (OECD, 2006). The trend is accelerating as the Internet, cheap telecommunications, and business re-engineering converge to create giant global supply chains (Capineri and Leinbach, 2004).

Economic globalization and increased outsourcing make supply chains more complex and interdependent. Correspondingly, supply networks are becoming more vulnerable to disruption because the failure of any single link in the chain can cause the whole system to fail. Disruptions can be instigated by a diverse range of events such as natural disasters, accidents, terrorism, war, political and economical instability, supply unavailability, transportation delays, and labor strikes or conflicts.

As globalization has expanded, supply chain resilience has decreased. In many industries supply chains are at a greater risk than ever and further endangered due to scarce back-up capacities (Sheffi, 2005). Nowadays, many companies are heavily focused on "lean" practices, such as just-in-time deliveries, single sourcing, or consolidated manufacturing in low cost countries. As a result, there is a lack of supply chain redundancies in many industries. In case of a disruption, the lack of redundancies can be greatly exacerbated by long transport lead times for raw materials or finished goods.

This research focuses on international maritime transport related supply chain disruptions. To understand the causes, implications, and costs of disruptions, in depth interviews with logistics and supply chain managers were undertaken. The research is organized as follows: section two provides a literature review. Section three describes the interview process and the collection of data. Section four presents a description of the companies surveyed and the disruption costs and disruption management strategies employed. Section five presents the analytical framework utilized to estimate disruption costs. Section six discusses the values of time, reliability, cargo damage, and sailing frequency. Section seven ends with conclusions.

2. LITERATURE REVIEW

A widely used classification distinguishes among six types of supply chain disruption types (Caniato et al., 2003): disruption in supply, disruption in transportation, disruption at facilities, freight breaches, disruption in communications, and disruption in demand. Although there is an increased awareness and recognition among managers, consultants, and academics that supply chain performance is increasingly important to business success, the implementation of measures to prevent or minimize the costs of disruptions are not widespread. Recent survey results indicate that 82 percent of companies are concerned about supply chain resiliency and disruptions, however, only 11 percent companies are actually taking actions to avoid or minimize disruptions (Klie, 2006).

Transportation related disruptions can be caused by a diverse array of issues natural disasters such as earthquakes and tsunamis, terrorist attacks, congestion at ports, airports, and intermodal facilities, sanitary controls for quarantines or epidemics, lengthy customs inspections, customs software glitches, lack of capacity in the transportation network to accommodate surges in the demand, labor disputes, etc. Transportation disruptions increase lead time variability and as a result companies require greater levels of inventory safety stock. Alternatively, if safety stock levels are unchanged, supply chain performance as measured by on-time delivery and stock-out rates decreases (Wilson, 2007). At an aggregated level, large scale freight transportation disruptions have a significant impact on a country's economy (Brooks and Button, 2006). Hence, the understanding of transportation disruptions costs and causes is also of vital importance for governments and policy makers.

The evaluation of shippers' value of time has not received as much attention as the evaluation of passengers' value of time. De Jong (De Jong, 2000) and Massiani (Massiani, 2003) discuss theoretical and practical issues that complicate the evaluation of travel time savings in freight transportation. Zamparini and Reggiani (Zamparini and Reggiani, 2007) present a comprehensive survey of methodologies and empirical studies. They also indicate that since the early 1990s the large majority of the empirical studies aim to determine shippers' willingness to pay (WTP) to reduce the travel time of a specific shipment. In addition, most of the empirical studies are based on stated preference (SP) methods due to the greater flexibility and control over the data collection process. The quantification of freight value of time and reliability has been successfully undertaken using discrete choice methods. Discrete choice techniques have been successfully applied to study shippers' choice of freight transport/logistics services in a diversity of contexts.

In a seminal work, Swait et al. (1994) combined stated preference (SP) and revealed preference (RP) data to understand how shippers chose carriers or transport service providers. Kawamura (2000) collected RP data in California to estimate the value of time for trucking shipments as a function of company and shipment characteristics. In Australia, Wigan et al. (2000) estimated truckers' value of time per pallet per hour in metropolitan multidrop services using SP data. Kurri et al. (2000) conducted a SP freight road and rail study in Finland. As expected, the study revealed that shippers that chose trucking services have a higher valuation time and reliability than shippers that chose rail services. Bolis and Maggi (2003) analyzed how shippers in Italy and Switzerland value transport and logistics service characteristics. Twenty-two firms were surveyed and it was found that transit time and reliability were dominant factors for companies using JIT principles or directly serving the consumer market. Frequency of service was also significant and cost was particularly important for low value commodities.

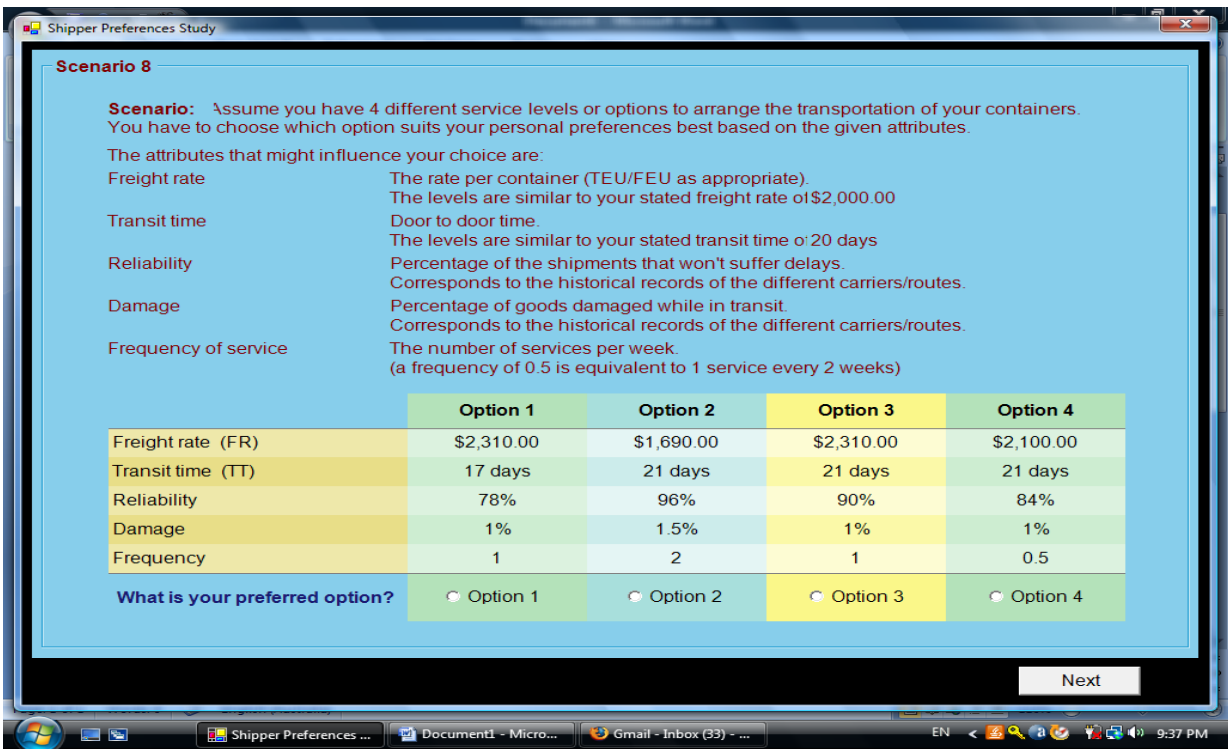
Summarizing, several studies have been conducted with regards to risk management and supply chain disruptions; however, little has been done to measure the consequences of a fallout. In particular, to the best of the authors' knowledge, there is no scholarly work that has collected data regarding how companies perceive transport related supply chain disruptions and what they are doing to respond and address them. Further, there have been no attempts to quantify the cost of disruptions using measures that can be applicable and useful from a transportation planning perspective.

The next section describes the data collection process and the generation of choice data used in this research.

3. DATA COLLECTION PROCEDURE

The analysis presented in this research is based on supply chain and choice data provided by logistics and supply chain managers based in Sydney, Australia. With the cooperation of local logistics/supply chain associations, companies were carefully selected to ensure that a wide range of products and industries were represented in the survey. A group of 30 companies were interviewed.

Computer aided personal interview (CAPI) software designed and tailored specifically for this research was utilized. The software allowed for a systematic data collection process and ensured the integrity and completeness of the data. The first part of the interview was designed to obtain qualitative data regarding supply chain operations and disruption management strategies. In the second part of the interview, the logistics managers, were asked to provide company-specific information about a recent containerized import or export shipment. This shipment information was used to construct a series of alternative choice scenarios that were realistic and relevant to the company's operation; the choice was among four alternative shipping options that entailed five different attributes: door-to-door freight rate, door-to-door transit time, reliability, damage, and service frequency. To illustrate this point, a screen sample is presented in Figure 1 .


Shipper Preferences Study

Scenario 8

Scenario: Assume you have 4 different service levels or options to arrange the transportation of your containers. You have to choose which option suits your personal preferences best based on the given attributes.

The attributes that might influence your choice are:

Freight rate	The rate per container (TEU/FEU as appropriate). The levels are similar to your stated freight rate of $2,000.00
Transit time	Door to door time. The levels are similar to your stated transit time of 20 days
Reliability	Percentage of the shipments that won't suffer delays. Corresponds to the historical records of the different carriers/routes.
Damage	Percentage of goods damaged while in transit. Corresponds to the historical records of the different carriers/routes.
Frequency of service	The number of services per week. (a frequency of 0.5 is equivalent to 1 service every 2 weeks)

	Option 1	Option 2	Option 3	Option 4
Freight rate (FR)	$2,310.00	$1,690.00	$2,310.00	$2,100.00
Transit time (TT)	17 days	21 days	21 days	21 days
Reliability	78%	96%	90%	84%
Damage	1%	1.5%	1%	1%
Frequency	1	2	1	0.5
What is your preferred option?	Option 1	Option 2	Option 3	Option 4

Next

Figure 2 Questionnaire screen offering an example transportation choice scenario

The technique of "pivoting" on real-life shipping decision in increasingly used by researchers to ensure the robustness of the value of time estimations (Hensher and Puckett, 2004). Attribute units and definitions also have a great impact on the numerical results and meaning. Extensive pilot studies and care was needed to define meaningful attributes. Freight rate was expressed in dollars, expected transit time in days, reliability was expressed as a percentage of on-time arrival, damage was expressed as a percentage of the declared cargo value, and frequency was expressed as number of the sailings per week. Freight rate, expected transit time, and frequency were explained as attributes of a specific ship/route. Reliability and damage were associated to the long-term reputation or service level of the carrier.

In the third and last part of the interview, logistics managers were asked to analyze a series of disruption scenarios. These scenarios were built by the CAPI software using company related disruption data from the first part of the interview and specific shipment information from the second part of the interview. The manager was asked to relate the choice situation of a previously experienced transportation disruption where delays were seven days or longer. Subsequently the manager was presented with alternative options to expedite the shipment. The attributes of the third part of the scenario were: expediting cost, time saving, reliability, and damage. Expediting cost was expressed in dollars, time saving in days, reliability was expressed as a percentage of on-time arrivals, and damage was expressed as a percentage of the declared cargo value. Expediting cost and time savings were explained as attributes of an alternative mode/route. Reliability and damage were associated with the long-term reputation or service level of the carrier.

The employment of a computer-aided personal interview (CAPI) was crucial to ensure that the choice sets provided in the second and third part of the interview were meaningful and that the large amounts of choice/preference data collected were properly stored and readily analyzed by econometric modeling software. The experimental design was performed using an efficient design (Huber and Zwerina, 1996). Efficient designs minimize the asymptotic variance-covariance matrix of the chosen econometric and are particularly useful for multinomial choice models which have a non-linear log-likelihood function (Rose et al., 2008); NGENE, a specialized software for efficient design was utilized to generate the choice situations.

The interviewer had previous employment experience in a freight forwarding company and all interviews were conducted by the same interviewer. Post-interview feedback indicated that utilizing an interviewer with industry experience was highly positive. A clear understanding of industry issues and jargon added credibility to the interview and guaranteed managers' cooperation. The interviewer collaborated in the scenario design and attribute definition, hence, managers found the scenarios practical and easy to understand.

4. COMPANY AND DISRUPTION DATA

As evidence of the different industry and supply chain structures, the "official" organizational role of interviewees' was diverse and included the following: logistics managers, supply chain managers, shipping managers or directors, marketing managers, distribution managers, operation managers, financial controllers, purchasing managers and logistics strategies managers (roles presented in order of decreasing occurrence). The reliability of the data obtained in a SP survey strongly depends not only on the capability of the researcher to describe and choose the alternatives but also on the interviewee's understanding of company level costs and operations. Hence, a substantial number of pre-interview telephone calls were carried out to collect general company information and to ensure that the interview would be conducted with a manager that had authority over the company shipping decisions as well as full knowledge regarding the supply chain constraints imposed by customer demands or manufacturing/distribution activities. If a potential interviewees had no decision making power to select among alternative shipping arrangements, the interviews were cancelled or postponed until a suitable manager was available. This prescreening methodology was time consuming but ensured the quality of the data collected.

The pool of participating companies ranged in size of annual sales from one million to over one billion dollars. Annual TEU volumes handled by the managers were also diverse, 60% of respondents reported an annual TEU volume of more than 500 TEU but less than 50,000 TEU. The median volume of TEU shipped per year was 2,000. Equally diverse were the values of containers shipped, ranging from $6,250 per TEU (grains) to a maximum of $800,000 per TEU (cosmetics). By commodity type, the largest percentage of companies and shipments were related to electrical equipment/products (33% of total), farming and food products (19%), construction products (13%), machines/automotive parts (10%), textile products (10%), consumer products (7%), and mechanical products (4%).

Managers were asked to prioritize the most significant types of cost associated with transportation related disruptions. A considerable majority of the respondents (65%) considered that the most important costs associated with supply chain disruptions was lost sales and related loss of market share or product spoilage (for perishables). Many respondents were also concerned about additional expediting costs (e.g. by using airfreight instead of sea transportation) as well as increased fees/penalty associated with demurrage and storage costs (44%). A significant percentage of the respondents (30%) were concerned about increased reporting and administrative costs such as: increased employee hours to track shipments, higher communication costs, extra documentation, additional reporting for back orders and out of stocks, rescheduling priority deliveries, and follow-ups. Damages to the company's reliability/reputation to deliver the promised products/services on time were cited more frequently (22%) than increases in pipeline or in-transit inventory costs (13%). Finally, some respondents were concerned about payment delays and negative impacts on cash flows (9%).

When disruptions take place, respondents identified different correction methods for short-term immediate solutions versus long-term precautions. In the short-term the majority of respondents (78%) indicated that they would change the shipping plan for sea transportation (e.g change shipping/loading port or change transportation mode to inland or air freight for part of the shipment), change freight forwarder or use back up carriers/suppliers. In most cases (70%) respondents indicated that increased communication and information sharing along the supply chain was very important to handle the negative impacts of disruptions. In the medium-long term, respondents (52%) indicated that they would increase safety stocks or increase the number of suppliers/sources (60%) if disruptions were considered a significant supply chain problem.

5. ANALYTICAL FRAMEWORK

The logit model is based on consumer behavior theory and is well suited to estimate value of time and willingness to pay for transportation service attributes (Hensher et al., 2005). A shipper's utility is represented by a function that is dependent on a transportation alternative cost, time, reliability, damage, and sailing frequency. Formally, the utility U_{ijt} of company i when choosing alternative j in choice situation t is expressed as:

$$U_{ijt} = \beta_{FR} FR_{ijt} + \beta_{TT} TT_{ijt} + \beta_R R_{ijt} + \beta_D D_{ijt} + \beta_F F_{ijt} + \varepsilon_{ijt}\ .$$

The term ε_{ijt} is the logit error term that measures all the unobserved attributes related to the utility. The freight rate, travel time, reliability, damage rate, and frequency of sailing transportation attributes associated with alternative j for company i in choice situation t are represented by $FR_{ijt}, TT_{ijt}, R_{ijt}, D_{ijt}, F_{ijt}$. In a utility maximization framework, company i will choose alternative j if and only if:

$U_{ijt} > U_{ikt}$, for all alternatives $k \neq j$.

Since there are multiple choice situations for each respondent, the estimation must deal with state dependences and serial correlations in the error terms (Morikawa, 1994). The parameters $\beta_{FR}, \beta_{TT}, \beta_R, \beta_D, \beta_F$ are estimated using the econometrics software NLOGIT taking into account the state dependence of the error term across the multiple choice situations for a given company.

A useful property of this type of logit model is that the monetary values of service attributes can be estimated using the ratio of cost and any service parameter. For example, the ratio of time/cost parameters indicates the tradeoff between time and transportation cost or rate. For example, the willingness to pay (WTP) for travel time is obtained as follows:

$$\text{WTP}(TT) = \frac{\beta_{FR}}{\beta_{TT}}$$

6. ANALYSIS OF RESULTS

Using the data collected in the second and third part of the interviews two multinomial logit models were estimated. The data collected in the second part of the interviews was used to estimate parameters under normal operating conditions, i.e. without disruptions. The data collected in the third part of the interviews was used to estimate parameters assuming delays caused by a disruption. The log-likelihood values were -215.36 and -239.99 respectively; data from 30 respondents and 240 choice situations was used in each estimation. Table 1 presents the estimated parameters.

Attribute	Normal Operations		With a Disruption	
	Estimated Parameter	t-Ratio	Estimated Parameter	t-Ratio
FREIGHT RATE	-0.0029	-6.6360	-0.0025	-5.123
TRANSIT TIME	-0.0957	-2.1500	-0.4579	-7.735
RELIABILITY	0.1219	9.8230	0.1085	8.83
DAMAGE	-0.5719	-4.1310	-0.9714	-3.648
FREQUENCY	0.4462	3.1140	-	-

Table 2 – Estimated Parameters Without and With a Disruption

All the attributes were statistically significant in the two models. As indicated by t-tests, there is a significant difference between the estimated values of transit time and damage. On the other hand, the null hypothesis cannot be rejected when freight rate and reliability parameters are compared.

Attribute	Measurement Units for the Willingness to Pay (WTP)	WTP Normal Operations (1)	WTP With a Disruption (2)	Ratio WTP (2)/(1)
TRANSIT TIME	For a one day reduction	\$33.10	\$180.66	5.46
RELIABILITY	For a 1% increase in on-time deliveries	\$42.17	\$42.81	1.02
DAMAGE	For a 1% reduction in damages	\$197.75	\$383.27	1.94
FREQUENCY	For an additional sailing per week	\$154.31	-	-

Table 3 – Summary of Willingness to Pay in U\$S

The willingness to pay results are presented in Table 4. Under normal operating conditions, on average and per TEU, managers are willing to pay \$33 for a one day reduction in transit time, \$42 for a 1% increase in on-time reliability, \$197 for a 1% reduction in the damage rate, and \$154 for an additional sailing or delivery per week. If a disruption takes place, the willingness to pay changes significantly for transit time and damage. Using the data gathered in the third and final part of the interview, when a disruption takes place managers are willing to pay \$180 for a one day reduction in transit time, \$42 for a 1% increase in on-time reliability, and \$343 for a 1% reduction in the damage rate. Frequency of service was not a factor because it was not relevant when preparing a response for a specific disruption.

These results indicate that willingness to pay for travel time increases, on average, 5.46 times when a disruption takes place. As indicated by the managers in the interviews and by the increase in the willingness to pay for a one-day transit time reduction, air shipments become an attractive alternative in case of disruptions. For many products and industries it is worth expediting at least part of the shipment to mitigate stock-out costs and other disruption costs. The willingness to pay for a reduction in the damage rate almost doubles; this indicates that the cost of cargo damages is compounded by travel time delays. From an inventory control perspective this is reasonable. With delays, the likelihood of stock-outs increases and shippers cannot afford a damaged shipment. The willingness to pay for reliability remains practically unchanged. Although from an inventory control perspective an increase would be reasonable if there is a disruption; it seems that managers focus on expediting the shipment rather than on increasing travel time reliability.

7. CONCLUSIONS

The results of a survey to understand and quantify disruption costs and response strategies are presented. Managers' responses indicate that disruption costs include lost sales, expediting costs, intangibles such as loss of reputation, and financial impacts on companies' cash flows. All these costs are very difficult to quantify even with full access to a company's proprietary operational, financial, and sales data. The results of this research indicate that it is possible to estimate transportation disruption costs using discrete choice models and data collected at in-depth interviews with logistics managers. Results clearly indicate that, on average, shippers' willingness to pay for travel time reductions have a fivefold increase when a transportation disruption takes place. Furthermore, in situations where disruptions are frequent, the economic costs of delays and expediting can be severely underestimated using average freight travel time values. Further research is needed to generalize these results and find methodologies to include disruption costs in the economic evaluation of freight transportation projects.

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REFERENCES

BOLIS, S. & MAGGI, R. (2003) Logistics strategy and transport service choices: An adaptive stated preference experiment. *Growth and Change,* 34(4)**,** 490-504.

BROOKS, M. & BUTTON, K. (2006) Market Structures and Shipping Security. *Maritime Economics & Logistics,* 8(100-120.

CANIATO, F., FLECK, J., RICE, J. & SHEFFI, Y. (2003) Supply Chain Response to Global Terrorism: a situation scan. *Center for transportation and logistics, MIT, Cambridge,US, Working Paper*.

CAPINERI, C. & LEINBACH, T. R. (2004) Globalization, E-economy and trade. *Transport Reviews,* 24(6)**,** 645-663.

DE JONG, G. (2000) Value of freight travel-time savings. *Handbook of Transport Modelling,* 1(553-564.

HENSHER, D. & PUCKETT, S. (2004) Freight Distribution in Urban Areas: The role of supply chain alliances in addressing the challenge of traffic congestion for city logistics. *Working Paper ITS-WP-04-15*.

HENSHER, D. A., ROSE, J. M. & GREENE, W. H. (2005) *Applied Choice Analysis: A Primer*, Cambridge University Press.

HUBER, J. & ZWERINA, K. (1996) The importance of utility balance and efficient choice designs. *J. Mark. Res.,* 33(3)**,** 307–317.

KAWAMURA, K. (2000) Perceived value of time for truck operators. *TRANSPORTATION RESEARCH RECORD 1725***,** 31-36.

KLIE, L. (2006) Disaster-proofing the Supply Chain. *Food Logistics,* *www.foodlogistics.com*.

KURRI, J., SIRKIA, A. & MIKOLA, J. (2000) Value of time in freight transport in Finland. *TRANSPORTATION RESEARCH RECORD 1725***,** 26-30.

MASSIANI, J. (2003) Can we use hedonic pricing to estimate freight value of time? *10th International Conference on Travel Behaviour Research.* Lucerne, Switzerland.

MORIKAWA, T. (1994) Correcting state dependence and serial correlation in the RP/SP combined estimation method. *Transportation,* 21(2)**,** 153-165.

OECD (2006) *Decoupling the Environmental Impacts of Transport from Economic Growth,* OECD - Organisation for Economic Co-operation and Development.

ROSE, J., BLIEMER, M., HENSHER, D. & COLLINS, A. (2008) Designing efficient stated choice experiments in the presence of Reference Alternatives. *Transportation Research B,* 42(395–406.

SHEFFI, Y. (2005) *The resilient enterprise: overcoming vulnerability for competitive advantage*.

SWAIT, J., LOUVIERE, J. J. & WILLIAMS, M. (1994) A Sequential Approach To Exploiting The Combined Strengths Of Sp And Rp Data - Application To Freight Shipper Choice. *Transportation,* 21(2)**,** 135-152.

WIGAN, R., ROCKLIFFE, N., THORESEN, T. & TSOLAKIS, D. (2000) Valuing long-haul and metropolitan freight travel time and reliability. *Journal of Transportation and Statistics,* 3(83-90.

WILSON, M. C. (2007) The impact of transportation disruptions on supply chain performance. *Transportation Research Part E,* 43(4)**,** 295-320.

ZAMPARINI, L. & REGGIANI, A. (2007) Freight Transport and the Value of Travel Time Savings: A Meta-analysis of Empirical Studies. *Transport Reviews,* 27(5)**,** 621-636.