Abstract Number: 011-0229

Modelling external transport costs in distribution networks
C. ORTOLANI, A. PERSONA, F. SGARBOSSA

Department of Management and Engineering, University of Padova, Stradella San Nicola, 3 36100 Vicenza – Italy
(†) Corresponding author

Tel: +39.0444.998735 - Fax: +39.0444.998889

Email: alessandro.persona@unipd.it
chiara.ortolani@unipd.it
fabio.sgarbossa@unipd.it

POMS 20th Annual Conference
Orlando, Florida U.S.A.
May 1 to May 4, 2009

Abstract

This work investigates the “Green Impact” concern in the transport sector. Generally companies which work to reduce their environmental impact act on three subsequent levels: optimising the existent networks and flows; optimising modes of transport; increasing efficiency of routes and journeys. Similarly, some of the most widespread actions meant to decrease transport pollution costs consist in minimizing empty running of the trucks, encouraging co-operative retailer distribution, running more efficient vehicles: all measures that, before abating pollution and congestion costs, have the substantial benefit of pulling down the transport operative costs directly paid by companies. This article gathers many of the main contributions on the theme in literature, showing how dispersed data regarding full transport cost appear to be. An analytical aggregation of the different results is offered, in order to obtain and homogeneous transport cost function, and several applications have been introduced to explain the proposed models.

Keywords: Green Impacts; Supply Chain Management, Supply Network Design, Industrial Applications.
INTRODUCTION

A recent but predominant trend currently concerning Supply Chain management in many economic fields is what could be defined as the “Green Impact”. This definition refers to all those initiatives and actions aimed at measuring, evaluating and (in the most successful cases) reducing the negative impacts that a specific economic activity generates on the environment and on society.

The increased attention on the social effects of a business can be seen as a consequence of a number of linked causes, first of which is the growing concern of the customers towards environmental issues. As a matter of fact, more and more consumers are beginning to be sensitive to topics like the “food miles”, questioning why they should buy products which travelled thousands of kilometres before arriving in their houses or which are uselessly accompanied by oversized and often unrecyclable packaging. The public perception of the attitude of a firm toward such themes is valued as an important cost voice, especially in the public sector where there is a lot of visibility of Corporate Social Responsibility and, as a consequence, of environmental and sustainability issues.

As investors are increasingly aware of the damaging effect that a negative social behaviour could have on their market perception and stock valuation, corporate responsibility and environmental issues are becoming part of the business strategy itself. Many big companies have indeed gone public with corporate environmental strategies, showing a green agenda of a high profile.

From a broader point of view, the necessity of correctly estimating emissions and pollution costs becomes a strategic issue in a modern Supply Chain perspective, where transparency is a main imperative: lack of transparency would convey limited confidence in initiatives and assertions by companies. This is especially valid for transport and logistics operations, where several companies are involved and transparency is necessary to look further up and down the supply chain and to better exploit challenges and opportunities. From a Supply Chain point of view, then, quantifying emissions “provides a baseline from which mitigation strategies can be developed and performance
measured. It allows companies to set goals, understand trade-offs and optimise modes of transport” (Van Agtmaal, 2008).

At the same time, governments and regulations are paying more and more attention to the environmental impacts of the economic activities: regulations like the Kyoto protocol (1997) define targets in terms of emissions and pollution reduction and force the ratifying parties to constantly monitor, report and reduce greenhouse gases and emissions. The combination of the two mentioned effects – a marketing-led approach based on consumer’s perceptions of supply chain practices and a legislative approach based on quantifiable measures – has made many firms start to worry about the best way of quantifying the emissions (and the related costs) generated by their daily activities.

One of the main fields in which this analysis is being run is the transport sector: transport is valued to be one of the most polluting activities in the industrial system. Azar et al. (Azar et al, 2003) estimate that in 1990 the sole transportation sector was responsible for some 25% of the world’s energy use, and 22% of the global energy emissions. This is the reason why most managers who are acting on green supply issues are focusing their efforts on logistics. A global survey, conducted in 2008 by management and technology consultancy BearingPoint, in partnership with Supply Chain Standard, has examined the impact of the environmental agenda on the business strategy by questioning almost 600 senior managers belonging to a wide range of companies. Regarding the efforts being done in order to face environmental issues, 81% of them had taken action in transport and logistics, the most common initiative being reorganising to reduce the number of journeys, as well as changing modes of transport.

Generally companies which work to reduce their environmental and transport impacts act on three subsequent levels: the first step consists in optimising the existent networks and flows; the following typically involves optimising modes of transport (by using eventually multimodal transport); the last one is bounded to the increased efficiency of routes and journeys.

What is particularly valuable about such initiatives run to reduce transport environmental impacts is the fact that the necessity of taking care of environmental issues often seems to become an incentive
to develop optimising policies which then have important effects on the transport cost itself. In other words, the environmental impact often represents a starting point for a series of optimising policies which act on the overall transportation activity, generating also immediate benefits in terms of logistics costs and efficiency.

Being realistic, in fact, no companies would take care of environmental costs if this hadn’t objective and quantifiable outcomes. “Green” issues are often considered as a starting point for economic and strategic evaluations: for example, growing awareness within companies of the importance of environmental initiatives has raised the question of the opportunity of changing current sourcing policies, switching from Far East to closer low-cost locations such East Europe. This would definitely abate pollution and emission costs due to reduced transportation activity, but it surely wouldn’t have been considered as a feasible route if not supported by elements like the increased labour cost in Far East countries or the fast growing fuel prices. Similarly, some of the most widespread actions meant to decrease transport pollution costs consist in minimizing empty running of the trucks, encouraging co-operative retailer distribution, running more efficient vehicles: all measures that, before abating pollution and congestion costs, have the substantial benefit of pulling down the transport operative costs directly paid by companies. As stated by Dupras (Dupras, 2008), in a situation where energy and commodity prices are at, or near, all-time highs, driven by market volatility, uncertainty about how long-term supply and the onward march of the oil price, going greener often also means cutting costs, being more efficient and providing a better service to customers.

Aggregating the benefits of both a better environmental behaviour and an abatement of costs becomes a necessity when, as it is happening today, consumers are paying more and more attention to the “green side” of economy without yet being inclined to tolerate a correspondent significant increase in market prices.
In most of the literature contributions, the overall transport cost is divided into two main fields: internal transport costs and external transport costs.

The collection, distribution, transhipment, handling of goods moved within a transport network are considered as the internal costs of the network itself (Janic, 2007): these costs are typically clearly identifiable and valuable and are connected with the physical moving of units between shippers and receivers. Nevertheless, as stated again by Janic (Janic, 2007), because of a lack of full property bright allocation, each step of the delivery operation in the network generates burdens on society. If intensive and persistent, and not reflected in prices, these burdens are considered as external costs. These are costs that, substantially, the network imposes on society: they are often indirectly linked to the transportation activity and can be estimated using methods like willingness-to-pay for avoiding, mitigating or controlling particular impacts.

In other words, external costs can be considered as demonstrated expected damages that are not paid and consequently not taken into account in the decision making process of a certain activity.

This section will focus on the estimation of the most critical field of cost, which is represented by the external costs, as the internal transportation costs can be easily obtained by real providers’ list prices and tariffs.

Specifically, regarding transport activities and networks, it is possible to identify some main cost categories (www.externalcosts.eu). The most common costs are the ones linked to atmospheric pollution, which causes damages to human health, to buildings and monuments, and to ecosystems. Emissions from vehicular traffic are one of the major sources of pollution: the main pollutants are carbon monoxide (CO), nitrogen oxides (NO\textsubscript{X}) and volatile organic compounds (VOCs) emitted by vehicles in the environment. An extensive research in literature is being conducted (see Yin and Lawphongpanich, 2006; Guo, 2007) aiming at finding the best way to internalise such costs trough tools like road pricing. However, as stated by Janic (Janic, 2007), air pollution does not only come
from fuels burning in road transport: all of the transport modes generate air pollution as a consequence of their energy usage. If electric energy is used, as it happens in some railways, the generated air pollution is indirect, dependent on the composition of sources from which the electric energy is obtained. The impacts of air pollution are constantly under control, mainly because many of its effects are still not well known. Nicolas et al. (Nicolas et al., 2005) consider that, firstly, there are still uncertainties on the evolution of the background ozone and on finer particles. Secondly, there are growing expectations of urban populations faced with environmental and public health questions. Finally, epidemiological research has increasingly confirmed that air pollution has a significant long-term impact on human health.

The climate change impacts due to human activities also belong to the major external costs categories. The problems of the human influence on climate have been analysed for many years by IPCC (Intergovernmental Panel on Climate Change), an international organism in charge since 1988 for the appraisal of the various environmental, social and economic aspects of climate change. Economic valuation of climate change impacts is periodically reviewed by IPCC, by considering the work of research institutes or scientific networks from all over the world. This type of research needs very complex models to be integrated, so damage valuation results could be very different depending on research hypothesis, in fact the extent of climate change net damages is influenced by a multitude of different factors that may intervene in a very broad time period. One of the main uncertainty factors in the economic valuation is the difficulty to evaluate with the present monetary unit of measure (willingness to pay of present generations) the projected effects on ecosystems that will be experienced by future generations. The concrete risk of not including the impacts on ecosystem in the economic valuation is to underestimate sustainability issues in the present decision-making. Climate change impacts due to transport sector are mainly related to global warming caused by carbon dioxide (CO₂) emissions: the amount of CO₂ released per unit of transportation service is directly related to the energy efficiency of the mode providing that service.
**Noise external costs** are related to the fact that noise generated by vehicles operating the collection and distribution of goods, when exceeding tolerable limits, causes annoyance and, if persistent, can cause a decline in productivity and can even have adverse health effects. Nevertheless, obtaining reliable data on people exposure to noise and on its psychological effects is very difficult. In literature studies applying all kinds of possible methodologies may be found: from hedonic price methods (considering the loss of value for real estates exposed to persistent noise sources), to abatement cost method (the cost of anti-noise barriers), to contingent valuation methods (which measure the willingness to pay by exposed people to benefit from noise reduction measures). Results of the different methods may vary significantly.

The category of **accidents external costs** in the transport sector comprises factors such as direct health impacts, impacts on vehicles and infrastructures, “cool blooded” costs such as net output loss, ambulance costs, medical costs (Calthrop and Proost, 1998). Traffic accidents, in fact, cause damage and property loss to network operators and third parties, in addition to the loss of life and injuries to the affected people: this is why Forkenbrock (Forkenbrock, 1999) states that “the external cost of a unit of transportation service is the uncompensated cost of deaths, injuries, and property damage that occurs due to an additional trip by the mode in question”.

Finally, **external costs of congestion** are linked to the fact that trucks performing the collection and distribution of load units usually move in densely urbanised and/or industrialised zones (Janic, 2007): they may experience congestion and consequent private delays, but they may also impose delays on other vehicles, whose costs are counted as externality. The main impacts associated to congestion are represented by economic damages linked to the loss of time suffered by the goods transported and by vehicle users, to greater vehicle operation costs, to costs of increased pollution, to costs of increased accident risk.
DATA COLLECTION

External transport cost estimates that can be found in literature are characterized by a high degree of dispersion and variability in the final outcomes: Nicolas et al. (Nicolas et al., 2005), on the theme of the impact of air pollution on the environment and the quality of life, assert that when starting studying the financial estimates of such impact one gets struck by the diversity of the measurement methods and by the variability of the results. Moreover, in transport more than in most other economic sectors, causal factors can be complex and are often numerous; local specificities play an important role and areas are large. As a consequence, as remarked by Van Agtmaal (Van Agtmaal, 2008), an increasing number of emissions calculators are available, but the outcomes of these differ widely as various methodologies and emissions conversion factors are used: differences in outcomes are inevitable because of differences in methodologies, logistics categories and data availability. Even if a common methodology is used, there can be significant variations in the outcomes due to the different definition of boundaries and allocation keys. As a consequence, again quoting Nicolas et al. (Nicolas et al., 2005), this extreme diversity of impacts would require evaluations in many different domains, but the different valuation methods developed neither necessarily have the same approach nor provide the same results.

The main causes of possible dispersion in the data are described in detail in Quinet’s work (Quinet, 2004): the author numbers among these causes first of all the specifics of the situation, meaning with this that the situation can vary according to the location and density of the settlement studied. Another main point is the type of cost which is taken into consideration, as some studies calculate average costs while others deal with marginal costs. Moreover, there is the type of valued external cost to be taken into consideration, as not all the studies take into account the same effects. The physical relations (physical laws that link the cause of damages to effects) and the hypotheses used by the modelling framework have then to be valued. Finally, variable unit values (such as value of time and statistical value of life) used in the different analyses need to be considered.
Nevertheless, from the industrial point of view, the need of evaluating a reasonable and reliable value of the overall transport cost conveys the necessity of having a standardized framework aggregating all the different estimates.

This section offers a review of various literature contributions that deal with transport cost estimates and aggregates analytically the different results in order to obtain and homogeneous transport cost function. The result obtained by merging all the different contributions could be claimed not to be fully reliable, given those high dispersion-generating factors that are listed above. Actually, the reliability of the obtained function is assured by the same Quinet’s work (Quinet, 2006): as a matter of fact, the author reaches the conclusion that the main differences found in the contributions come from the specificity of the situation under review and the type of cost calculated. This means that, once all the costs and the various situations are homogenized (especially in terms of unit of measurement and time horizon of reference) the final result can be considered as a reliable estimation of the overall cost, even despite the high variability of the original values.

The contributions examined regarding the evaluation of the external transport cost can be classified in three main categories, based on how each of them takes into consideration the cost itself:

- qualitative studies;
- analytical studies;
- quantitative studies.

Qualitative studies typically deal indirectly with external transport cost: they do consider one or more external cost fields but do not give any quantitative or analytical indications regarding these costs, or give only a rough overall value.

Analytical studies do not provide any values, but give some analytical formulas that can be used to estimate the costs.
Finally, quantitative studies provide real values (coming from surveys or real network analyses) for some or all the considered cost fields. All of the cost categories were taken into consideration during the analysis phase, while, in order to simplify the aggregation phase without introducing elements that could have highly affected the final result, only quantitative values were considered when estimating the final cost function.

A factor that deeply affects the cost calculation is the nature of the network. Typically literature contributions define such costs for two main types of distribution network: freight and rail networks. As the estimated costs for the two networks differ significantly, the analysis will take into consideration separately the two cases.

**Freight transport**

**Qualitative studies**

Qualitative studies regarding freight transport networks take into account a considerable variety of costs. The most complete contribution, given by Parry (Parry, 2008), develops and implements a framework for estimating optimal taxes on the fuel use and mileage of heavy-duty trucks in the United States, accounting from external costs from congestion, accidents, pavement damage, noise, local and global pollution (deriving from both emissions and greenhouse effect). Those externalities are considered as depending directly on fuel use (this is valid for local pollution and greenhouse warming) or varying with vehicle covered distance (this is the case of congestion, accidents, noise, pavement damage).
Similarly, Guo (Guo, 2007) studies the internalisation of the external costs (mainly bound up with air pollution, but considering also congestion, accidents and noise effects) into the total distribution cost, in order to analyse the influences of external cost burdens on a logistics company mode and route choices from a user charge perspective.

Azar, Lindgren and Andersson (Azar et al., 2003) state that the transportation sector involves various negative environmental consequences: it impoverishes local air quality, causes acidification and is a major emitter of CO$_2$. Nicolas et al. (2005) are considering analogously air pollution as the main environmental drawback of a transportation network.

Mazzarino (Mazzarino, 2007) evaluates that the social cost of global warming by freight transport amounted to a mean of 558,293,323 $ in 1995.

Finally, in May, Jopson and Matthews (May et al., 2003) transport is considered as one of the most significant sources of unsustainability in urban areas. The authors consider that, in European cities alone, traffic congestion costs in excess of 100,000,000 € every year, that local pollution and the resultant health impacts impose costs of a similar magnitude, and that there are around 20,000 fatalities on urban roads each year.

**Analytical studies**

Analytical studies typically integrate the formulation of the transport cost in a global simulation model. Janic (Janic, 2007) develops a model for calculating comparable combined internal and external costs of intermodal and road freight transport networks: external costs include in this case the costs of impacts of both networks on society and on the environment such as local and global air pollution, congestion, noise pollution and traffic accidents.

Calthrop and Proost (Calthrop and Proost, 1998) assert that although much progress has been made in recent years in defining and measuring the external costs of transport, still it doesn’t exist any practical example of textbook road pricing. They address three key issues: a correct identification of
marginal external costs, the simultaneous treatment of different externalities in assessing policy options, and the potential for incorrect incentives facing government. Specifically, some analytical formulations are defined which can lead to the estimation of costs connected to air pollution, congestion and accidents.

Finally, Yin and Lawphongpanich (Yin and Lawphongpanich, 2006) address in their paper issues relevant to internalising traffic emission externality on road networks with fixed travel demands. They state that a major source of air pollution is represented by the emissions from vehicular traffics, which contribute considerably to the level of carbon monoxide (CO), nitrogen oxides (NO$_x$) and volatile organic compounds (VOCs) in the environment. Because it is almost solely emitted by vehicles, CO is considered as a meaningful indicator for the level of atmospheric pollution generated by vehicular traffics and an analytical formulation is given for the computation of this kind of emission.

**Quantitative studies**

Quantitative studies provide real external transport cost values, which are typically estimated through empirical analysis or evaluation of research data.

As it is shown in the following table, the different perimeters of analysis, methodologies, unit values used by the authors are the main causes of the high variability of the calculated costs. Most of the analyses are conducted in Europe, some of them considering the entire perimeter, some other focusing on a specific country with its peculiarities and distinctive traits. Another main difference in the outcomes is given by the choice of considering urban or extra-urban transport. The impact of the different cost voices will be very different in the two cases: extra-urban transport, for example, will be much less affected by congestion costs. At the same time, transportation-generated noise will affect fewer people in rural areas, so it will appear as a less detrimental externality in case of extra-urban transport, although, as stated by Forkenbrock (Forkenbrock, 1999), noise represents a
negative externality wherever vehicular traffic occurs. The main difference among the different contributions is yet represented by the units of measurement through which the costs are estimated. Some authors, in fact, refer to a ton-mile or ton-kilometre cost, some others to a vehicle-mile or vehicle-kilometre value, attributing then these costs to a wide range of years (going from 1994 to 2005) during which the value of money has continuously changed. As a consequence, two main approximations have to be included in the analysis. The first one is bound to the need of defining a standard value of ton/vehicle in order to be able to define all cost voices on a ton basis: this value was fixed to 14,3. The second approximation derives from the need of discounting back all cost voices to a present value in order to evaluate them considering the same cost of money.
<table>
<thead>
<tr>
<th>Article</th>
<th>Nature of transport network</th>
<th>Reference area</th>
<th>Perimeter of analysis</th>
<th>Methodology</th>
<th>Emissions - Air pollution</th>
<th>Emissions - Greenhouse effect</th>
<th>Congestion</th>
<th>Noise</th>
<th>Accidents</th>
<th>Road Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>External costs of intercity truck freight transportation (D.J. Forkenbrock, Transportation Research Part A, pp. 595-526, 1999)</td>
<td>Road</td>
<td>USA</td>
<td>Extra-urban</td>
<td>Data analysis</td>
<td>0.082 cent $/ton-mile (1994)</td>
<td>0.15 cent $/ton-mile (1994)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The marginal external costs of urban transport (I. Neyerse, S. Ochelen, S. Proost; Transportation Research Part D, pp. 111 – 130, 1996)</td>
<td>Road</td>
<td>Europe</td>
<td>Urban</td>
<td>Data analysis</td>
<td>0,147 €/vehicle km (2005)</td>
<td>1,391 €/vehicle km (2005)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimating the cost of air pollution from road transport in Italy (R. Danello, A. Chisari; Transportation Research Part D, pp. 249 – 258, 1988)</td>
<td>Road</td>
<td>Europe (Italy)</td>
<td>Urban</td>
<td>Data analysis</td>
<td>99,95 cent $/vehicle mile (1992)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Literature Contributions on External Costs of Road Transport
**Rail transport**

Regarding rail transport, the most meaningful contributions are represented by quantitative studies, which in most cases take into consideration the same cost components previously seen in the case of freight transport (with the exceptions of road congestion and road damage costs).

Nevertheless, it is more difficult to develop accurate estimates of social costs for rail transportation than for road networks: as pointed out by Forkenbrock (Forkenbrock, 2001), this is mainly due to the scarcity of data available in this field and to some critical factors such “joint production among rail companies (sharing trackage or rolling stock), economies of scale and density, and a lack of data on specific expenditures pertaining to individual freight movements”.

Again, reference area is mainly Europe, but in this case all the contributions take into consideration extra-urban transport more than urban one: this is clearly bound to the nature of the specific mode. Regarding the units of measurement, in this case the used ones are ton-mile and ton-kilometre, again considered between years 1994 and 2005. A part from the approximation linked to the actual value of money, these data seem then to be more homogeneous than the ones identified for road transport.
<table>
<thead>
<tr>
<th>Article</th>
<th>Nature of transport network</th>
<th>Reference area</th>
<th>Perimeter of analysis</th>
<th>Methodology</th>
<th>Emissions - Air pollution</th>
<th>Emissions - Greenhouse effect</th>
<th>Noise</th>
<th>Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison of external costs of rail and truck freight transportation</td>
<td>Rail</td>
<td>USA</td>
<td>Extra-urban</td>
<td>Data analysis</td>
<td>0.01 cent $/ton-mile (1994)</td>
<td>0.02 cent $/ton-mile (1994)</td>
<td>0.04 cent $/ton-mile (1994)</td>
<td>0.17 cent $/ton-mile (1994)</td>
</tr>
<tr>
<td>A meta-analysis of Western European external costs estimates</td>
<td>Rail</td>
<td>Europe</td>
<td>Urban and extra-urban</td>
<td>Literature analysis</td>
<td></td>
<td>0.009 €/ton mile (2004)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimal pricing of transport externalities in an international environment: some empirical results based on numerical optimization model</td>
<td>Rail</td>
<td>Europe (Belgium)</td>
<td>Urban and extra-urban</td>
<td>Empirical analysis</td>
<td>0.003 €/ton km (2005)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Literature Contributions on External Costs of Rail Transport
DATA ANALYSIS

As the purpose of the analysis was to find an aggregate cost function, the following step consisted in translating all the different costs given by the literature into a homogeneous unit of measurement, which was euro/kilometre, and in summarizing each cost voice in a single coefficient representing a sensible mean, minimum and maximum value of all the examined ones. This was done by using the two approximations mentioned before regarding the average load of a truck and the value of money. The final obtained function depends on three relevant factors: the travel time \((T)\), the travelled kilometres \((km)\) and the environmental aspects \((EA)\):

\[
C_{\text{tot freight}} = f(T, km, EA)
\]  

(1)

As explained by:

\[
C_{\text{tot freight}} = C_{\text{int}} + C_{\text{ext}}
\]  

(2)

**Internal costs**

As defined by Janic (Janic, 2007), the collection, distribution, transhipment, handling of goods moved within a transport network are considered as the internal costs of the network itself: these costs are typically clearly identifiable and valuable and are connected with the physical moving of units between shippers and receivers.

These costs depend on the first two factors introduced before: the travel time \((T)\) and the travelled kilometres \((km)\).

\[
C_{\text{int}} = f(T, km)
\]  

(3)
In fact, in many supply chain networks the total transportation cost function is minimized by combining the two factors (travelled time and kilometres). To give an unique and homogeneous unit of measurement between time and kilometres the cinematic quotient can be used, being it defined as the mean speed for different parts of the travelled route. Using this assumption, for a typical delivery travel two parts of the route can be defined: one being outside the urban centre and the other one being inside. The first part will be characterized by a higher mean speed than the second one. The speed local ratio \( s_j \) can be used to compare the two fractions and to express firstly the inside urban centre path as a function of only travelled kilometres \( (km) \); the external urban centre travel will depend on the same factor.

As a consequence, internal costs can be defined as a pure function of travelled kilometres \( (km) \):

\[
C_{int} = f(f_j(s_j,km),km)
\]

(4)

We have analyzed and introduced several values of \( C_{int} = f(km) \) on international (Europe) and national (Italy) travels, as shown in figure 1.

![Figure 1. Internal Costs of Road Transport for European and Italian deliveries](image-url)
External Costs

External costs, as introduced and explained in previous sections, include all environmental aspects. As it happens with internal costs, external ones are function of travel time \( T \) and of travelled kilometres \( km \). Moreover, these costs depend on the environmental aspects \( EA \). Using the assumption introduced for the internal costs, we can define:

\[
C_{ext} = f(T, km, EA)
\]  

where:

\[
T = f_1(s, km),\text{ considering the speed local ratio;}
\]

\[
EA = f_2(EI, km),\text{ taking into consideration the different impacts on environment (EI) for several transports methods (road and rail):}
\]

Road transport:

\[
EA = f_2(EI, km) = (a_1 + a_2 + a_3 + a_4 + a_5 + a_6)
\]  

where:

\[
a_1 = \text{emissions – air pollution coefficient} = 0,1688 \pm 6 \% \text{ €/km}
\]

\[
a_2 = \text{emissions – greenhouse effect coefficient} = 0,1339 \pm 5 \% \text{ €/ km}
\]

\[
a_3 = \text{congestion coefficient} = 0,4707 \pm 4 \% \text{ €/ km}
\]

\[
a_4 = \text{noise coefficient} = 0,0387 \pm 3 \% \text{ €/ km}
\]

\[
a_5 = \text{accidents coefficient} = 0,1497 \pm 3 \% \text{ €/ km}
\]

\[
a_6 = \text{road damage coefficient} = 0,0285 \pm 2 \% \text{ €/ km}
\]

Rail transport:

\[
EA = f_2(EI, km) = (b_1 + b_2 + b_3 + b_4 + b_5)
\]  

where

\[
b_1 = \text{emissions – air pollution coefficient} = 0,6267 \pm 6 \% \text{ €/ km}
\]
\[ b_2 = \text{emissions – greenhouse effect coefficient} = 0,6352 \pm 4 \% \text{ €/ km} \]
\[ b_4 = \text{noise coefficient} = 0,5826 \pm 3 \% \text{ €/ km} \]
\[ b_5 = \text{accidents coefficient} = 0,6064 \pm 4 \% \text{ €/ km} \]

As for both categories the result was meant to be expressed in the same unit of measurement (€/km), for both road and rail transport it was necessary to go beyond the dependency from the load carried. This was done by considering and average value of 14,3 tons carried per vehicle and considering that the loading capacity of a train is almost the same as 26 vehicles. The obtained cost functions were supposed to have a linear trend, meaning with this that the contribution of each external factor sums up with all the other coefficients obtaining in this way the total external cost. The hypothesis under this way of proceeding is that all cost contributions have the same weight: a valuable further investigation will be the evaluation of the relative weight of each cost coefficient and the subsequent optimisation of the overall cost functions.

Finally, external costs can be defined as depending only on travelled kilometres \((km)\), thanks to the assumptions introduced before:

\[ C_{ext} = f(f_1(s,km),km,f_2(EI,km)) \]

\[(8)\]

**CASE STUDIES**

**CASE A) Cool and food transport**

The new formula was applied while designing McDonald’s Italian distribution network. It is a 100% road transport network, the goods are stocked inside the vehicles and kept at three different
temperature levels. The different suppliers deliver the products to two HUBs and then the goods are distributed through over 400 restaurants characterized by different dimensions. The conservation temperatures are respectively: -25° Celsius for frozen products, like bread, meal and ice cream; +2° Celsius for refrigerated goods, like salads, milk and yogurt; room-temperature for other products like drinks and merchandising. The proposed model has been applied in order to study the issue of transport type splitting. In particular, the convenience of a unique transport with multi-temperature vehicles in comparison with a set of mono-temperature vehicles has been evaluated. The results show that considering only the internal costs the two alternatives are quite similar, while if the environmental aspects are taken into consideration, transport using multi-temperature vehicles becomes more convenient (figg. 2-3). The chosen solution has been the second one, with multi-temperature vehicles. The study has been extended also to the choice of logistics partners.

Figure 2. Northern Italy network (city trailer truck)
CASE B) Reverse logistics of Industrial Liquid Wastes

This case deals with the application of the proposed model for designing a network for picking activities and disposal of industrial liquid wastes located in northern Italy. Given three disposal points (located near three important cities) and known the amount of production of industrial liquid wastes of a series of over 6000 firms located in several local areas (fig. 4), the aim of the project was to design the best transport network. The optimisation process, if considering only the internal costs, carried out a 100% road transport systems and relative optimisation of routes. On the contrary, considering also environmental aspects and external costs has brought to a different optimal solution, characterized by a mix of two different transport types: 60% road transport and 40% rail transport, as shown in figure 5. In this case, the rail transport network consists in a loop travel system of a train with 26 vehicles, operating between three train stations close to the disposal centres. This has been the adopted solution.
Figure 4. Industrial Liquid Wastes Network

Figure 5. Environmental Cost Savings vs. Rail Transport Ratio
CONCLUSIONS

The aim of the present review was to gather most of the main contributions in literature not only defining the transportation cost from an operational point of view but considering also the indirect cost effects of the transport itself. Transport activities, in fact, impose significant burdens on society and environment when producing effects such as air pollution, noise, accidents, congestion, without paying for it.

This activity showed how dispersed data regarding full transport cost appear to be, underlying the necessity of further researches and studies in order to define reliable cost voices, able to be adapted to a multitude of different scenarios. As a matter of fact, current available estimates of transport costs are strongly dependent from the conditions under which the analysis is being run, this causing a big variability in the outcomes. Moreover, as stated by Nicolas et al. (Nicolas et al., 2005), regarding the problem of valuating the local impact of air pollution, it is necessary to consider not only immediate impacts, but also future effects, including in the analysis a dynamic vision of the long term situation. This necessity can be perfectly declined to all other kinds of transportation external impacts and introduces a further complexity in the analysis itself. Finally, the analysis is made difficult by the fact that many of the different externalities are strictly connected: the level of an externality typically influences the level of the others. This can be easily understood taking the case of congestion: as it is increases also noise effects will be increasing, accidents will be more likely to happen and pollution will be increased due to the fact that more vehicles are stuck in the streets.

Calculating the effective transport cost value is becoming more and more important thanks to the growing environmental awareness of consumers and, as a consequence, to the increased attention paid by Supply Chain management towards those themes: a complete definition of transportation costs represents an essential tool for companies aiming at optimising their transportation practices and distribution networks and channels. This becomes strategic in a fast changing economy where purchasing policies directed to Far East countries are starting not to be as automatically convenient
as a few years ago and where opportunities located in closer countries (i.e. East European locations) appear more and more favourable if considered in terms of the trade off between manufacturing and transportation costs.

Even in the existing collection and distribution networks, estimating the overall transportation cost can convey relevant strategic decisions in terms of, for example, the modes of transport to be used. In fact, taking into account external transport costs shows an increased advantage in the use of rail transport instead of road freight, suggesting that intermodal transport could be increasingly be used appearing to be competitive even for reduced distances. Breuthe et al. (Breuthe et al., 2002) suggest, at this proposal, an adequate pricing policy including the external effects of each mode and promoting the use of transportation modes with lesser negative effects (i.e. rail and waterway) and their intermodal combination with road, in order to substitute these modes to the use of direct road transports.

The theme of defining an appropriate pricing policy for transport is indeed one of the most investigated in literature: as stated by Forkenbrock (Forkenbrock, 1999), by properly considering transport external costs, “ideally, each unit of transportation service used would be assigned a price that would reflect the incremental cost to society of that service” and, following with a more recent article (Forkenbrock, 2001) “policy makers would effectively create a market through which transportation users could weight the benefits of consuming a particular transportation service against the true costs”. Externalities are considered as a form of market failure because they do not allow true costs be taken into consideration when production and consumption decisions are made: if external costs were greater than external benefits, not considering externalities would lead to an over-consumption of transportation. A road pricing policy integrating transport external effects would, first of all, allocate the full transport cost (or, at least, a big part of it) to the entity which is responsible for it, refunding in some way society and environment for the damages produced, but mainly such politics would convey a sensible reduction of the transport externalities and the connected consequences. If charged for the environmental damages produced, in fact, shippers and
transportation providers would look for more and more efficient modes and networks to use, pursuing then both their immediate gain and a sensible benefit from the social point of view. A significant contribution on this theme consists in a document presented by the European Commission in July, 2008 entitled: “Strategy for external costs internalization”. It presents the main principles to be followed in order to internalize external transportation costs and considers as a feasible objective the full application of these principles in all European countries within year 2013. Future developments in the long term will consist in further analysis in order to better identify cost voices (both at present and in the future) and to eventually develop a proper transport pricing policy; in the short term the idea is to deepen the identified functions for external transport costs and to apply them to a real case in order to test the reliability of the functions themselves and to estimate which is the real contribution of the examined costs to the overall transport activity.

REFERENCES


