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DI PADOVA**

**UNIVERSITÀ DEGLI STUDI DI PADOVA**

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**PARAMETRIC MODELLING OF FREIGHT  
NETWORKS:  
OPERATIONAL AND ENVIRONMENTAL  
COSTS**

**DIRETTORE DELLA SCUOLA: CH.MO PROF. PAOLO BARIANI**

**COORDINATORE DI INDIRIZZO: CH.MO PROF. ALBERTO TREVISANI**

**SUPERVISORE: CH.MO PROF. ALESSANDRO PERSONA**

**DOTTORANDA: CHIARA ORTOLANI**



*To my family*



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## ABSTRACT

The increased awareness of the environmental and social impacts caused by logistics and distribution has brought to a deeper focus on this theme by both industry and literature. Research in this field has been developed in order to take into consideration the so-called “green effects” while studying distribution networks.

It is commonly acknowledged that transportation activities generate both operational and environmental costs. Operational costs are typically well defined and computed in logistics providers’ rates. Nevertheless, there is a full set of impacts (such as gasses and particles emissions, noise, congestion, accidents) generating costs that are not reflected into transport prices: these are the environmental costs.

As consumers’ environmental consciousness is growing and legislative organizations are pushing for stricter regulations, from the industrial point of view the request is rising of correctly estimating overall transportation costs. Generally companies which work to reduce their environmental impacts focus on distribution as it is commonly recognized as one of the most polluting activities. As a consequence, they act on three subsequent levels: optimization of the existent networks and flows; optimization of the modes of transport; increase of the efficiency of routes and journeys. Some of the most widespread actions meant to decrease transport environmental impacts consist in minimizing empty running of trucks, encouraging intermodal distribution, running more efficient vehicles: all measures that, besides abating pollution and congestion costs, have the substantial benefit of pulling down the overall costs generated by companies.

However, only few literature contributions give quantitative models to estimate external transport costs. Most of the current studies develop qualitative and multi-objective researches, trying to define and estimate external impacts, without though giving any proper cost values.

As a starting point of this work I am presenting an extensive literature analysis, which shows how dispersed data regarding full transport costs are.

Starting from these data, I elaborated new analytical functions which overcome the limits of the existing formulations and which allow the calculation of both internal and external transport costs for freight distribution networks. These new functions can

effectively estimate the total transport cost: their reliability, as well as their effectiveness, are proved through the application to real industrial cases.

The developed functions represent then the analytical input of an innovative calculation framework. The new framework which I realized as the main objective of my research permits to achieve a reliable and straightforward calculation of the overall transport cost –both internal and external– for any road distribution networks. While requiring in input an extremely reduced amount of data, the model calculates the total transportation cost by considering specific distribution constraints and variables. Both effective operational applicability and results reliability are achieved.

The application of the new model to real industrial cases shows that the framework gives reliable outputs, as the calculated internal costs are comparable to the costs paid by the companies to their forwarders. Nevertheless, the overall costs (considering the sum of internal and external contributions) exceed the actual, operational costs. This highlights immediately the fact that there are certain unpaid amounts which are linked to the presence of external costs. External costs have big impacts, with a weight which is on average the 18% of the total cost. Being so significant, such costs cannot be ignored. On the contrary, finding strategies in order to minimize them becomes more and more important. As these costs are influenced by a considerable number of factors, it is necessary to identify on which values to act in order to effectively minimize the external cost. Through a sensitivity analysis it has been possible to highlight the most meaningful factors affecting both internal and external cost values: the highly significant elements are the vehicle saturation and the travelled distance in urban peak conditions. These will be the variables to act on when developing a cost minimization strategy.

## SOMMARIO

L'augmentata consapevolezza delle conseguenze in termini di impatti ambientali e sociali delle attività di logistica e distribuzione ha generato un'attenzione particolare in merito a questi temi da parte sia dell'industria che del mondo accademico. Ciò ha portato allo sviluppo di un filone di ricerca orientato allo studio di quelli che sono stati definiti "green effects", ovvero effetti ambientali e sociali legati allo sviluppo delle reti logistiche.

E' comunemente riconosciuto come le attività di trasporto generino sia costi di tipo operativo che costi di natura ambientale. I costi operativi sono facilmente definibili e vanno a formare parte delle tariffe di trasporto tipicamente proposte dai fornitori di servizi logistici. Esistono tuttavia una serie di impatti (come l'emissione di gas e particelle inquinanti, l'inquinamento acustico causato dai veicoli, la congestione stradale, gli incidenti) i quali danno luogo a costi che non si riflettono nelle tariffe di trasporto: questi sono i costi ambientali.

L'attenzione da parte dei consumatori, da un lato, e la pressione sempre maggiore dal punto di vista legislativo, dall'altro, fanno sì che il mondo industriale richieda in modo sempre più pressante strumenti in grado di stimare correttamente quali siano i reali costi generati dal trasporto. Tipicamente le aziende che lavorano in un'ottica di minimizzazione dei propri impatti ambientali si focalizzano proprio sull'ambito della distribuzione in quanto questa rappresenta una delle attività in assoluto maggiormente inquinanti. A livello operativo l'azione viene declinata su tre livelli: in primo luogo, l'ottimizzazione delle reti e dei flussi esistenti; quindi l'ottimizzazione dei mezzi utilizzati per il trasporto; infine l'augmentata efficienza dei viaggi che vengono svolti sulla rete con i mezzi a disposizione. Alcune delle azioni più diffuse consistono, ad esempio, nel minimizzare i viaggi a vuoto, nell'incoraggiare la distribuzione intermodale, nell'acquistare veicoli con prestazioni migliori. Tutte misure, queste, che ancor prima dell'indubbio merito di abbattere una serie di costi ambientali, hanno il vantaggio di portare ad una diminuzione anche dei costi operativi effettivamente sostenuti dall'azienda.

In letteratura, tuttavia, questo tema è ancora scarsamente affrontato: solo pochi contributi a livello internazionale forniscono modelli quantitativi in grado di calcolare i

costi esterni di trasporto. La maggior parte degli studi sviluppa infatti analisi di tipo qualitativo e multi-obiettivo, tentando di definire gli impatti esterni ma non fornendo alcun costo reale associato a tali impatti.

Il punto di partenza di questo lavoro è rappresentato da un'estesa analisi della letteratura che mostra come i dati a disposizione siano dispersi e spesso non immediatamente interpretabili. A partire da questa analisi ho sviluppato una serie di nuove funzioni di costo in grado di superare i limiti delle formulazioni tradizionali e di calcolare i costi interni ed esterni associati ad una generica rete di trasporto su strada. Tali funzioni consentono di ottenere una stima reale del costo totale di trasporto: la loro affidabilità, nonché l'efficacia, sono dimostrate grazie all'applicazione ad una serie di casi reali.

Le funzioni sviluppate rappresentano il cuore del modello analitico innovativo. Questo modello, che ho realizzato come obiettivo ultimo della mia ricerca, consente il calcolo dei costi complessivi di trasporto –interni ed esterni– per una qualsiasi rete di distribuzione su strada. A partire da un numero estremamente ridotto di dati in ingresso, il modello è in grado di calcolare il costo totale di trasporto andando a considerare gli specifici vincoli e le variabili associate al determinato percorso distributivo. Si ottengono così da un lato un'effettiva applicabilità delle nuove funzioni di costo, dall'altro una dimostrata affidabilità dei risultati. L'applicazione del modello ad una serie di casi reali conferma, infatti, la validità del modello stesso, il quale calcola un costo operativo assolutamente confrontabile con la tariffa effettivamente pagata al fornitore di trasporto. Tale applicazione, inoltre, mette in luce come i costi totali di trasporto (calcolati come somma di costi operativi ed esterni) eccedano le tariffe attuali. Questo sottolinea come ad oggi esistano alcuni effetti dell'attività di trasporto il cui costo non viene sostenuto da chi genera il trasporto stesso: tali effetti sono imputabili proprio alla componente esterna del trasporto. I costi esterni hanno impatti rilevanti, con un peso che è in media pari al 18% del costo totale di trasporto: essendo così significativi, non possono in alcun modo essere ignorati. Al contrario, identificare strategie che portino alla loro minimizzazione diventa una necessità sempre più urgente. L'applicazione di un'analisi di sensitività ai fattori coinvolti nel calcolo del costo ha reso possibile l'individuazione delle voci più critiche in quanto a conseguenze sul costo finale: si tratta della saturazione del veicolo e della distanza percorsa su strade urbane in condizioni di picco, ovvero di traffico elevato. Sono pertanto questi i fattori più importanti sui quali fare leva nel momento in cui venga sviluppata una strategia di minimizzazione dei costi.

## INTRODUCTION

A recent but predominant focus of Supply Chain management is an approach commonly named “Green Impact”. This definition refers to all those initiatives and actions aimed at measuring, evaluating and 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. The public perception of the attitude of a firm toward such themes is valued as an important cost voice, especially in sectors 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. 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.

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 define targets in terms of 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 consumers’ 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: an efficient transport system has always been considered as the lifeblood of a successful economic system. Nevertheless, in the modern and fast-changing economies, being

efficient might not be enough: there is a pressing demand for transport to be not only efficient, but also sustainable, and transport is valued to be one of the most polluting activities in the industrial system. Achieving sustainability in the transport sector is one of the most critical aims of a long series of social and economical policies. “Greening transport” policies are meant to steer transport towards an enhanced sustainability by adopting optimized transport strategies and by ensuring that transport prices reflect the real cost to society.

Calculating the effective transport cost value is therefore becoming more and more important, as a complete definition of transportation costs represents an essential tool for companies aiming at optimising their transportation practices and distribution networks and channels. In the existing collection and distribution networks estimating the overall transportation cost can convey relevant strategic decisions in terms of the modes of transport to be used. Nevertheless, most of the contributions that can be found on this theme in literature tend to define transport cost categories without yet giving any numerical estimates of the costs.

The aim of this work consists in developing a new analytical framework for a straightforward calculation of both internal and external transportation costs of a specific route. As a matter of fact, companies are constantly facing two potentially conflicting requirements. From one side, there is the need of having reliable information outputs: required results and numbers (especially if they are related to monetary activities) need to be clear and well defined. From the other side, though, there is often the difficulty of obtaining the required input data. Many companies do not have advanced ERP tools able to store and summarize the required information. Often, then, they do not run any specific analyses because they feel that the effort needed in order to gather the data in input would be more than the benefit given by the results.

The framework which I developed is meant to overcome both disadvantages. The output is a pure cost value: it gives both the internal and external transport cost the company is meant to pay for a specific route. All the constraints (such as type of vehicle, type of route, saturation) are already included in the calculations, so the cost given in output can be simply taken as it is. At the same time, the data required in input are a few and straightforward ones, such as distance to be covered and volume to be loaded. These values can be easily gathered, even without a proper ERP system, and they are directly available once the transport is organized.

The new calculations of internal and external transportation costs follow specific paths as the two types of cost can be influenced by different factors; moreover, a clear distinction between them allows the company to be aware of the actual importance of each value. This is meant to avoid the underestimation of the external transport costs which is often made. The application of the created framework to real industrial cases demonstrates that external costs have significant impacts on the overall transportation amount. The development of a sensitivity analysis, then, shows that such costs are deeply influenced by two specific factors: vehicle saturation and urban transit in peak conditions.

The structure of the thesis is the following:

Chapter 1 introduces the theme of sustainability in the Supply Chain. The increased environmental and social focus in the Supply Chain is discussed and an extensive definition of Green Supply Chain is presented. Moreover, the impacts of such a trend into the transportation field are investigated. It is shown how consumers' increased environmental consciousness, from one side, and institutional constraints, from the other, are contributing to a green turn of the overall industrial activity.

Chapter 2 explains in detail the difference between internal and external transport costs and lists all the cost voices grouped under the two categories. For each cost a comprehensive definition is given, together with current values of reference, historical and future trends. Moreover, an overview on external costs valuation techniques is given and the main evaluation methods are explained. Finally, best practices for cost calculation for each category are presented.

Chapter 3 is focused on European strategies towards sustainability: it describes the European legislation and the new incentives towards the environment and the external costs internalization. It explains which were the global and European historical commitments, such as the Kyoto Protocol and the Trans-European Networks Programme. Moreover, it describes the current actions and the future legislative objectives. Finally, it gives an overview on the current taxation methods and on the possible future solutions for internalization.

Chapter 4 offers an overview on intermodal transport as a mode which convenience increases significantly once environmental costs are considered in the analyses. It gives quantitative and analytical formulations for costs estimation of both intermodal routes and terminals. Moreover, it explains how intermodality can become a strategical tool for overall costs abatement.

In Chapter 5 the extensive literature analysis is presented. Causes of variability in the external costs valuation are explained, and the opportunity of using different estimates of the costs is discussed. All the literature contributions are classified in three main clusters (quantitative, analytical and qualitative studies) and for both road and rail transport a detailed categorization is presented: it underlines how external costs are currently dispersed and often under-evaluated.

Chapter 6 presents the new analytical formulations of internal and external costs which I developed as a consequence of the literature research. Such formulations overcome the limits of the traditional cost functions and allow a complete calculation of the transport costs, including both internal and external effects. This chapter also gives the results of a sensitivity analysis which was run in order to evaluate the effects of each cost voice. Finally, it includes two real cases which show how the introduction of the new external cost functions modifies the structure of the distribution network, from one side, and encourages the use of intermodal transport also for reduced distances, from the other side.

Chapter 7 presents the innovative framework which I created for the total transport costs calculation. This new model estimates both the operational and environmental costs associated to a specific freight activity on a road network, given in input the type of vehicle used, the loaded volume, the type of road and the overall distance to be covered. The development of such a tool represents an important innovation for the overall transport costs calculation: while traditionally only operational costs could be estimated, now the total burdens generated by the transport activity are monetized and finally allocated. The framework is applied to real cases and shows to be absolutely consistent with current logistics providers' tariffs. Moreover, it shows that external costs have a significant impact on the overall cost so they cannot be ignored while calculating the total transport cost. The chapter also presents the results of a sensitivity analysis which

was carried out in order to understand which are the factors of major influence on the framework final outcomes.

Finally, the conclusions of the research are presented and some future developments are proposed, such as the extension of the framework calculations to railway, maritime and air transport.



# 1. Environmental Focus in the Supply Chain

## 1.1. Supply Chain and Sustainability

Sustainability is defined as the ability to meet today's needs without sacrificing our ability to meet tomorrow's needs (Hart and Milstein, 2003). It has become the latest challenge faced by operations and Supply Chain management. As stated by Neto (2006), for reactive companies the main drivers into a more sustainable existence are legislation and negative consumer response. The push to sustainability comes partly from the fact that while the last two decades have resulted in significant economic value creation, the consumption of resources by a growing population coupled with ever-shrinking product life cycles has left doubt as to how long such a system might continue unchecked. These concerns have led to increased pressure placed on firms via increasing environmental legislation and attention from consumers to environmental impacts. Consumers have also become more aware and educated about environmental issues: firstly because of the increasing exposure of environment related topics, such as acid rain, greenhouse effect and desertification; secondly because of the appearance of eco-certificates, which help the consumers to identify eco-friendly products. As an example, more and more people are beginning to be sensitive to topics like the "food miles", questioning why they should buy products which travelled thousands of kilometers before arriving in their houses or which are uselessly accompanied by oversized and often unrecyclable packaging.

Alongside external motivators, firms have realized that short term profitability is merely one factor in long term economic viability, and success in the long run requires the incorporation of *people* and the *planet* alongside *profit* in decision making, the so-called 3 P's of the triple bottom line.

The combination of all the mentioned effects – mainly a marketing-led approach based on consumers' 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. 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).

A number of companies already proactively moved in favor of a more sustainable development. Among those, some also perceived the economical potential of environmental friendly logistic networks. IBM, for instance, has developed programs to receive end-of-use products, promote second hand items internet auctions and dismantle equipment as a source of spare parts (Fleischmann *et al.*, 2003). HP has programs in place to upgrade obsolete machines, to recover end-of-life products, and to help the donation of used equipment to charity institutions. BMW remanufactures and resells components, such as engines and water pump engines (Ayres *et al.*, 1997). Yet, although these initiatives proved to be profitable and environmental friendly, they are still exceptions. Substantial improvement in the industrial environmental behavior seems to be often only possible with substantial investments bringing none or negative financial returns (Walley and Whitehead, 1994). The goal of improvements in economic activities, including logistic networks, is now smartly compromising costs with negative environmental impacts.

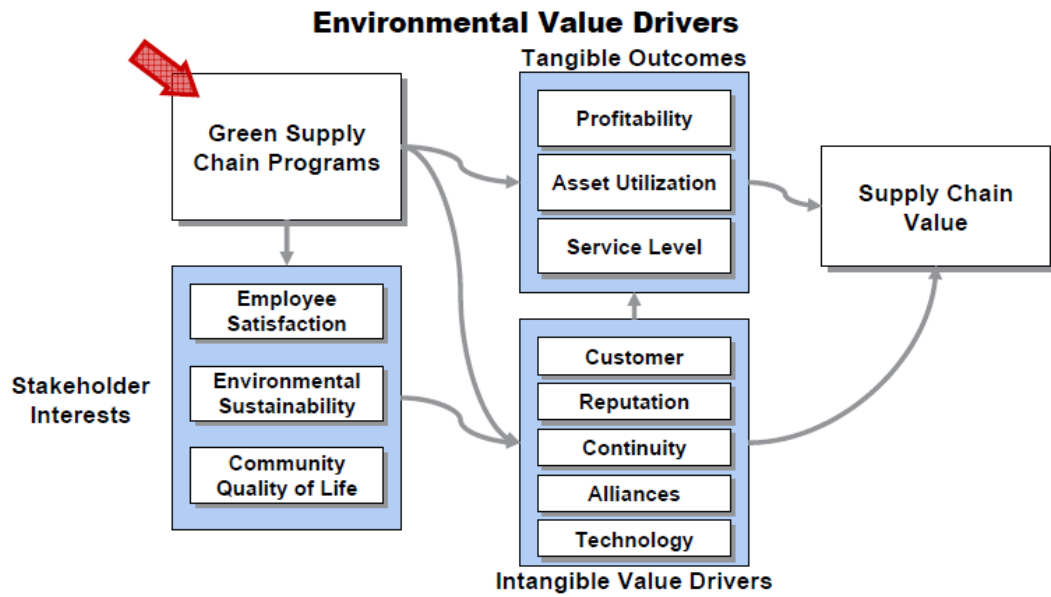


Figure 1.1. Green SCM leverages the role of the environment in SC value creation  
(source: LMI, 2005)

## 1.2. *Green Supply Chain Management*

Consciousness of the environment has been strongly increasing in the last few decades. More people are aware of the world's environmental problems such as global warming, toxic substance usage, and decreasing in non-replenish resources. Governments have released campaigns to promote this problem, a number of organizations responded to this by applying green principles to their companies, such as using environmental friendly raw materials, reducing the usage of petroleum power, using recycle papers for packaging. The green principles have been expanded to different departments within organizations, including Supply Chain. Green Supply Chain Management (GSCM) has been emerging in the last few years. This idea covers every stage in manufacturing from the first to the last stage of the life cycle, and can be also applied to a number of different fields: not only manufacturing, but a variety of business sectors such as government, education and services (Khiewnavawongsa and Schmidt, 2009).

One definition of Green Supply Chain Management (GSCM) comes from Srivastara (2007). His study collects and classifies previous literature on Green Supply Chain Management: he defines GSCM as integrating environment thinking into Supply Chain management, including product design, material sourcing and selection, manufacturing

processes, delivery of the final product to the consumers, and end-of-life management of the product after its useful life. According to this definition, GSCM relates to a wide range of production from product design, to transport, to recycle or destroy, or from cradle to grave. The product life cycle provides a degree of structure to the life of products and thereby provides direction for the diverse functional efforts required to produce and deliver product/service offerings (Birou *et al.*, 1998). Many studies address product life cycle along with Supply Chain or GSCM. Stonebraker and Liao (2006) discuss that the stage of life cycle variables is associated with the various dimensions of Supply Chain integration.

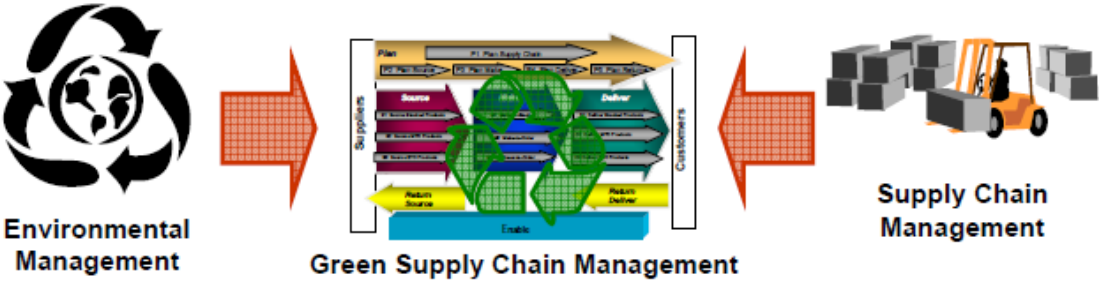


Figure 1.2. Green Supply Chain integrates Supply Chain management with environmental consciousness  
(source: LMI, 2005)

According to Boks and Stevels (2007), the denomination “green” can be categorized into three types depending on the different perceptions of the environment among different stakeholders involved: scientific green, government green, and customer green. In scientific green, life cycle assessment (LCA) can be used to determine the environmental impact of products, processes, and systems. However, this perspective only considers emissions, not any other aspect. In government green, several factors are involved such as population density, geographical position, and the availability of energy sources. These factors affect the government agenda to maintain or improve the quality of life. For customer green, the perceptions of green are strongly linked to

emotions that have a direct impact on people, especially health and safety, more than resources or emissions.

Greening the Supply Chain, therefore, means much more than just reducing resources usage and pollution. At the same time, the benefits are not limited only to less toxic consuming or less waste. The GSCM principle can be applied to all departments in the organization: its effects expand to a variety of areas, both tangibly and intangibly.

Among the studies mentioning the benefits of adopting GSCM, Stevels (2002) demonstrates the benefits of GSCM to different roles of Supply Chain including environment and society in terms of different categories: material, immaterial, and emotion. Regarding material, GSCM helps lower environmental load, generates lower cost prices for supplier, lower cost for producer, lower cost of ownership for customer, and less consumption of resources for society. In terms of immaterial, GSCM helps overcoming prejudices and cynicism for environment, brings less rejections for suppliers, easier manufacturing for producers, convenience for customers, and better compliance for society. Regarding emotion, GSCM helps motivation of stakeholders for the environment, promotes a better image for supplier and producer, improves quality of life for customer. Duber-Smith (2005) identifies ten reasons for which the company should go green: target marketing, sustainability of resources, lowered costs/increased efficiency, product differentiation and competitive advantage, competitive Supply Chain pressures, adaptation to regulation and risk reduction, brand reputation, return on investment, increased employee morale, ethical imperative.

The drivers that make the company adopt a green perspective are of different nature and come from the following main actors: governments, market, competitors and customers. Governments boost the environmental consciousness of the company through regulations and laws which reward “green behavior”, such as reduced emissions and scraps, limited noise impact, efficient distribution. The incentives by market and competitors come from the fact that in today’s business world the competitiveness among company is pushed to the extreme. From one side, to impress and attract customers the company needs to clearly stand out from others: being environmental friendly is one way to differentiate from the competitors. From the other side, in case competitors already adopted GSCM, the company finds itself under pressure. Therefore, implementing GSCM appears to be convenient no matter whether the competitors have already adopted it or not.

Not only competitors, but also customers affect to the company’s decision to adopt GSCM. In many cases, customers are the ones who require special treatments or special products and the company needs to make specific changes in order to satisfy them. Some papers investigate the relationship between GSCM application and customers’ requirements: Simpson *et al.* (2007) explore the moderating impact of the relationship between a customer and its suppliers and the effectiveness of customer’s environmental performance requirements.

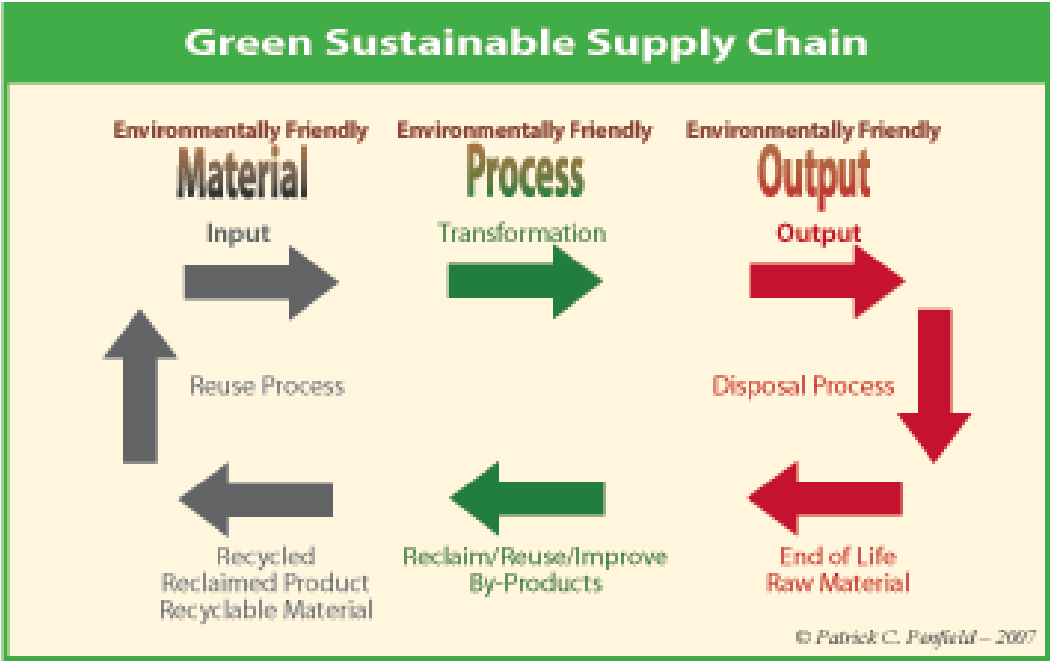


Figure 1.3. Green Sustainable Supply Chain concept (source: Penfield, 2007)

A number of forward thinking companies are using the environmental issues to their advantage (Penfield, 2007). They are innovating and coming up with cutting edge solutions that help them become more profitable while helping the environment, such as reducing wastes, re-designing products packaging or avoiding unnecessary trips while distributing. If addressed properly, asserts Penfield (2007), sustainability can be a tremendous weapon for companies to reduce costs: developing a sustainable Supply Chain can mean money that can be saved by not having to dispose harmful products,

reducing obsolescence, decreasing the amount of money spent on scrap and the resources spent on adhering to regulatory issues.

Yet, despite the potential for significant financial gains, most Supply Chain managers still do not focus on environmental concerns (EPA, 2000). One reason for this is that cost accounting systems typically hide the frequency and magnitude of the “environmental costs” that companies incur. While raw material and labor costs are directly allocated to the appropriate product or process, other costs are accumulated into overhead accounts, which are allocated proportionally (i.e. based on the number of units manufactured) to all products, processes, or facilities. This allocation method might be appropriate for many overhead costs, such as rent and upper management salaries. However, this approach can lead to inaccurate costing and ineffective decisions when significant costs, such as waste disposal, training expenses, environmental permitting fees, and other environmental costs are not allocated to the responsible products and processes. For these reasons, Supply Chain managers often cannot achieve their overall objectives unless they tackle important environmental concerns.

Many companies have addressed this issue by looking for environmental accounting techniques to substantially reduce Supply Chain costs. With these costing methods, companies try to systematically identify environmental costs throughout the Supply Chain, while these costs typically are not captured through conventional accounting methods. Once the costs (or potential benefits) are identified, companies can analyze the cost drivers and evaluate alternative cost reduction opportunities.

### ***1.3. Environmental Consciousness in Transport***

Freight and passenger transport is developing almost in parallel to economic growth. This is not surprising, since economic development is the driver behind many factors in society which also have an impact on transport. Increasing personal income results in increased possibilities for optimizing residential location, for purchasing transport and for carrying out longer and more frequent trips. The economy of society is greatly influenced by production and trade which, again, require transport. The overall consequence of global trade patterns on transport is seen in the close relationship between GDP and freight transport growth. Indeed, the last decades of unprecedented

growth of world trade, and in particular the post-1990 acceleration, have seen a growing share of long distance trade: more goods were and are still transported over long distances than before. As a result, the freight transport volume, as shown in Figure 1.4, grew in recent years faster than GDP.

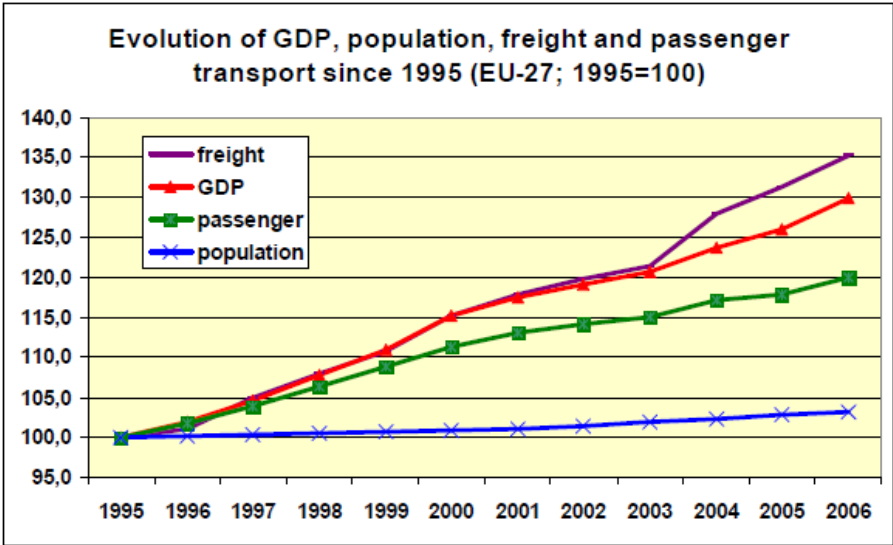


Figure 1.4. Evolution of transport demand and GDP in Europe (1995 = 100)  
(source: TRANSvisions, 2009)

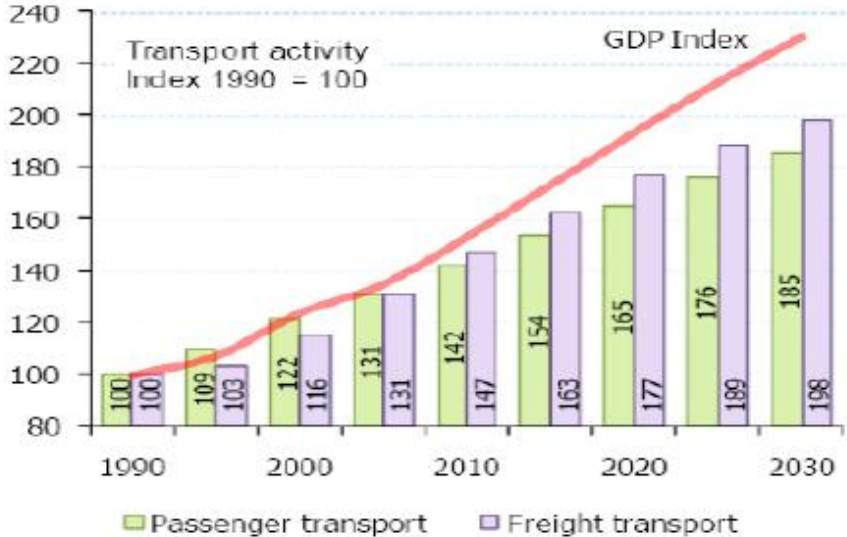


Figure 1.5. Transport activity growth in EU, 1990-2030  
(source: European Commission, 2008)

Road is often the preferred transport mode, as it gives the most immediate and short-term benefits, even though rising road traffic volumes means more congestion, more pollution and in the end, higher costs. Achieving sustainability in the transport sector is one of the most critical aims of a long series of social and economical politics: environmental issues are having an increasing impact on transportation. This is due both to increasingly tight regulations on emissions and to the recognition of the impacts of population increase and modern life on the environment, landscape, biodiversity, and mankind's own life. In order to maintain the mobility, which is one of the basic necessities in the modern society, it is important to ensure that mobility itself is sustainable and that it does not inflict irreparable damages to the environment. At the same time, it is important to take into consideration transportation related aspects like accidents, safety, noise infliction, emissions, in order to minimize their negative effects (TRANSvisions, 2009).

As transport is valued to be one of the most polluting activities in the industrial system, 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.

“Greening transport” politics are meant to steer transport towards an enhanced sustainability by adopting optimized transport strategies and by ensuring that transport prices reflect the real cost to society. In this way environmental and social damage costs can gradually be reduced in a way that boosts the efficiency of transport itself and ultimately the economy as a whole. This can be achieved by addressing issues such as pollution and climate change, and by making sure that the environmental damage is charged to the polluter, instead of to the general taxpayer. As Button and Hensher (2000) state, transport efficiency can be improved significantly – and costs can be reduced – by internal institutional reform. If charged for the environmental damages produced, for example, transportation providers and users would look for more efficient modes and networks to be used. A more efficient and sustainable transport system could

thus be obtained, this resulting in the long run in a more user-friendly and cheaper transport system.

The adoption of environmentally friendly logistic networks has already proved to bring several benefits to companies. The association of greenness from a certain service or product, for instance, is a positive differential among environmentally conscious consumers. Green certifications, such as the ones promoted by the European Union, are initiatives which add value for green behaviors. In industrialized countries, consumers may also boycott products and services they consider harmful to the planet. MPG, a British product development consultancy, surveyed in 1989 American customers and found that more than half of them refused buying products that may harm the environment (Cairncross, 1992). Products derived from the unsustainable use of tropical forests, for instance, suffer rejection by consumers in industrialized nations (Schimidheiny, 1998). At a sector level, environmental friendly logistic networks may avoid costly mandatory adjustments. This comes from the fact that governments are more keen to approve legal restrictions to logistic networks (recycling quotas, for instance) in sectors that are not proactively working in reducing their environmental impacts. Furthermore, companies may have to preserve the environment for the simple reason that their existence is intrinsically related to a sustainable exploration of certain natural resources. The pulp and paper industry, for instance, will exist in the future due to a rational exploration of its forests.

The full exploration of more environmentally friendly solutions in logistic networks is, however, bounded in many cases by the increase in costs. In closed-loop Supply Chains, for instance, the process of recycling and shredding is nowadays preferred to cleaner solutions, such as complete or partial (spare parts) re-using, because for most cases disassembly costs overcome the prices of new raw material. Whenever the producers are not responsible for their end-of-use products, and recovery value is low, land filling will most probably be the final destination of such products. Companies and government should be aware of the trade-offs between business and economy and the environment. It is essential, therefore, to search for solutions that smartly compromise these two dimensions.

#### **1.4.            *Calculating Transport Environmental Costs***

As stated previously, calculating the effective transport cost value is becoming more and more important thanks to the growing environmental awareness of consumers and the increased attention paid by Supply Chain management towards those themes. Nevertheless, as stated by Quinet (2004), “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”: this complexity has generated a series of widely dispersed analyses in literature and legislation. Most of the contributions that can be found on this theme tend to define transport cost categories without yet giving any numerical estimates of the cost. Where estimates are given, they are often calculated by using online software tools which do not give details on how the costs are obtained, or which calculate transport impacts such as emission rates or other pollution indicators without yet defining the cost generated by these impacts.

A complete definition of transportation costs represents an essential tool for companies aiming at optimising their transportation practices and distribution networks and channels. In the existing collection and distribution networks estimating the overall transportation cost can convey relevant strategic decisions in terms of 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 can be competitive even for reduced distances. Beuthe *et al.* (2002) suggest that an adequate pricing policy needs to include all the external effects of each mode, thus promoting the use of transportation modes with lesser negative effects (i.e. rail and waterway) and their intermodal combination with road.

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 as Eastern Europe. This might 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 (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. Today's real challenge becomes, then, achieving sustainability together with competitiveness. Sustainable operations potentiating long run profitability necessitate the incorporation of the planet (environment) and people (stakeholders) alongside traditional performance measures of cost and profit used in decision making. Since these competing objectives do not always result in a win-win situation but rather often trade-off against each other, decision makers must be given tools which enable them to mindfully deliberate the consequences of alternatives. Aggregating the benefits of both a better environmental behavior 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. Nevertheless, Neto *et al.* (2006) observe that literature in logistic network design is mostly divided in two approaches: minimizing costs or maximizing profits and minimizing environmental impacts. There is little done integrating these two formulations (Bloemhof-Ruwaard *et al.*, 2004). The drawback of such perspectives is straightforward: it is not possible to look for solutions compromising both objectives.

Neto *et al.* (2006) propose the optimization of both objectives simultaneously, in order to make it possible for the decision maker, in logistic networks with centralized decision makers, to evaluate his choice and select, out of a number of solutions provided by the given model, the one that best compromises his objectives in terms of the environment and cost. The authors also define upper bounds for networks with multiple agents. The usefulness of such bounds is threefold: first of all, it allows evaluation of the current situation in terms of the system's efficiency relative to environmental impact and costs. Secondly, trade-offs between the resulting environmental impact and costs in a logistic network can be determined. This allows an easy visualization and straightforward interpretation between the trade-offs. Finally, it allows an evaluation of the necessity of legislation and, if so, to assess the efficiency of different types. The idea of exploring the best alternatives is based on Pareto Optimality. The Pareto optimal frontier is composed by the set of the images of all efficient solutions of the network in relation to two objectives: optimization of both economical and environmental goals.

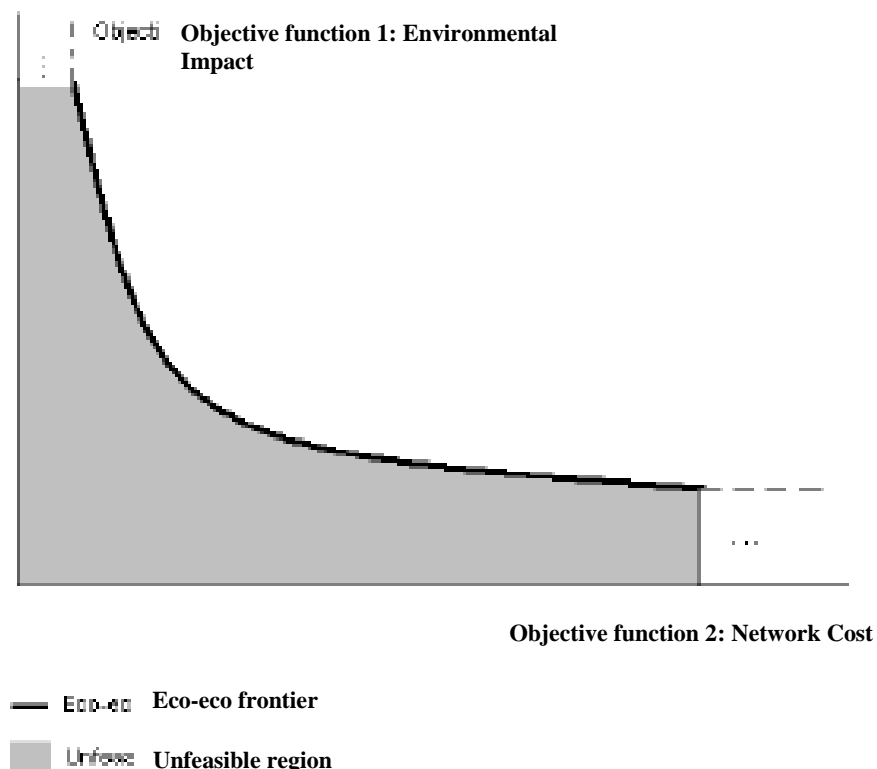


Figure 1.6. Pareto Optimal Frontier

(source: Neto *et al.*, 2006)



## **2. Transport: Internal and External Costs**

### ***2.1. Introduction***

The collection, distribution, transshipment, handling of goods moved within a transport network are considered as the internal costs of the network itself (Janic, 2007): they are connected with the physical moving of units between shippers and receivers. External costs, instead, are burdens that the distribution network imposes on society: they are often indirectly linked to the transportation activity and 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.

As most of the external costs are intangible or difficult to measure, the perception that transport providers and consumers often have is that they are irrelevant or negligible. On the contrary, these costs often have a significant impact and ignoring them would lead to an important underestimation of the total travel cost. Decision-making can be biased by a tendency to focus on easy-to-measure impacts: for this reason, it is often helpful to monetize (measure in currency values) non-market impacts so they can be incorporated into economic analysis. Impacts that are not monetized (those called intangibles), in fact, tend to be overlooked and undervalued. Monetizing nonmarket goods and aspects such as external costs is increasingly common for planning and policy analysis, allowing more consistent and equitable decision-making.

Figure 2.1 illustrates the costs for an average car ranked by magnitude, with internal and external components combined. This shows that the largest categories of costs tend to be internal, including vehicle ownership, travel time, vehicle operation and crash risk borne directly by individual motorists. External costs tend to be smaller, and so are easy to overlook, but numerous, so their aggregate value tends to be significant.

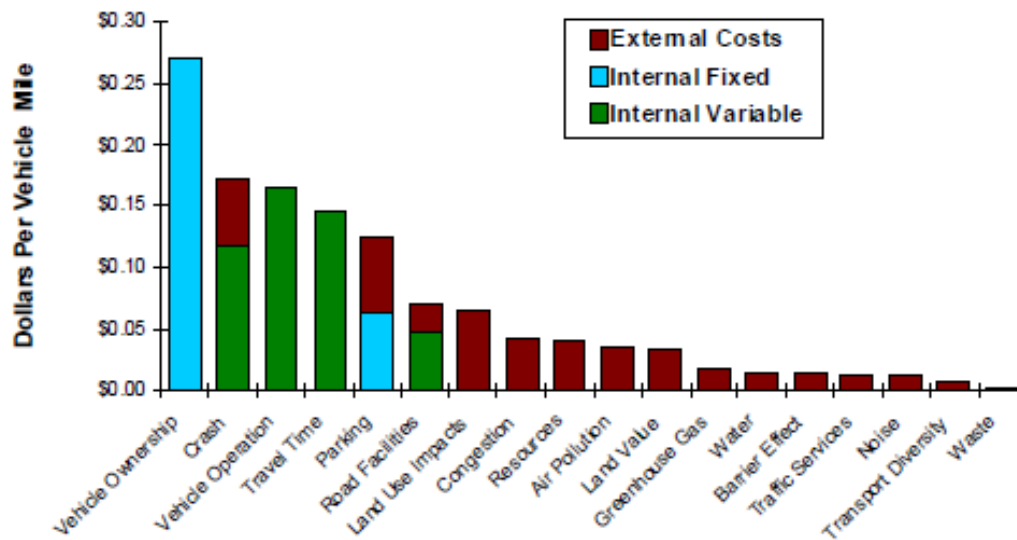


Figure 2.1. Average car costs per vehicle mile, ranked by magnitude  
(source: Litman, 2009)

Figure 2.2 shows the distribution of costs aggregated. About a third of total costs are external and about a quarter are internal-fixed, leaving less than half internal-variable. This indicates that a significant underpricing is there: prices, which do not take into account external costs, are significantly below total costs.

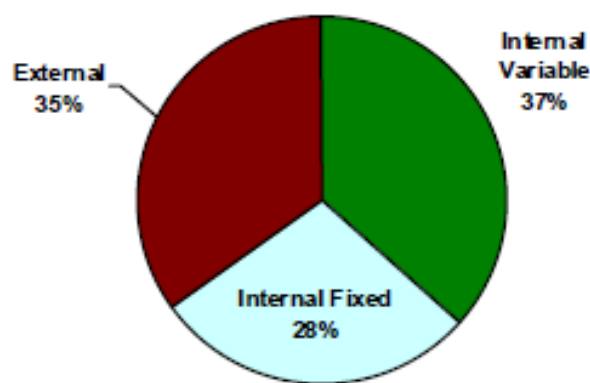


Figure 2.2. Average car costs per vehicle mile, ranked by magnitude  
(source: Litman, 2009)

Finally, Figure 2.3 compares costs per passenger-mile for various modes. Both the magnitude and the distribution of costs vary significantly between modes. Transit costs are based on average U.S. ridership levels and would be lower in areas with higher ridership rates.

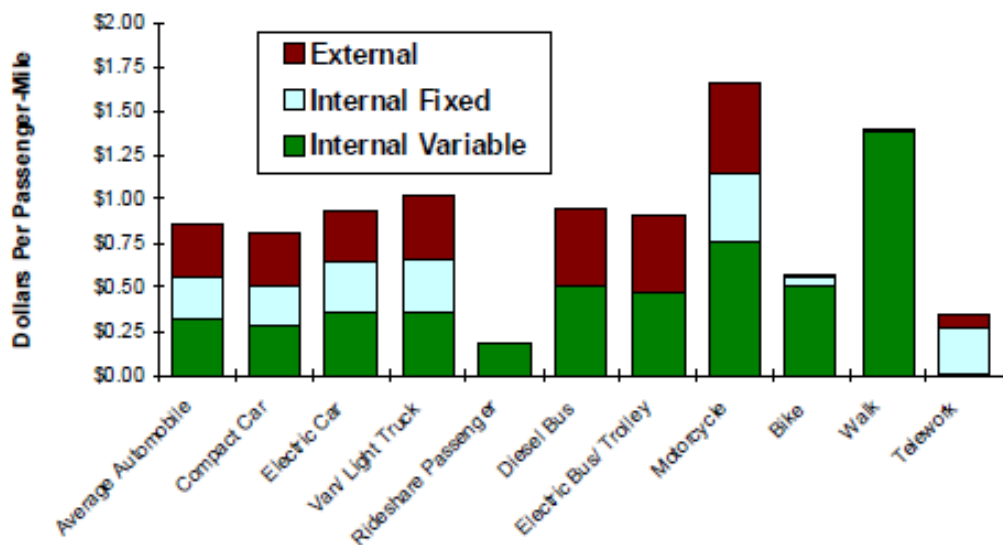


Figure 2.3. Costs distribution by mode  
(source: Litman, 2009)

The literature analysis indicates that transportation costs are for a significant portion external (not borne by a good's consumer but by others) and non-market (they involve goods that are not regularly traded in markets such as clean air, crash risk, and quiet). On average, Litman (2009) estimates, each dollar spent on vehicle operating expenses imposes about \$2.55 in total costs to society. Such costs tend to be undervalued in transportation planning, even though they are significant in magnitude if compared with impacts normally considered. Failure to consider external costs can lead to decisions that result in negative net benefits. For example, society is overall worse off if a roadway expansion saves motorists 5¢ per mile in average travel time costs but imposes 10¢ per mile on average in additional economic and environmental costs.

Again quoting Litman, more research is needed to better estimate transportation costs under various conditions and locations. Transport equity and diversity appear to be

significant values which deserve more research. Decision-makers need better information on consumer demands, such as the value people place on improved travel convenience and comfort. Research is also needed to evaluate the synergistic effects of combined planning decisions.

The research and analysis here will be focused on the costs for road and rail transport, as they are the most widespread modes used for distribution at European level. Nevertheless, an introduction on sea shipment internal costs will also be given.

## **2.2. *Internal Costs Definition***

Internal transport costs are mainly given by vehicle costs, which include direct user expenses to own and use private vehicles. Vehicle costs can be fixed, if they do not increase with vehicle mileage, or variable, if their amount increases with the increase of travelled distance. Nevertheless, some costs usually characterized as fixed are actually partly variable: they decrease to some degree with vehicle use, and decline when travel is reduced.

Fixed costs include:

- Vehicle purchase or lease,
- Insurance,
- Registration and vehicle taxes.

Variable costs include:

- Fuel and fuel taxes,
- Oil and tyres,
- Maintenance and repair,
- Paid parking and tolls,
- Driver wage.

These costs are usually well defined but can vary largely, considering the space and time horizons of the analysis: this is quite straightforward for costs like vehicle purchase or lease costs (which are bounded to variables such as age and level of use of the

vehicle), insurance, registration and vehicle taxes, and it is valid also for variable cost categories.

Figure 2.4 illustrates the differences in vehicle costs for various transport modes. Some modes (such as automobile) have relatively high fixed costs and relatively low variable costs, at least as they are normally perceived, while other modes such as taxi and car sharing have minimal fixed costs but higher variable costs.

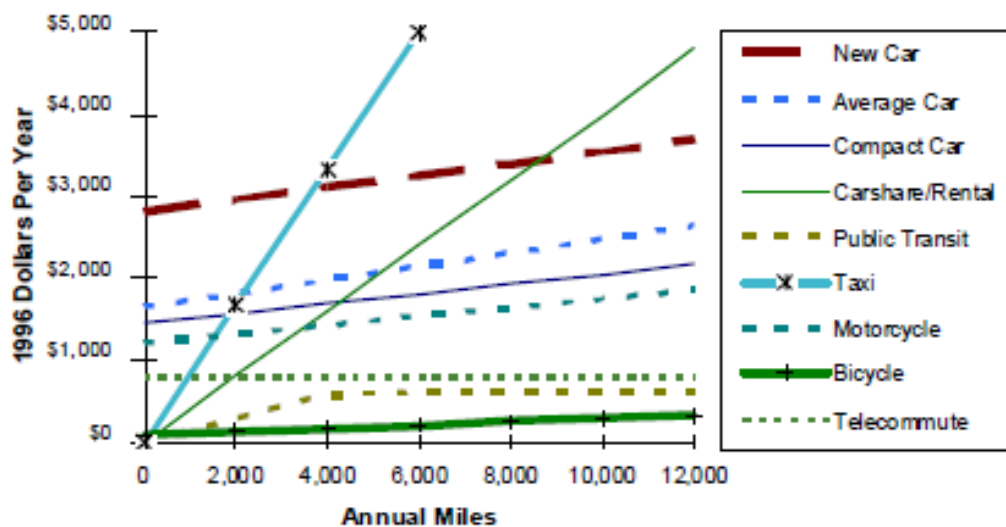


Figure 2.4. User expenses for various modes  
(source: Litman, 2009)

A study conducted by the Italian Ministry of Transport found that the mean purchase cost in 2008 for a commercial truck in Italy amounts to 129,895 € for tractor (without considering the tyres) plus 35,105 € for semitrailer, this resulting in a total sum of 165,000 €.

Insurance costs depend strongly on the geographical area of interest: Italian estimates in 2008 give a mean yearly value of 5,865 € (considering only the fixed insurance cost) but the variance among different regions or macro areas is substantial.

Fuel costs can vary significantly over time, due to economical and political reasons, while costs due to oil and tyres are mainly function of the kilometers traveled. In 2007, Italian prices for diesel showed a mean value of 1.162 €/liter, with a maximum value of

1.286 and a minimum value of 1.083 €/liter (source: Italian Ministry of Production Activities, 2007).

Oil and tyres consumption depends mainly on the traveled distance: a truck covering a mean distance of 150,000 kilometers per year uses up to two sets of tyres every year.

Costs for maintenance and repair take into account both ordinary maintenance and extraordinary repairing that are needed throughout the vehicle life cycle: for a standard life cycle (600,000 kilometers traveled) the total time spent for ordinary maintenance is estimated in 75.75 working hours, while the total time for extraordinary maintenance amounts to 288 working hours (Italian Ministry of Transport, 2008).

Paid parking and tolls can be highly variable: an analysis on the costs held by Italian logistics companies in 2005 shows that the roadway costs per kilometre can have variations up to 30% and even more from road to road.

Finally, driver wages are usually given by three contributions: base salary, extraordinary salary and transfers. Nevertheless, these costs vary strongly from state to state: if considering Europe, Eastern European countries like Poland or Slovenia pay up to 60% lower hourly wages than countries like Italy or France.

Litman (2009) confirms that transit cost and subsidy data should be used with caution since there is great variation between countries, transit systems and specific routes. For example, it can be difficult to allocate cost responsibility between peak and off-peak transit use. Peak trips tend to set capacity requirements and so incur high capital costs, particularly for rail transit, but have higher load factors and therefore fare revenues. As a result, urban-peak transit runs often recover their full operating costs and sometimes their full capital costs (a transit company that only provides such service could be profitable). Such runs can be considered to subsidize off-peak and rural transit operating costs, or at least require less subsidy per passenger/mile.

### **2.3. *External Costs Definition***

As said previously, the collection, distribution, transshipment, handling of goods moved within a transport network are considered as the internal costs of the network (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 (2007), because of a lack of full property right 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. An external cost arises when the social or economic activities of one group of people have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group (ExternE, European Commission, 2005).

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.

In this analysis different types of external costs will be considered: all of the current estimates of these costs are taken from current literature papers, clearly each one of them uses a specific research method in order to derive its values.

External costs are costs which - without policy intervention - are not taken into account by the transport users. Transport users are thus faced with incorrect incentives for transport supply and demand, leading to welfare losses. From a society's perspective, all costs and benefits must be considered in each decision, but the perspective of individual decision makers is often more limited. People tend to have different, often conflicting perspectives of transport costs and benefits, depending on their role. These differing perspectives and definitions create conflicts over goals, objectives and strategies, and can result in economically inefficient decisions.

Another way to view the conflicts in transportation decision making is to consider the perceived relationships between average costs and quantity of driving from three perspectives: *users* (who decide how much to travel), *transportation professionals* (who plan transport facilities) and *society* (which bears environmental and social costs and provides facility funding). These relationships are illustrated in Figure 2.5. Since most motor vehicle costs are fixed, marginal costs decline with increased annual mileage, giving to vehicle owners an incentive to maximize driving. Facility development has a downward sloping cost curve (due to economies of scale) when traffic is low, since increased driving allows costs to be divided among more miles of use, but once the system is congested average costs increase.

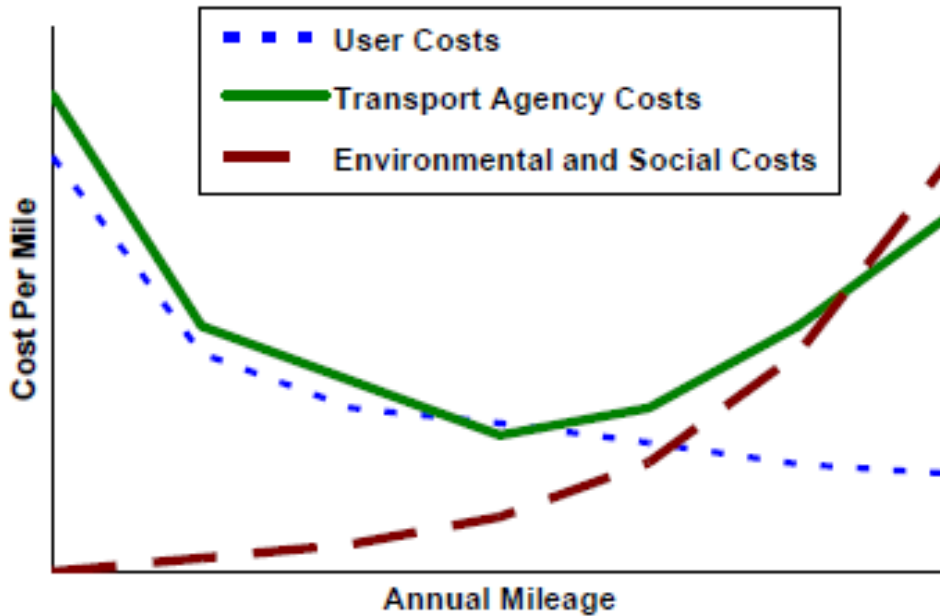


Figure 2.5. Motor vehicle use conflicting cost curves  
 (source: Litman, 2009)

Individuals face incentives to maximize driving, “to get their money’s worth” from large fixed vehicle costs. The transport agency’s U-shaped average cost curve implies economies of scale when roadway development is a goal. Only after congestion becomes a problem do transport agencies perceive benefits from reducing traffic demand, and even then they frequently experience incentives to encourage driving, such as fuel taxes dedicated to road building. The upward sloping cost curves associated with other social and environmental costs mean that society benefits from reduced driving. As a result of these different price signals the perspectives of individual drivers and automobile oriented transport planners conflict with society in general, and these conflicts are the main causes of the generation of high external costs.

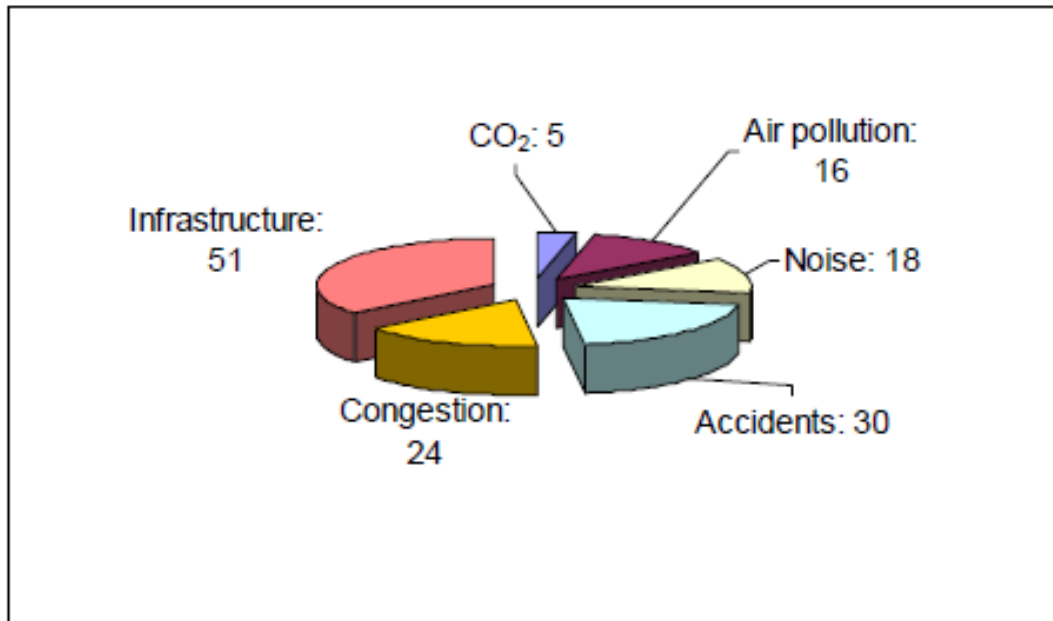


Figure 2.6. Share of different cost categories in total external costs of European heavy goods vehicles transport [billion Euros]  
(source: Den Boer *et al.*, 2009)

In this analysis different types of external costs are considered: as stated previously, all of the current estimates of these costs were taken from current literature papers, where an extensive variety of different research methods is used. Nevertheless, all papers consider as “external” costs the users are not insured against: as said, all of the given costs are not reflected in prices; otherwise they would be in the market and not external to it.

### **2.3.1. Atmospheric Pollution**

#### **2.3.1.1. Emissions**

The most common external 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<sub>x</sub>) and volatile organic

compounds (VOCs) emitted by vehicles in the environment. Table 2.1 summarizes various types of motor vehicle pollution emissions and their impacts.

Emission	Description	Sources	Harmful Effects	Scale
Carbon dioxide (CO <sub>2</sub> )	A product of combustion.	Fuel production and tailpipes.	Climate change	Global
Carbon monoxide (CO)	A toxic gas caused by incomplete combustion.	Tailpipes	Human health, climate change	Very local
CFCs and HCFC	A class of durable chemicals.	Air conditioners and industrial activities.	Ozone depletion, climate change	Global
Fine particulates (PM <sub>10</sub> ; PM <sub>2.5</sub> )	Inhaleable particles.	Tailpipes, brake lining, road dust, etc.	Human health, aesthetics.	Local and Regional
Road dust (non-tailpipe particulates)	Dust particles created by vehicle movement.	Vehicle use, brake linings, tire wear.	Human health, aesthetics.	Local
Lead	Element used in older fuel additives.	Fuel additives and batteries.	Human health, ecological damages	Local
Methane (CH <sub>4</sub> )	A flammable gas.	Fuel production and tailpipes.	Climate change	Global
Nitrogen oxides (NO <sub>x</sub> ) and nitrous oxide (N <sub>2</sub> O).	Various compounds, some are toxic, all contribute to ozone.	Tailpipes.	Human health, ozone precursor, ecological damage.	Local and Regional
Ozone (O <sub>3</sub> )	Major urban air pollutant caused by NO <sub>x</sub> and VOCs combined in sunlight.	NO <sub>x</sub> and VOC	Human health, plants, aesthetics.	Regional
Sulfur oxides (SO <sub>x</sub> )	Lung irritant and acid rain.	Diesel vehicle tailpipes.	Human health and ecological damage	Local and Regional
VOC (volatile organic hydrocarbons)	Various hydrocarbon (HC) gasses.	Fuel production, storage & tailpipes.	Human health, ozone precursor.	Local and Regional
Toxics (e.g. benzene)	Toxic and carcinogenic VOCs.	Fuel production and tailpipes.	Human health risks	Very local

Table 2.1. Vehicle pollution emissions  
(source: Litman, 2009)

The impacts of air pollution are constantly under control, mainly because many of its effects are still not well known. 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. Although mobile emission reduction efforts have already been done and have successfully reduced many pollutants' emissions rates, more needs to be done: the impacts of some emissions, such as air toxics, have only recently been recognized and so have minimal control strategies.

Moreover, motor vehicle emissions are considered more difficult to control than other emission sources, because they are numerous and dispersed and have relatively high damage costs due to the fact that motor vehicles operate close to people.

As pointed out by Litman (2009), effects of pollutants on human health are both quantifiable and unquantifiable ones. For example, quantifiable effects of particulates and sulphates are chronic and acute bronchitis, hospital admissions, lower and upper respiratory illness, chest illness, respiratory symptoms, days of work loss, moderate or worse asthma status. However, other consequences such as changes in pulmonary function and lung inflammation cannot be immediately quantified or easily connected to the cause. Similarly, carbon monoxide generates mortality, hospital admissions, congestive heart failure, decreased time to onset of angina, but also behavioral effects (extremely difficult to quantify) and other possible effects, such as cardiovascular and developmental consequences.

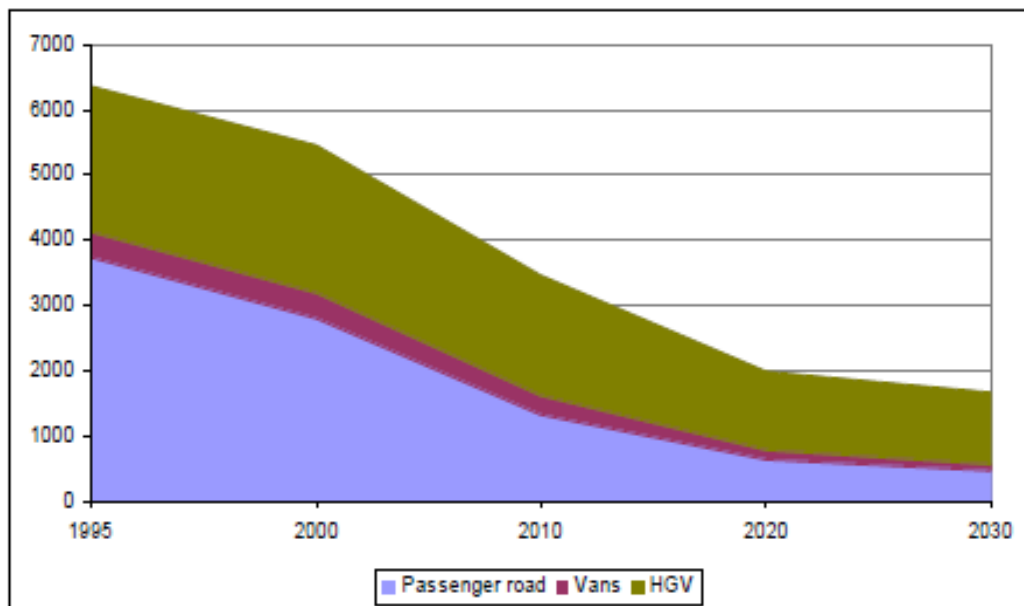


Figure 2.7. NO<sub>x</sub> emissions of HGV, vans and total road transport in the European Union [ktonne]

(source: Den Boer *et al.*, 2009)

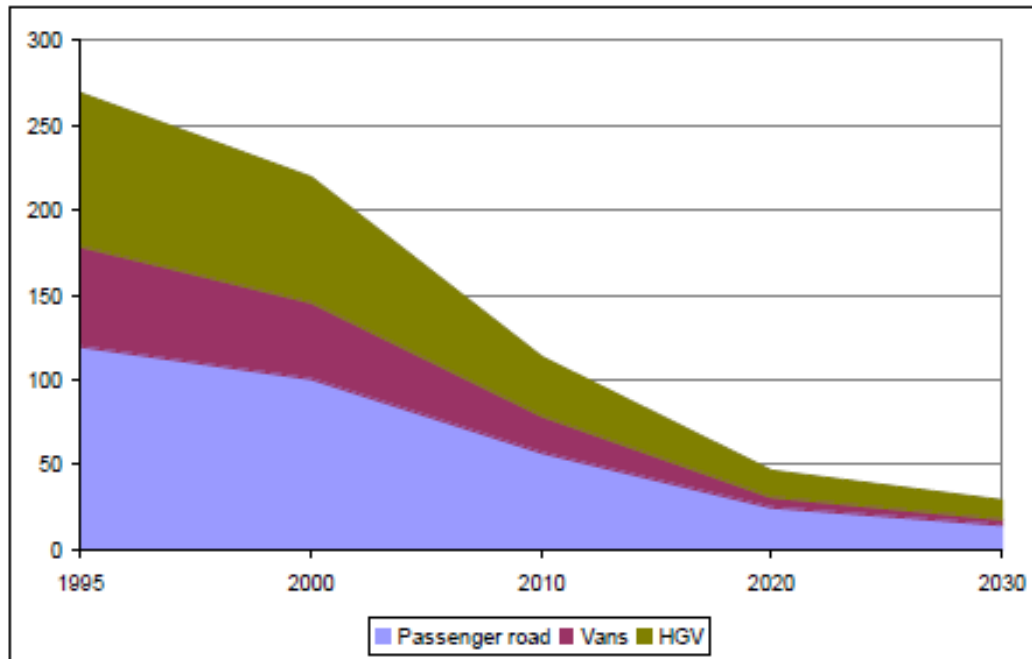


Figure 2.8. PM exhaust emissions of HGV, vans and total road transport in the European Union [ktonne]  
(source: Den Boer *et al.*, 2009)

### 2.3.1.2. *Climate Change*

Climate change is another main consequence of atmospheric air pollution: it refers to climatic changes caused by gases (*greenhouse gases* or *GHGs*) that increase atmospheric solar heat gain. Climate change impacts due to transport sector are mainly related to the global warming caused by carbon dioxide (CO<sub>2</sub>) emissions: the amount of CO<sub>2</sub> released per unit of transportation service is directly related to the energy efficiency of the mode providing that service. Major scientific organizations consider human caused global warming a significant cost (in terms of actual damages) and risk (in terms of future damages). 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.

Nevertheless, putting a value on GHG emissions is difficult due to uncertainty and differences in values concerning ecological damages and impacts on future generations. In addition, climate change impacts are not necessarily linear, many scientists believe that there may be thresholds or tipping points beyond which warming and damage costs could become catastrophic.

Figure 2.9 shows historical and projected values of CO<sub>2</sub> emissions of heavy goods vehicles (HGV), vans and total road transport in the European Union over the years (in Mtonne). It has to be noted that the emission estimates for future years are based on the assumption that European emission legislation will be fully effective. Figure 2.10 shows the share of these vehicle categories in total CO<sub>2</sub> emissions (Den Boer *et al.*, 2009).

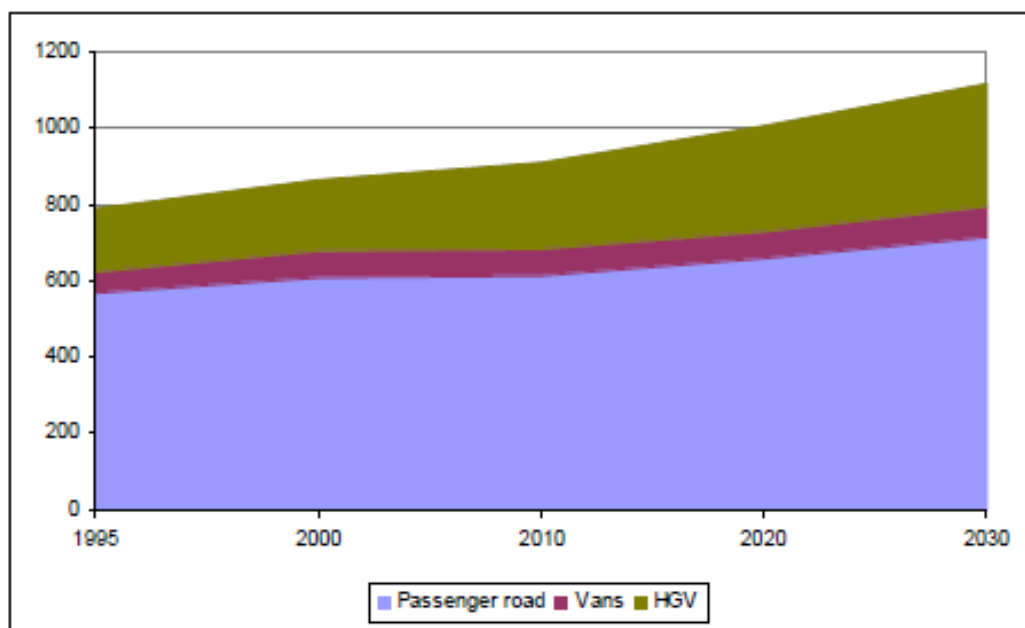


Figure 2.9. CO<sub>2</sub> emissions of HGV, vans and total road transport in the European Union (source: Den Boer *et al.*, 2009)

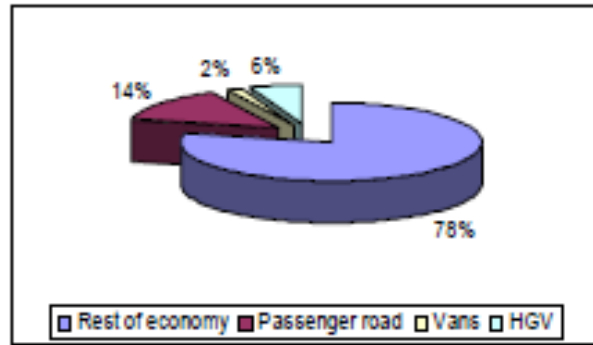


Figure 2.10. Share of different vehicle categories in total CO<sub>2</sub> emissions  
(source: Den Boer *et al.*, 2009)

CO<sub>2</sub> emissions from the transport sector attract the attention of both transport and climate change policymakers because of their share of overall emissions and their persistently strong growth. Over the past decades, carbon dioxide emissions from transport have risen faster than those from all other sectors and are projected to rise more rapidly in the future in case no proper action is taken. From 1990 to 2004, the carbon dioxide emissions from the world's transport sector have risen by 36.5%. For the same period, road transport emissions have risen by 29% in industrialized countries and 61% in the other countries, mainly developing countries or countries in transition (IEA, 2006). Figure 2.11 shows the projected increase in transportation CO<sub>2</sub> emissions by world region for 2050. At present industrialized countries are the main sources of transport emissions. However, the proportion of emissions being produced in developing countries is increasing rapidly, particularly in countries such as China and India. World CO<sub>2</sub> emissions from transport sector are projected to increase by 140% from 2000 to 2050 in case no legislative actions will be promoted, with the biggest increase in developing countries.

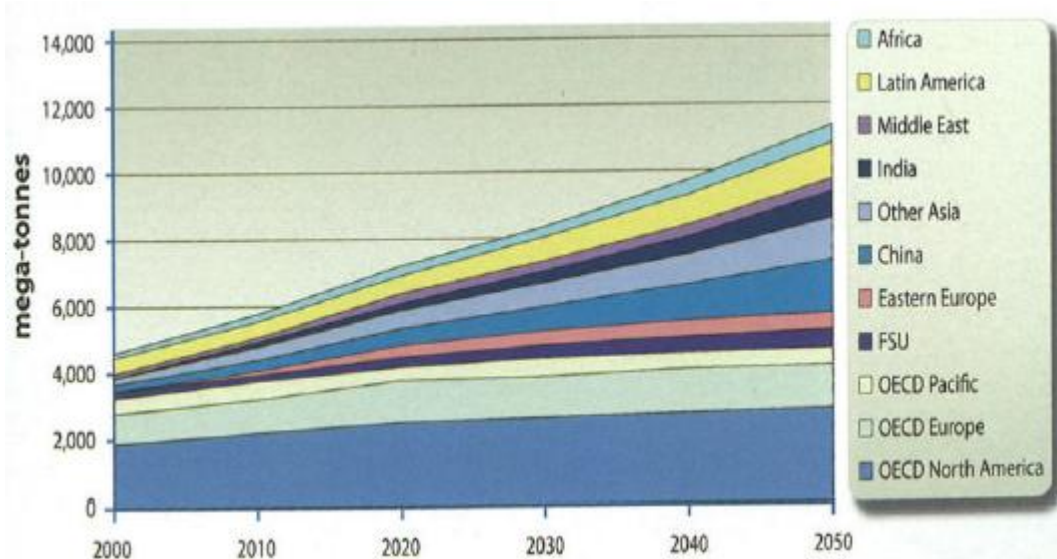


Figure 2.11. Transport vehicle CO<sub>2</sub> projected emissions by regions  
(source: TRANSvisions, 2009)

Figure 2.12 shows the evolution of international aviation and shipping CO<sub>2</sub> emissions since 1990.

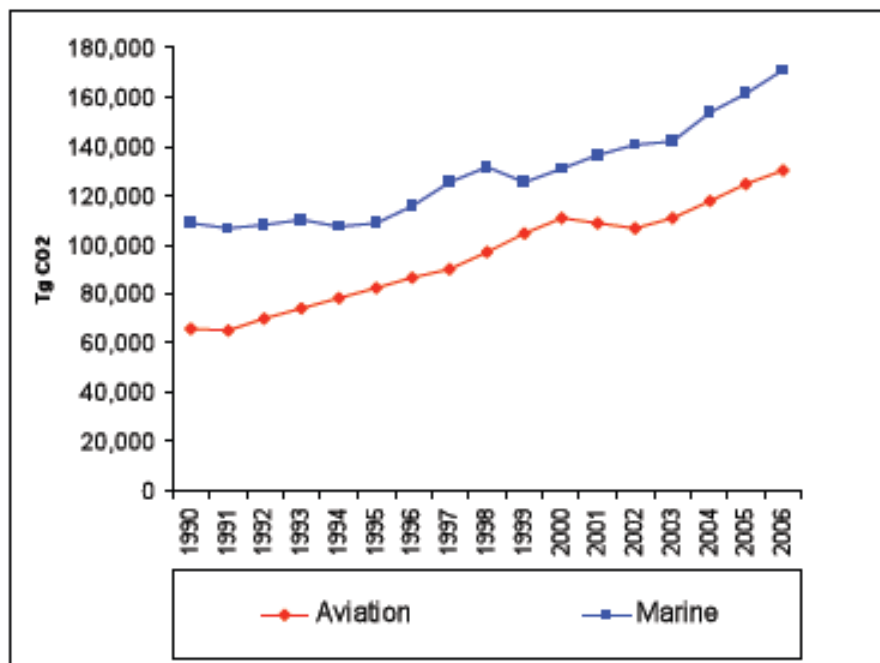


Figure 2.12. Aviation and marine CO<sub>2</sub> emissions  
(source: Transport&Environment, 2008)

As a matter of fact, although road transport represents the main cause of CO<sub>2</sub> emissions in the transport field, the other modes generate pollution as well. Emissions from transport represent a very high share of overall emissions and the harmful consequences do not come only from CO<sub>2</sub>. The contribution of harmful emissions (acidifying substances, particulate matter and ozone precursors), has decreased by 30% to 40% from 1990 to 2004 with exclusion of maritime transport and aviation contributions. Nevertheless, air quality in the areas immediately adjacent to transport activity, particularly in urban areas, is still a central problem mainly on account of adverse impacts for human health of pollutants such as particulate. And the growing use of diesel cars may contribute further to health problems.

#### ***2.3.1.2.1. Effects due to Road and Rail Transport***

The main focus in the field of air pollution costs is on road and rail transport: this is especially valid in Europe, where these two modes are extremely widespread and generate most of the external effects. Road and rail emissions costs estimated in literature are affected by various factors (Litman, 2009):

- *Scope*: emission analysis scope may be narrow, only considering tailpipe emissions, or broader, including emissions produced during vehicle operation, and during fuel and vehicle production.
- *Fuel type*: various fuels can power vehicles. Alternative fuels may reduce some emissions, but in many cases their net benefits (including “upstream” emissions during production and distribution) are modest. In some cases alternative fuels can have higher overall emissions than conventional fuels.
- *Units of measure*: emissions are measured in various units, including grams, pounds, kilograms, tons.

- *Vehicle-mile emission rates*: different vehicle emission models can be used to predict vehicle emissions under various circumstances. Emission rates are affected by various factors, such as:
  - *vehicle type*, as larger vehicles tend to produce more emissions;
  - *vehicle age and condition*, as older vehicles have less effective emission control systems and vehicles with faulty emission control systems generate high emissions;
  - *driving cycle*, as emission rates tend to be relatively high when engines are cold;
  - *driving style*, as faster accelerations tend to increase emission rates;
  - *driving conditions*, as emissions per mile increase under hilly and stop-and-go conditions, and at low and high speeds.
  
- *Per capita emission rates*: various factors affect per capita annual vehicle mileage, and therefore per capita vehicle emissions, including land use patterns, vehicle ownership rates, pricing, and the quality of alternative modes, such as walking, cycling and public transit.
  
- *Location and exposure*: local pollutants such as carbon monoxide, air toxins and particulates tend to be concentrated in vehicles and along adjacent to roadways. Air pollution costs (per ton of emission) are higher along busy roads, where population densities are high, and in areas where geographic and climatic conditions trap pollution and produce ozone. Emissions in situations where air pollution tends to concentrate due to geographic and weather conditions (such as in valleys during inversions) impose greater damages than the same emissions in less vulnerable locations.

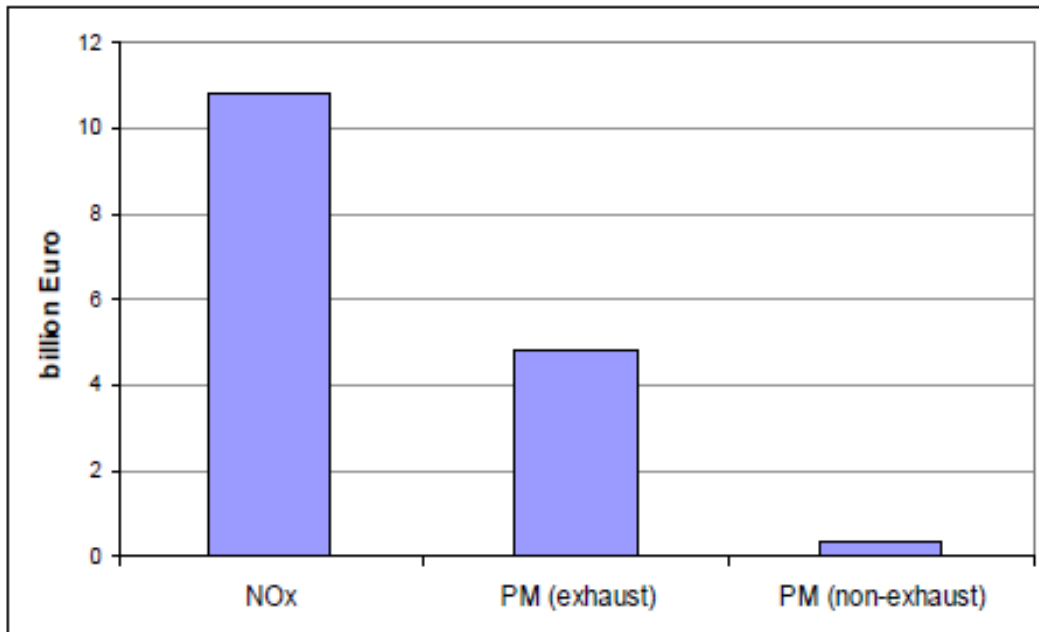


Figure 2.13. Total costs of air pollutants emitted by HGV in the EU in 2006 [Euros]  
 (source: Den Boer *et al.*, 2009)

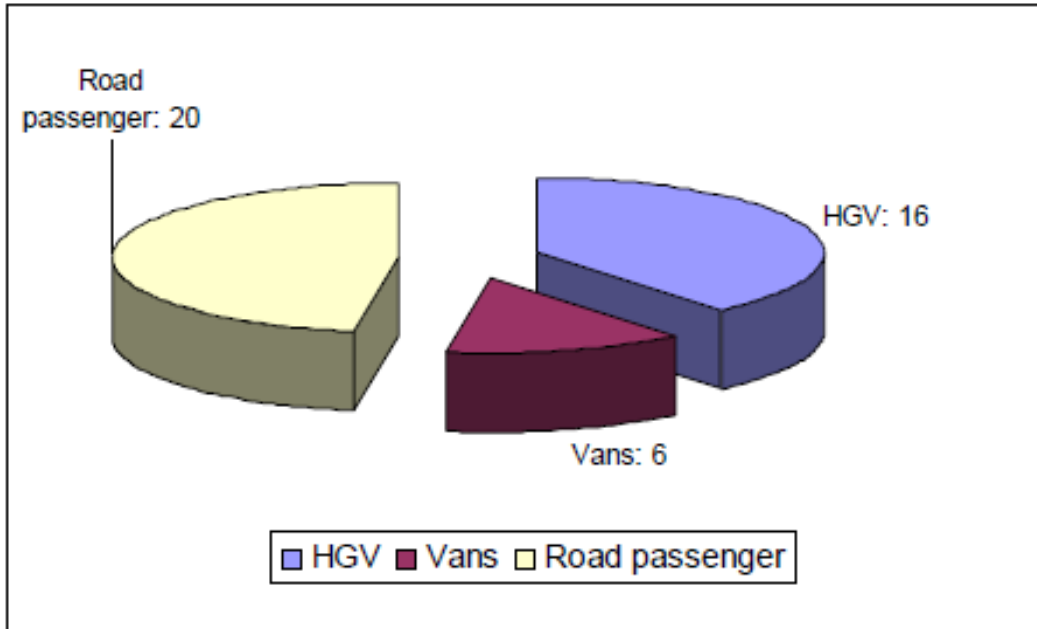


Figure 2.14. Share of transport segments in air pollution costs of road transport [billion Euros]  
 (source: Den Boer *et al.*, 2009)

### 2.3.1.2.2. *Effects due to Sea Transport*

Research in the field of climate pollution due to alternative sectors is really poor and historical data are rare: this makes almost impossible to properly model such costs and to express them analytically. Some indicative values on air pollution generated by both ships and planes can be found in technical reports at European or national level. The emissions from ships engaged in international trade in the seas surrounding Europe – the Baltic Sea, the North Sea, the north-eastern part of the Atlantic, the Mediterranean and the Black Sea – were estimated at 2.3 million tonnes of sulphur dioxide (SO<sub>2</sub>), 3.3 million tonnes of nitrogen oxides (NO<sub>x</sub>), and 250,000 tonnes of fine particles (PM) a year in 2000. Under the current legislation, it is expected that shipping emissions of SO<sub>2</sub> and NO<sub>x</sub> will increase by 40–50 per cent up to 2020, if compared to 2000. By 2020 the emissions from international shipping around Europe are expected to equal or even surpass the total from all land-based sources in the EU member states (see Figures 2.15 and 2.16).

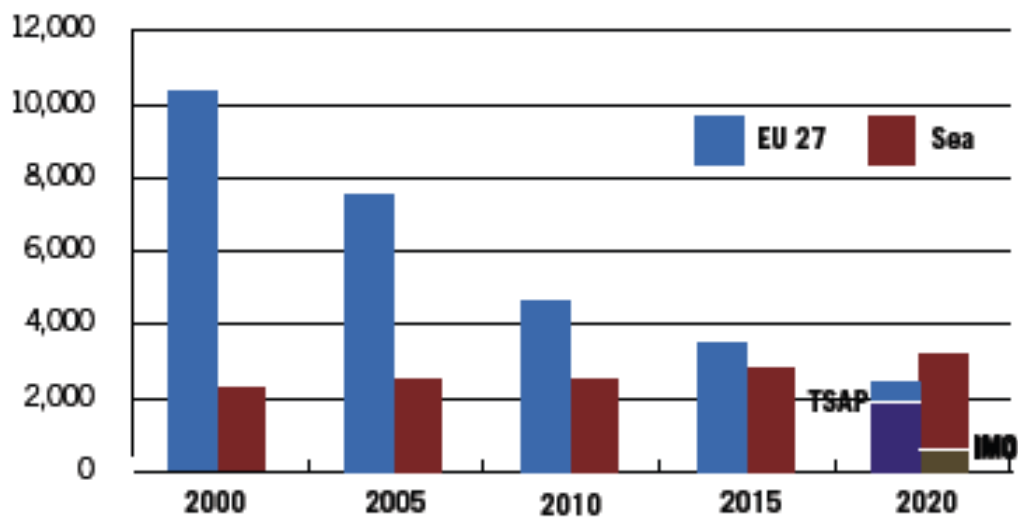


Figure 2.15. Emissions of SO<sub>2</sub> 2000–2020 [kt tonnes]

(source: Transport&Environment, 2008)

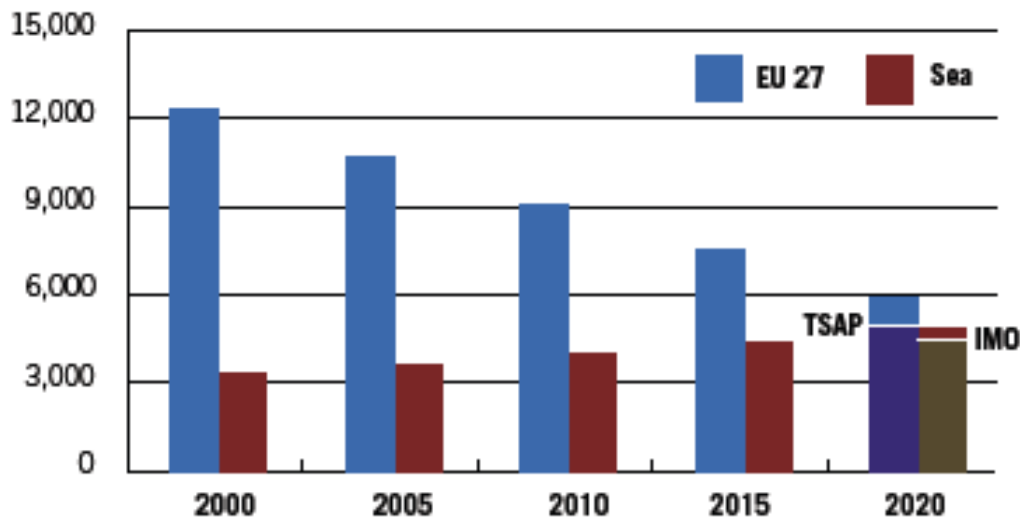


Figure 2.16. Emissions of NO<sub>x</sub> 2000–2020 [ktonnes]  
 (source: Transport&Environment, 2008)

It should be noted that the values in these figures, high as they are, refer only to ships in international trade. They do not include emissions from shipping in countries' internal waterways or from ships plying harbors in the same country, which are given in the domestic statistics of each country.

Since they cause acidification of soil and water, the emissions of SO<sub>2</sub> and NO<sub>x</sub> continue to be a serious problem in large parts of Europe. NO<sub>x</sub> also contribute to the formation of ground-level ozone, which damages vegetation as well as human health, and contributes to global warming. Moreover, NO<sub>x</sub> lead to eutrophication in coastal waters. In 2000, the depositions of sulphur and nitrogen exceeded the critical loads for acidifying substances over 260,000 square kilometers (20%) of sensitive forest ecosystems in the EU. Still in 2000, the depositions of nitrogen in the EU exceeded the critical loads for eutrophication over more than 1 million square kilometers (70%) of sensitive terrestrial ecosystems, and approximately 800,000 square kilometers (60%) of the EU forest area were exposed to ozone concentrations exceeding the critical level. After years of negotiation, an agreement was reached in 1997 on an air pollution at the IMO's MARPOL Convention, which came into force in 2005. It includes a global cap of 4.5% on the sulphur content of fuel oil, and contains provisions allowing for special emission control areas (ECAs) to be established with more stringent control on sulphur emissions. In these areas, the sulphur content of fuel used onboard ships must not

exceed 1.5%. Alternatively, ships must fit an exhaust gas cleaning system or use other methods to limit their SO<sub>2</sub> emissions. There was also agreement on nitrogen oxide (NO<sub>x</sub>) emission standards for new ship engines in two steps. In the first step, emissions would be cut by 16–22% by 2011 relative to 2000, and in the second step by 80% by 2016. The latter (longer-term) limit would only apply in the specially designated ECAs, however. The European Commission has recently been investigating the economic, legal, environmental, and practical implications of coordinated European action for reducing the emissions of air pollutants from ships. This initiative has been partly spurred by the EU directive on national emission ceilings requiring the Commission to present a programme of action for reducing emissions from international maritime traffic. If the international agreements on SO<sub>2</sub> and NO<sub>x</sub> emission standards will be effectively implemented, experts forecast that by 2020 emissions of SO<sub>2</sub> should come down significantly, while those of NO<sub>x</sub> would still increase, but not as much as was earlier anticipated.

#### ***2.3.1.2.3. Effects due to Air Transport***

Regarding aviation emissions, some figures have to be considered: it has been estimated that only in 2000 air transport accounted for 4 to 9% of the climate change impacts of human activities - the range reflects uncertainty surrounding the effect of cirrus clouds (Transport&Environment, 2008). A figure of 2%, often quoted by the aviation industry, applies only to CO<sub>2</sub> emissions and refers to 1992 data. Moreover, carbon dioxide (CO<sub>2</sub>) emissions from European international aviation increased by 90% between 1990 and 2005. If this trend continues, growth in the EU's international aviation emissions will offset more than a quarter of the reductions required by the Community's target under the Kyoto Protocol. Aviation has by far the greatest climate impact of any transport mode, whether measured per passenger kilometer, per tonne kilometer, per Euro spent, or per hour travelling. CO<sub>2</sub> emissions are directly linked to fuel consumption: every liter of jet fuel burnt leads to 2.5 kg of CO<sub>2</sub> emitted in the air.

### 2.3.2. *Noise*

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. Motor vehicles cause various types of noise, including engine acceleration, tire and road contact, braking, horns and vehicle theft alarms. Heavy vehicles can cause also vibrations and infrasound (low frequency noise). It is estimated that over half of Europe's population is exposed to unacceptable noise levels.

Noise from road transport is the major source, followed by aircraft and railway noise. Obtaining reliable data on people exposure to noise and on its psychological effects is very difficult. Studies applying all kinds of possible methodologies may be found in literature: from hedonic price methods (considering the loss of value for real estates exposed to persistent noise sources), to abatement cost methods (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, also because several different factors affect the amount of noise emitted by traffic and perceived by people. Among these factors some can be listed (Litman, 2009):

- *Vehicle type*: motorcycles, heavy vehicles (trucks and buses), and vehicles with faulty exhaust systems tend to produce high noise levels;
- *Engine type*: older diesel engines tend to be the noisiest, followed by gasoline and natural gas, hybrid, and electric vehicles being quietest;
- *Traffic speed, stops and inclines*: lower speeds tend to produce less engine, wind and road noise. Engine noise is greatest when a vehicle is accelerating or climbing an incline. Aggressive driving, with faster acceleration and harder stopping, increases noise;
- *Pavement type and condition*: certain pavement types and smoother road surfaces emit less noise;
- *Distance and barriers*: noise declines with distance and is reduced by structures, walls, trees, hills and sound-resistant design features such as double-paned windows.

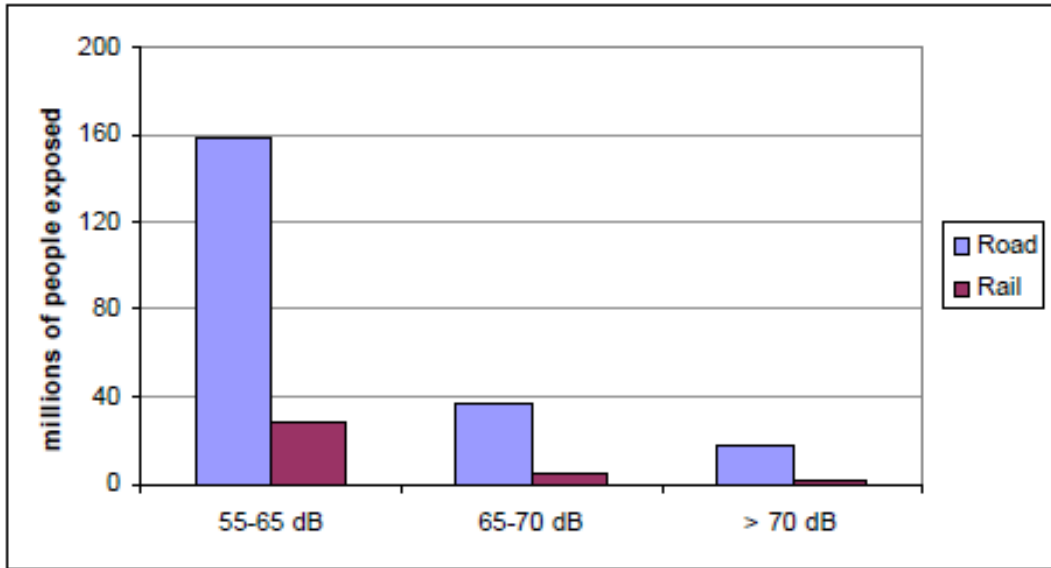


Figure 2.17. Number of people exposed to traffic noise in EU countries in 2000 (source: Den Boer *et al.*, 2009)

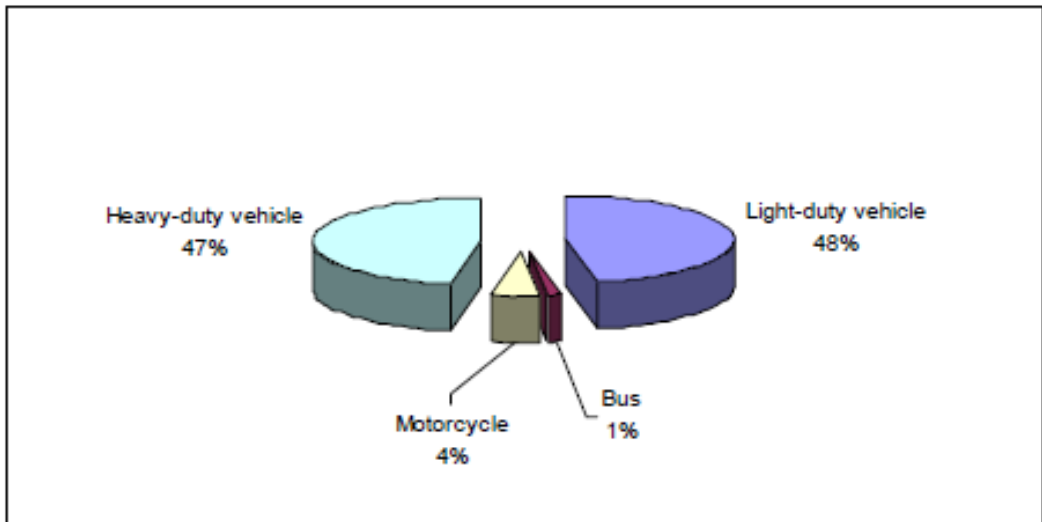


Figure 2.18. Share of vehicle classes in total noise-related costs in EU countries (source: Den Boer *et al.*, 2009)

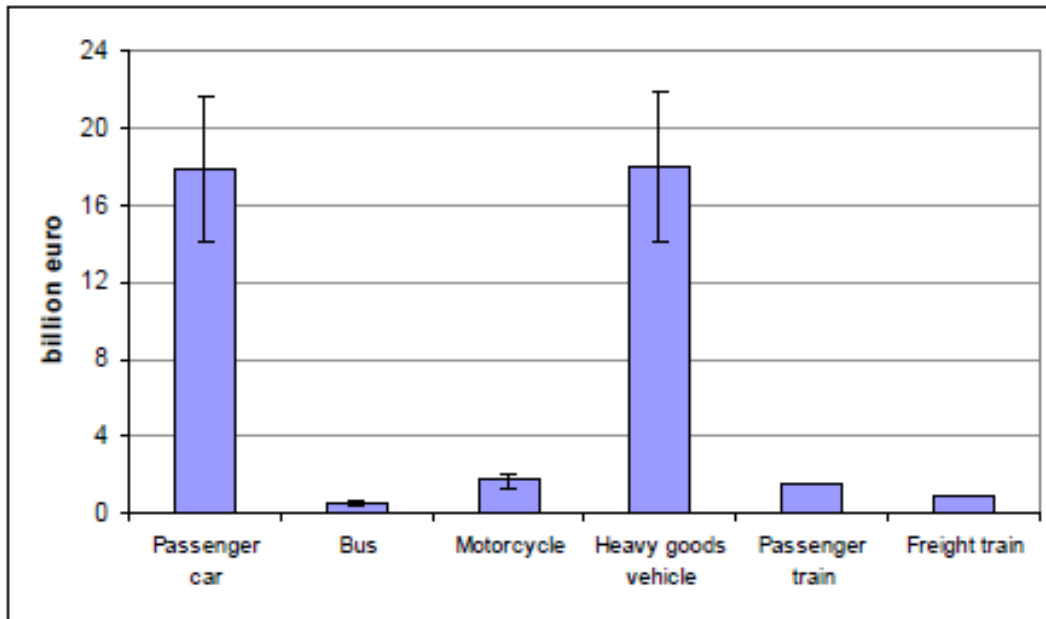


Figure 2.19. Share of transport modes in external costs of traffic noise in EU countries  
(source: Den Boer *et al.*, 2009)

Traffic noise has a variety of adverse impacts on human health (Den Boer and Schrotten, 2007). Community noise, including traffic noise, is already recognized as a serious public health problem by the World Health Organization (WHO). Of all the adverse effects of traffic noise the most widespread is simply annoyance. There is also substantial evidence for traffic noise disturbing sleep patterns, affecting cognitive functioning (especially in children) and contributing to certain cardiovascular diseases. For raised blood pressure, the evidence is increasing. For mental illness, however, the evidence is still only limited. The health effects of noise are not distributed uniformly across society, with vulnerable groups like children, the elderly, the sick and the poor suffering most. In 2000, more than 44% of the European population (about 210 million people) were regularly exposed to over 55 dB of road traffic noise, a level potentially dangerous to health. In addition, 35 million people in Europe (about 7%) are exposed to rail traffic noise above 55 dB. Millions of people indeed experience health effects due to traffic noise. It has been estimated that about 57 million people are annoyed by road traffic noise, 42% of them seriously. An analysis has shown that each year over 245,000 people in Europe are affected by cardiovascular diseases that can be traced to traffic noise (Den Boer *et al.*, 2009). About 20% of these people (almost 50,000) suffer a lethal

heart attack, thereby dying prematurely. The annual health loss due to traffic noise increased strongly between 1980 and 2000 and is expected to increase up to 2020. At a conservative estimate, the social costs of traffic noise in Europe amount to at least 40 billion per year (0.4% of total GDP). The bulk of these costs (about 90%) are caused by passenger cars and lorries. Vehicle noise costs are becoming then more and more important, especially in light of growing traffic volumes and the proximity between transport infrastructure and residential and living areas, all aspects that will make noise pollution consequences raise in the future.

### **2.3.3.        *Accidents***

The category of accidents external costs in the transport sector includes 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 (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”.

Monetizing crash impacts is not a straightforward task, especially when it comes to external costs. Several analytic techniques are used to monetize human health risks. Human life is not a commodity: most people place infinite value on their own life (they would not willingly die for any amount of money), but many decisions involve tradeoffs between marginal changes in risk and market goods. For example, vehicle purchasers must sometimes decide whether to pay extra for safety equipment such as airbags for a small increase in safety. Such tradeoffs indicate the value consumers place on marginal changes in risk, described as willingness-to-pay or willingness-to-accept. For example, if consumers pay an average of 100 Euros for optional safety equipment that reduces their chances of crash injury by one millionth, then other strategies that provide equal safety benefits for the same financial investment can be considered cost effective. The proper conceptual framework for determining fair and efficient compensation for damages that resulted from a crash caused by another driver is willingness-to-accept,

that is, the amount of financial compensation that a particular victim requires before he or she would volunteer to experience such damages. This reflects the assumption that individuals have a right to live without being injured by others. Willingness-to-pay tends to result in lower values than willingness-to-accept due to budget constraints. For example, consumers may value increased safety but cannot afford to pay for it, so willingness-to-pay values are low, yet they would be unwilling to accept reduced safety in exchange for a financial reward, so their willingness-to-accept values are relatively high.

Another element that can generate ambiguity, specifically for road transport, is that generally accidents involving trucks (where trucks include all possible means through which goods transport is made) can be classified in two different categories: unilateral accidents and multilateral accidents.

In case of unilateral accidents involving a truck, all the victims can plainly be attributed to this vehicle category. With multilateral accidents, however, the international literature provides no standard method for allocating the victims to the respective parties. There are essentially three allocation methods available:

- allocation on the basis of accident involvement;
- allocation on the basis of guilt;
- allocation on the basis of intrinsic risk.

Allocation on the basis of accident involvement simply attributes the costs associated with the victims on an equal basis. The consequence of this choice is that in a collision between a bicycle and a car or lorry, with the cyclist being the obvious victim, 50% of the costs will be allocated to the cyclist. As cars and lorries pose far more of a threat on roads than bicycles, however, this method is not generally applied as it would give unrealistic results. The second method allocates on the basis of guilt, assigning victims to the party causing the accident. This method is usually not applied for the following main reason: responsibility for suffering does not lie solely with the party making a mistake, because *every* traffic participant poses an intrinsic danger. Generally speaking, mobility always involves a certain intrinsic risk, even when traffic regulations are adhered to. This is the case with a car entering a residential area, but is equally true on the motorway. Vehicles that are faster and heavier obviously pose a greater threat, an intrinsic risk that can be clearly derived from the statistics. In an accident involving a passenger car and a lorry, the driver of the former has a far smaller chance of survival than the lorry driver. Even though the latter may not be guilty of making a mistake,

then, the mere presence of lorries on the roads creates a responsibility for the severity of the accidents they are involved in. The principle of intrinsic risks is also applied in the law as a means of protecting vulnerable road users like pedestrians and cyclists. The question is how the notion of intrinsic risk can be used to derive a key for allocating costs across the various vehicle categories: this decision generates other assumptions which imply further uncertainty to be considered in the calculation of costs.

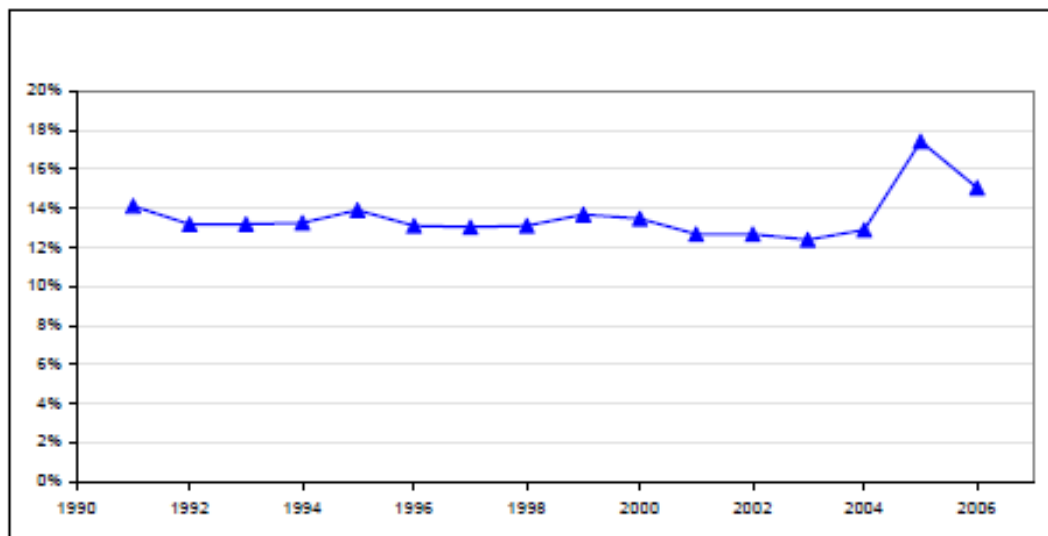


Figure 2.20. Percentage of road accident fatalities arising in accidents involving HGV in EU countries  
(source: Den Boer *et al.*, 2009)

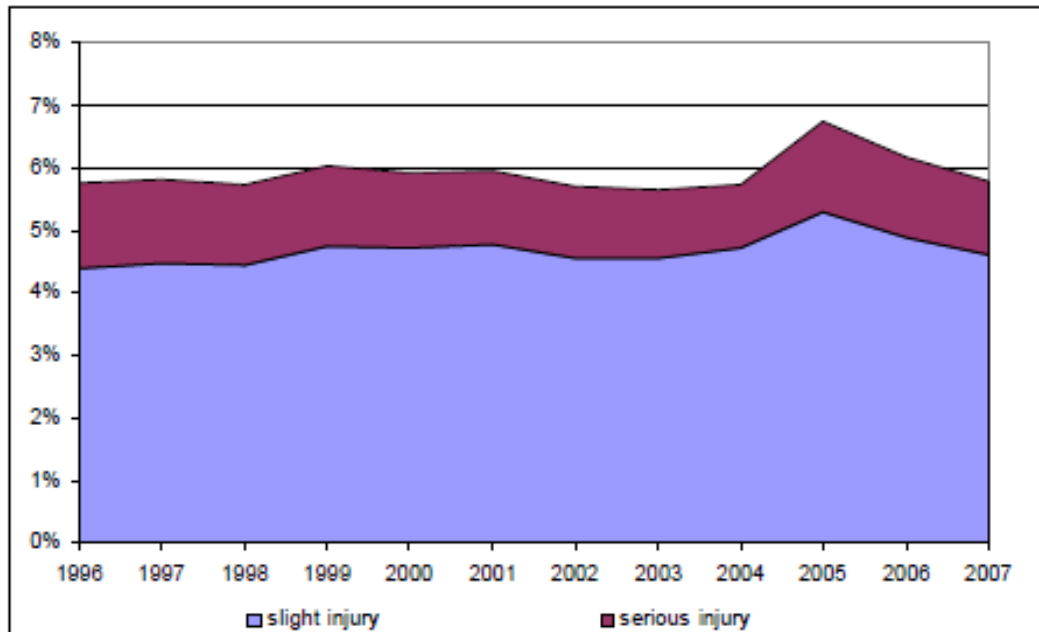


Figure 2.21. Percentage of road accident injuries arising in accidents involving HGV in EU countries  
(source: Den Boer *et al.*, 2009)

### 2.3.4. Congestion

External costs of congestion consist in 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 and costs of increased accident risk. Traffic capacity and congestion are highly affected by vehicle size: large and heavy vehicles cause more congestion than small and light ones because they require more road space and they are slower to accelerate. 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 also impose delays on other vehicles, whose costs are counted as externality.

### 2.3.5. *Roadway Facilities*

Roadway facilities costs include public expenditures to build and maintain road facilities, including land, road construction, maintenance and operations. Roadway costs are relatively easy to measure because they are mostly reflected in government budgets and agency reports; what appears to be less straightforward is the cost allocation: it refers to methods used to calculate the share of roadway costs imposed by different vehicle classes, and how these costs compare with roadway user payments by that class. Roadway expenditures not funded through user fees can be considered an external cost since people pay regardless of how much they use roads.

Vehicles' roadway costs are affected by three general factors (Litman, 2009):

- *Strength required and damage inflicted:* high volumes of heavy vehicles imply higher road and bridge construction standards and higher costs than lighter vehicles. Roadway wear also increases exponentially with axle weight, so heavy vehicles impose much greater maintenance and repair costs than lighter vehicles. A heavy truck imposes roadway costs equal to hundreds or thousands of light vehicles, depending on weight and road type. Studded tyres also significantly increase road repair costs;
- *Space required:* larger vehicles require more road space, for example wider lanes. Also, as speeds increase so does the “shy distance” required between vehicles and other objects, so higher speed traffic requires wider lanes, greater road capacity and more clearance. Road space requirements are measured in “passenger car equivalents,” or PCEs. A large truck or bus typically imposes 2-5 PCEs;
- *Design requirements:* faster traffic requires higher roadway design speeds and imposes greater risk, which increases safety requirements such as barriers and clear space.

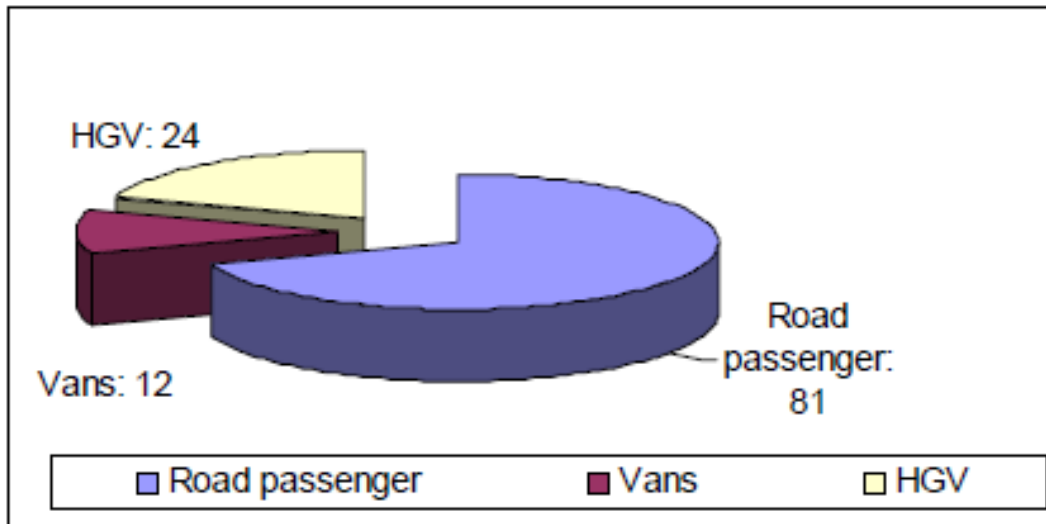


Figure 2.22. Share of transport segments in congestion costs of road transport in Europe [billion Euro]  
(source: Den Boer *et al.*, 2009)

### 2.3.6. *Minor External Costs*

In addition to the listed main categories of external costs, some others can be listed: they are typically less valued either because their impact is less meaningful or because the difficulty to estimate them as a consequence of the transportation activity spoils the reliability of the final outcome. Nevertheless, it is important to analyze such categories as well because their cumulative effect can be significant.

#### 2.3.6.1. *Resource Consumption*

Resource consumption costs are the costs of resources used in motor vehicle production and operation. These are costs which are not borne directly by users: they primarily refer to energy consumption but can also include natural resources, such as metals and water. Such external costs can include macroeconomic impacts, national security risks, health risks, environmental damage, depletion of non-renewable resources, and various financial subsidies. The cost estimates associated to these factors indicate the value to

society of resource conservation and efficiency. As a matter of fact, consumption of natural resources such as petroleum can impose a number of costs on society which are not borne directly by consumers. Resource exploration, extraction, processing and distribution cause environmental damages, including wildlife habitat disruption, noise, air and water pollution, solid waste, some of which is hazardous. These activities can also cause various health risks to people, including pollution-related illnesses, and injuries from accidents during processing and distribution. Although resource extraction industries have changed practices to reduce and mitigate these impacts, there are still significant residual damages. Some regulations do exist which tend to internalize environmental costs, but although they may reduce damages, there are still external costs imposed to people and to the environment.

#### **2.3.6.2.      *Roadway Land Cost***

Roadway land cost can be defined as the rent that road users would pay for roadway land. Roadway land value is often considered a sunk cost, with no rent or property taxes charged to users, except where land acquisition costs are incorporated into roadway user fees. Nevertheless, failure to charge for roadway land underprices space-intensive modes (such as single-occupant automobile travel compared with transit, ridesharing, cycling and walking), road transport relative to rail (which pays rent and taxes on right-of-way), roads compared with other land uses, and also transport relative to other goods. This underpricing reduces economic efficiency and results in overinvestment in roads.

#### **2.3.6.3.      *Land Use Impacts***

Land use impacts refer to the effects that transportation activities and facilities have on land use patterns. Transportation decisions do affect land use and patterns: motor vehicles require relatively large amounts of roads and parking facilities and encourage dispersed development. Direct impacts involve the land used for transport facilities, such as paths, roads, parking and terminals. Indirect impacts involve changes in the type, density, design and location of development. These impacts vary by mode since,

for example, automobile transport requires more space than other modes for travel and parking, and tends to encourage more dispersed land use patterns. Land use changes tend to impose various economic, social and environmental costs. Although these impacts are difficult to quantify, they appear to be quite significant in total. Reduced road requirements and less dispersed development patterns could benefit society by preserving green space, reducing public service costs, increasing accessibility and improving aesthetics, which could provide significant benefits. This is not to say that automobile use and low-density land use offer no benefits, but most of these benefits are internal, enjoyed by drivers and landowners, while these costs are mostly external. The impacts are difficult to monetize, in part because it is difficult to predict how a particular transport planning decision changes land use patterns, and in part because many of the economic, social and environmental impacts are themselves difficult to monetize.

Various types of transportation land use impact externalities can be defined (Litman, 2009):

- *Environmental degradation*: roads degrade environmental amenities and agricultural production directly by paving and clearing land, indirectly by encouraging increased development, sprawl and other disturbances, by severing and fragmenting habitat, and by introducing new species that compete with native plants and animals;
- *Aesthetic degradation and loss of cultural sites*: roads and parking facilities, vehicle traffic and low-density development often degrade landscape beauty in various ways. The value of attractive and healthy landscapes is indicated by their importance in attracting tourism and increasing adjacent property value;
- *Social impacts*: automobile-oriented transport tends to result in development patterns that are suboptimal for many social goals. Wide roads and heavy traffic tend to degrade the public realm (public spaces where people naturally interact) and in other ways reduce community cohesion;
- *Public service costs*: sprawl tends to increase the costs of public services such as policing and emergency response, school busing, roads, water and sewage;
- *Increased transportation costs/reduced access*: sprawl creates less accessible land use patterns, which increases mobility requirements to reach common

destinations, and reduces transportation options. This increases per capita vehicle ownership and use, increasing total transportation costs;

- *Economic productivity and development*: more accessible and resource efficient land use patterns can increase economic productivity and development. Increased density and clustering provides efficiencies of agglomeration, due to increased accessibility (the ability to reach desired activities and destinations), and interactions. It means, for example, that businesses can more easily interact and trade among themselves, customers can find competitive goods and services, suppliers can easily provide inputs, and specialized workers can expect greater employment opportunities. Activities that involve interaction among numerous people, such as education, finance and creative industries, are particularly affected by agglomeration.

#### **2.3.6.4. *Water Pollution and Hydrologic Impacts***

Water pollution and hydrologic impacts refer to the effects of harmful substances released into both surface and ground water and to changes in the flows due to these releases. Motor vehicles, roads and parking facilities are a major source of water pollution and hydrologic disruptions.

Water pollution factors include: crank case oil drips and disposal, road de-icing (salt) damage, roadside herbicides, leaking underground storage tanks, air pollution settlement. Hydrologic impacts lead to increased impervious surfaces, concentrated runoff and increased flooding, loss of wetlands, shoreline modifications and construction activities along shorelines.

These impacts impose various costs including polluted surface and ground water, contaminated drinking water, increased flooding and flood control costs, wildlife habitat damage, reduced fish stocks, loss of unique natural features, and aesthetic losses. Nevertheless, quantifying these costs is challenging. It is difficult to determine how much motor vehicles and roads contribute to water pollution problems since impacts are diffuse and cumulative. Roadway runoff usually meets water quality standards, but some pollutants concentrate in sediments or through the food chain. Even if we know the quantity of pollutants originating from roads and motor vehicles, and their

environmental effects, we face the problem of monetizing impacts such as loss of wildlife, reduced wild fish reproduction, and contaminated groundwater. However, consumers and industry are becoming more aware of water pollution problems: new policies designed to reduce pollution, prevent fuel tank leaks and internalize cleanup expenses may reduce some of these externalities.

#### **2.3.6.5. *Waste Disposal***

Waste disposal costs include damage costs associated with the inappropriate disposal of used tyres, batteries, junked cars, oil and other harmful materials resulting from motor vehicle production and maintenance. Motor vehicles produce various harmful waste products that can impose externalities. Many junked cars sit for years before they are recycled and some must be disposed of at public expense. Tire piles create environmental and health hazards, especially in case they catch fire. Although efforts are underway to find uses for waste tyres, none have eliminated landfill waste disposal. About 80% of cars can be recycled at the end of service life, mainly the metal parts. The remaining 20% includes plastics, rubber, glass, and metal pieces and it is mainly disposed of in landfills. Motor vehicle wastes are the major source of moderate risk, due to the presence of used oil, batteries, antifreeze, cleaners, paints and adhesives. These wastes impose various economic, human health, environmental and aesthetic costs. Costs might result from improper disposal and residual impact even when proper disposal is observed. Some new laws and policies are intended to internalize these costs. For example, crankcase oil recycling is encouraged, vendors are required to recycle used car batteries, and in some states a tire tax is dedicated to tire disposal. Nevertheless, it is uncertain to what degree these policies reduce external disposal costs. New technologies such as electric vehicles do not create waste oil, but they do produce used batteries, hulks and tyres, which may have disposal problems. There might seem to be a potential overlap between this costs and water pollution costs described previously. Water pollution costs actually cover impacts of oil and other fluids that drip during vehicle use, while waste costs address impacts of oil and other fluids after their useful life, during disposal.

### **2.3.6.6. *Traffic Services***

Traffic services costs include public costs like policing, streets lighting, parking enforcement, driver training, emergency services. Although they serve a wide range of users including pedestrians and cyclists, the need for these services, and therefore their cost, tends to increase with motor vehicle traffic, since motorized travel is more dangerous and so requires more management and emergency response.

### **2.3.6.7. *Barrier Effect***

Barrier effect costs refer to delays, discomfort and lack of access that vehicle traffic imposes on nonmotorized modes. In effect, road traffic tends to create a barrier to pedestrian and cyclist travel. The barrier effect is linked to traffic congestion costs (most traffic congestion cost estimates exclude impacts on nonmotorized travel). In addition to travel delays, vehicle traffic imposes crash risk and pollution on nonmotorized travelers: the barrier effect reflects a degradation of the nonmotorized travel environment. This does not mean that drivers intentionally cause harm, but rather that such impacts are unavoidable when heavy and hard vehicles traveling at high speed share space with vulnerable road users.

Although it could be argued that impacts are symmetrical, because nonmotorized modes cause traffic delays to motorists, pedestrians and cyclists impose minimal risk, noise and dust on motorists so the costs they bear are inherently greater than the costs they impose. The barrier effect reduces the viability of nonmotorized travel. This, in turn, reduces mobility for non-drivers, and reduces public fitness and health. It causes shifts from nonmotorized to motorized travel, and increasing external costs such as traffic congestion, increased parking demand, and pollution emissions. It tends to be inequitable because disadvantaged populations tend to bear a disproportionate share of this cost since they often depend heavily on nonmotorized transport. Studies indicate that people would like to walk and bicycle more but are constrained, in part, by heavy roadway traffic (Litman, 2009). In addition to direct costs to pedestrians, cyclists and residents, the barrier effect also imposes costs in terms of increased automobile dependency and use and increased chauffeuring.

## **2.4. *Methodologies for External Costs Valuation***

Several attempts have been made to estimate external costs in the transport sector. Although these costs cannot be easily measured, there is consensus at scientific level that external costs of transport can be estimated by best practice approaches and that general figures (within reliable bandwidths) can be used for policy use. This does however not mean that all cost categories are treated at the same level of accuracy, and all modes are covered equally. The approximation in the cost evaluation process is strictly connected to the capability of isolating the external part of each cost. This is not an easy task, and as a result cost allocation can be complex and highly arbitrary.

Among the others, following aspects have to be considered:

- parts of the congestion costs are paid by waiting and delay costs of the users; others, namely those imposed on other users, are not. The measurement of the external part has to consider congestion dynamics;
- parts of the accident costs are paid by third-party insurance, other parts are paid by the victim having itself caused the accident (either through own insurance or through suffering uncompensated damage, etc). Thus it is very important to consider the total volume of insurance fees related to the transport sector and the damage paid for outside the insurance system (also sometimes called “self-insurance”). Within existing practice of cost estimate, the focus is directly on the external part;
- Parts of environmental costs could be seen as already paid for, such as through energy taxes or environmental charges (i.e. noise related charges on airports). Thus, the allocation of environmental charges in the transport sector may be arbitrary.

Moreover, it has to be added that costs linked to accidents, congestion and environmental damages differ significantly with respect to the parts of society affected: while external accident costs are typically imposed on well-identifiable individuals (victims of an accident and their families), congestion costs are imposed to the collective of transport users caught in a traffic jam or having been crowded out. This holds even more for environmental externalities that are imposed on society at large, even affecting different generations (Van Hesse, 2008).

## **2.5. Valuation Approaches**

### **2.5.1. Main Evaluation Methods**

A comprehensive summary of the main methods used to monetize and quantify non-market impacts is presented by Litman (2009). In the following sections the most significant techniques are illustrated.

#### **2.5.1.1. Damage Costs**

This method reflects the total estimated amount of economic losses produced by an impact. For example, the damage costs of traffic crashes include vehicle damages, costs of providing medical and emergency services, lost productivity when people are disabled or killed, plus any non-market costs, such as pain, suffering and grief. Since this often involves different types of costs, measuring them requires different approaches and techniques.

#### **2.5.1.2. Hedonic Methods (or “Revealed Preference”)**

Hedonic pricing infers values for non-market goods from their effect on market prices, property values and wages. For example, if houses on streets with heavy traffic are valued lower than otherwise comparable houses on low traffic streets, the cost of traffic (conversely, the value of neighborhood quiet, clean air, safety, and privacy) can be estimated.

### **2.5.1.3.      *Contingent Valuation (or “Stated Preference”)***

Contingent valuation involves asking people how much they value a particular nonmarket good. For example, residents may be asked how much they would be willing to pay for a certain improvement in air quality, or acceptable compensation for the loss of a recreational site. Such surveys must be carefully structured and interpreted to obtain accurate results.

### **2.5.1.4.      *Control or Prevention Costs***

A cost can be estimated based on prevention, control or mitigation expenses. For example, if industry is required to spend 1,000 Euros per ton to reduce an pollutant emissions we can infer that society considers those emissions to impose costs at least that high. If both damage costs and control costs can be calculated, the lower of the two are generally used for analysis on the assumption that a rational economic actor would choose prevention if it is cheaper, but will would accept damages if prevention costs are higher.

### **2.5.1.5.      *Compensation Rates***

Legal judgments and other compensation rates for damages can be used as a reference for assessing nonmarket costs. For example, if crash victims are compensated at a certain rate, this can be considered to represent the damages. However, many damages are never compensated, and it would be poor public policy to fully compensate all such damages, since this may encourage some people (those who put a relatively low value on their injuries) to take excessive risks or even to cause a crash in order to receive compensation. As a result, compensation costs tend to be lower than total damage costs.

### **2.5.1.6.      *Travel Costs***

This method uses visitors' travel costs (monetary expenses and time) to measure consumer surplus provided by a recreation site such as a park or other public lands.

## **2.5.2.            *Overview on Current Techniques***

Many monetized estimates of external costs only reflect a portion of total damages. For example, some air pollution cost estimates only reflect human health impacts of ozone or particulates, but other harmful emissions, and agricultural and ecological impacts, are ignored. Some estimates only count health impacts that require medical treatments, but ignore less severe discomfort, and preventive actions such as foregoing outdoor recreation. It is important that people working with such values understand what portion of total impacts they reflect and what impacts may be excluded. For example, it may be inaccurate to say that a particular study indicates *the* costs of vehicle pollution, rather, it should be considered to indicate *certain* vehicle pollution costs. Which impacts are included, and which are not, should be identified.

### **2.5.2.1.        *Valuation of Individual Preferences***

The most widespread solution in order to value external costs imposed on society consists in estimating damage costs. Nevertheless, for some externalities, damage costs are not enough and long term risks as well as collective preferences have to be considered. In order to value individual preferences, the following approaches are relevant:

- the *willingness-to-pay* (WTP) for an improvement;
- the *willingness-to-accept* (WTA) as compensation for non improvement.

For example, many nonmotorized impacts are measured based on analysis of consumers' willingness-to-pay for improved safety or environmental quality, or willingness-to-accept compensation for reduced safety or environmental quality.

Although the analysis methodologies are basically the same, the results often differ. For example, people may only be willing to pay a 20 Euros per month rent premium for a 20% reduction in noise impacts (perhaps by moving to a quieter street or installing sound insulation in their homes), but would demand 100 Euros per month in compensation for a 20% increase in residential noise. This reflects a combination of budget constraints (they simply don't have much extra money to pay more for rent), and consumer inertia (the tendency of people to become accustomed to a particular situation, so they place a relatively small value on improvements and a relatively large value on degradation). Whether willingness-to-pay or willingness-to-accept is the proper perspective for evaluating an impact depends on property right, that is, people's right to impose impacts on others. If safety and environmental quality are considered rights then traffic crash risk and pollution emission costs should be based on recipients' willingness-to-accept incremental harms. If people are considered to have a certain right to impose risk or release pollution, then crash and pollution costs should be calculated based on victims' willingness to pay for an incremental reduction in risk and environmental degradation.

To estimate the willingness-to-pay to avoid external effects, various methods can be used. The two most relevant valuation methods are the following:

- *damage cost approach*;
- *avoidance cost approach*.

The *damage cost approach* assesses all the physical external impacts of transport and then assigns a value to the economic impacts to which they give rise. For example, traffic accidents result in a certain number of fatalities per year (physical impact), leading to costs being incurred in the form of production losses and the grief and suffering of relatives and friends. Again, various methods can be used to value the physical effects. Generally, two types of approach can be distinguished:

- *stated-preference methods*;
- *revealed-preference methods*.

In *stated-preference methods*, surveys are used to ask people directly how much they would be willing to pay to avoid certain physical impacts related to road freight

transport. In *revealed-preference methods*, on the other hand, the economic price of external effects is estimated using price developments on other economic markets. For example, the willingness-to-pay to avoid transport-related noise nuisance can be derived from variations in house prices, determined in part by differences in ambient noise levels. These differences can be seen as the willingness-to-pay to avoid the adverse effects (especially annoyance) of noise.

The *avoidance cost approach* is based on a cost-effectiveness analysis that determines the least-cost option to achieve a required environmental result, related to a policy target, for example. The target can be specified at various levels: national, European or global. An important drawback of this method is the implicit assumption that the policy target is a perfect reflection of the preferences of individuals.

Preference is often given to valuing environmental effects using the damage cost approach. However, if the physical impacts of environmental effects are hard to estimate and if policy targets are available, then an avoidance cost approach may be preferable (as in the case of CO<sub>2</sub> emissions, for example).

#### **2.5.2.2. *Direct Resource Cost Approximation***

Several methods can be used to approximate resource costs directly. They can be measured by market price of a certain effect (losses, compensation). In order to get the real costs, taxes and subsidies have to be extracted using factor costs. If resource costs are not available, hypothetical market situations have to be constructed. Several methods can be used, and all of them have strengths and weaknesses. The *stated-preference* (SP) method using a contingent valuation approach is directly measuring the willingness-to-pay, but depends very much on the survey design and the level of information, and suffers from the fact that it involves hypothetical expenditures only. Also indirect methods like *revealed-preferences* (RP; e.g. hedonic pricing where house price differentials can be used to estimate costs of noise) are therefore viable. For several environmental costs (e.g. relevant for long term risks and habitat losses), more differentiated approaches are necessary, since the stated preference approach is only useful for the valuation of individual key values such as the value of a human life. In

order to estimate the costs for a long term environmental problem (e.g. global warming), it is necessary to consider different risk scenarios: these contain direct and indirect costs to decrease and repair environmental damage and further costs of damages which cannot be repaired. A major recommended approach is the *impact pathway approach* (such as used by the ExternE model, specifically developed for air pollution) which follows the dose-response function considering several impact patterns on human health and nature.

The dose-response function (DRF) relates the quantity of a pollutant that affects a receptor (e.g. population) to the physical impact on this receptor (e.g. incremental number of hospitalizations). In the narrow sense of the term, it should be based on the dose actually absorbed by a receptor. However, the term dose-response function is often used in a wider sense where it is formulated directly in terms of the concentration of a pollutant in the ambient air, accounting implicitly for the absorption of the pollutant from the air into the body. The functions for the classical air pollutants (NO<sub>x</sub>, SO<sub>2</sub>, O<sub>3</sub>, and particulates) are typically of the that kind, and the terms exposure-response function or concentration-response function (CRF) are often used. Sometimes the lack of certain information on dose-response function makes it necessary to combine this approach with a standard price approach, as an alternative for the model estimate of the damage level. In this case, as a second best approach, the avoidance cost approach (cost to avoid a certain level of pollution) can be used.

Table 2.2 summarizes the best practice approaches for different cost categories pointing out the sensitive issues.

Cost component	Best practice approach
Costs of scarce Infrastructure	WTP for the estimation of the value of time (based on stated preference approaches). Alternatively: WTA. WTP for scarce slots (based on SP with real or artificial approaches). Alternatively: WTA.
Accident costs	Resource costs for health improvement. WTP for the estimation of Value of Statistical Life based on SP for the reduction of traffic risks. Alternatively: WTA.
Air pollution costs and human health	Impact pathway approach using resource cost and WTP for human life (Life years lost) base. Alternatively: WTA.
Air pollution and building/material damages	Impact pathway approach using repair costs.
Air pollution and nature	Impact pathway approach using losses (e.g. crop losses at factor costs).
Noise	WTP approach based on hedonic pricing (loss of rents – this reflects WTA) or SP for noise reduction. Impact pathway approach for human health using WTP for human life.
Climate change	Avoidance cost approach based on reduction scenarios of GHG-emissions; damage cost approach; shadow prices of an emission trading system.
Nature and Landscape	Compensation cost approach (based on virtual repair costs).

WTP = Willingness to pay. SP = Stated preference approach. WTA = willingness to accept.

Table 2.2. Best practice valuation approaches for most important cost components  
(source: Van Hesse, 2008)

## 2.6. *Procedures: Top-Down and Bottom-Up Estimates*

The estimation of external costs follows different paths in case the user needs to calculate marginal or average costs.

The assessment of marginal external costs is usually based on bottom-up approaches considering specific traffic conditions and referring to case studies. They are more precise and accurate, with potential for differentiation. On the other hand, these approaches are costly and difficult to aggregate (e.g. to define representative average figures for typical transport clusters or national averages). On the contrary, in order to get averages of external costs, the estimate of average (or average variable costs) are based on top-down approach. Such approaches are more representative on a general level, allowing also a comparison between modes for example. On the other hand, the cost function has to be simplified and cost allocation to specific traffic situations is lost: the differentiation for vehicle categories is rather aggregated.

In practice a mixture of bottom-up and top-down approaches (with representative data) should be used. Most important is the definition of appropriate clusters with similar cost levels (such as air pollution levels, traffic characteristics and population density).

Table 2.3 is showing the difference between marginal cost (bottom-up) and average cost (top-down) valuation.

Cost component	Difference between marginal and average costs	Practical implementation and proposed differentiation
Costs of scarce Infrastructure	In congested areas, marginal costs are above average costs: Difference is relevant to define external costs.	Estimation of marginal cost based on standardised curves for specific traffic clusters (urban-interurban, peak-off-peak). Top-down approaches are hardly feasible.
Accident costs	Marginal costs differ individually (for non-scheduled traffic). Clustering of Infrastructure users according to accident risk is possible (and typically applied by insurance companies). Thus, average and marginal costs can be assumed to be similar in each cluster.	Differentiation (cluster of users) according to schemes applied by insurance companies.
Air pollution costs and human health and building/material damages	Linear dose response function: Marginal costs similar to average costs.	Marginal (averaged) costs per type of vehicle (EURO-class) and traffic and population clusters (urban, interurban).
Air pollution and nature	Linear dose response function: Marginal costs similar to average costs.	Marginal (averaged) costs per type of vehicle (EURO-class) and traffic clusters (urban, interurban).
Noise	Decreasing impact of an additional vehicle with increasing background noise due to logarithmic scale. Marginal costs below average costs.	Marginal (averaged) costs per traffic and population clusters (urban, interurban).
Climate change	Complex cost function. As a simplification: Marginal damage costs similar to average costs (if no major risks included). For avoidance costs, marginal costs are higher than average costs.	Marginal (averaged) costs per type of vehicle and/or fuel.
Nature and landscape	Marginal costs are significantly lower than average costs.	Averaged (or marginal) variable costs per type of Infrastructure.

Table 2.3. Relation between marginal and average costs and links to internalization  
(source: Van Hessen, 2008)

## 2.7. *Commons and Differences among Modes of Transport*

Existing studies on external costs have mainly concerned road transport. The evidence shows that road transport has by far the largest share in total external costs of transport. In order to cover all transport modes and to transfer, where appropriate, existing knowledge on external cost estimates from one mode to other modes, some similarities and differences between modes have to be considered. Table 2.4 provides an overview.

Cost component	Road	Rail	Air	Water
Costs of scarce Infrastructure	Individual transport is causing collective congestion, concentrated on bottlenecks and peak times.	Scheduled transport is causing scarcities (slot allocation) and delays (operative deficits).	See Rail.	If there is no slot allocation in ports/channels, congestion is individual.
Accident costs	Level of externality depends on the treatment of individual self accidents (individual or collective risk) insurance covers compensation of victims (excluding value of life).	Difference between driver (operator) and victims. Insurance is covering parts of compensation of victims (excluding value of life).	See Rail.	No major issue.
Air pollution costs	Roads and living areas are close together.	The use of diesel and electricity should be distinguished.	Air pollutants in higher areas have to be considered.	Air pollutants in harbour areas are complicated to allocate.
Noise	Roads and living areas are close together.	Rail noise is usually considered as less annoying than other modes (rail bonus). But this depends on the time of day and the frequency of trains.	Airport noise is more complex than other modes (depending on movements and noise max. level and time of day).	No major issue.
Climate change	All GHG relevant.	All GHG relevant, considering use of diesel and electricity production.	All GHG relevant (Air pollutants in higher areas to be considered).	All GHG relevant.
Nature and landscape	Differentiation between historic network and motorways extension.	Differentiation between historic network and extension of high speed network.	No major issue.	New inland waterways channel relevant.

Table 2.4. Differences in transport costs according to transport modes

(source: Van Hessen, 2008)

## **2.8. Best Practices per Cost Category**

As external costs are so dispersed and of different nature, it is not possible to define a unique practice to calculate all of them. At the same time, not all the best practices are suitable to give a reliable value to each one of the cost categories. As a consequence, each external cost category can be calculated through a specific practice which is the one that will give the most reliable output.

The best practices and aspects to be taken into consideration for the most significant external cost categories are listed in the next paragraphs.

### **2.8.1. Air Pollution Costs Valuation**

#### **2.8.1.1. Overall Impacts of Air Pollution**

Air pollution costs are caused by the emission of air pollutants such as particulate matter (PM), NO<sub>x</sub>, SO<sub>2</sub> and VOC and consist of health costs, building and material damages, crop losses and costs for further damages for the ecosystem (biosphere, soil, water). Air pollution costs arise not only from transport related air pollutant emissions but also from other sources like industry, agriculture and private households. As a consequence, the share of transport related air pollutants in total pollutant concentrations has to be estimated or modelled: transport related air pollution causes damages to humans, biosphere, soil, water, buildings and materials.

Health costs (mainly caused by PM, from exhaust emissions or transformation of other pollutants) are by far the most important cost category. The state of research on these costs is surely more advanced than for the other components, mainly based on estimations carried out by the ExternE models funded by several European research projects. Nevertheless, studies on air pollution costs cover in general the all or many of the following impact categories:

- *Health costs*: impacts on human health due to the aspiration of fine particles (PM<sub>2.5</sub>/PM<sub>10</sub>, other air pollutants). Exhaust emission particles are hereby

considered as the most important pollutant. In addition Ozone (O<sub>3</sub>) has impacts on human health;

- *Building and material damages*: impacts on buildings and materials from air pollutants. Mainly two effects are of importance: the first one is soiling of building surfaces and facades mainly through particles and dust. The second important impact, especially on facades and materials, is the degradation through corrosive processes due to acid air pollutants like NO<sub>x</sub> and SO<sub>2</sub>;
- *Crop losses in agriculture and impacts on the biosphere*: crops as well as forests and other ecosystems are damaged by acid deposition, ozone exposition and SO<sub>2</sub>;
- *Impacts on biodiversity and ecosystems* (soil and water/groundwater): the impacts on soil and groundwater are mainly caused by eutrophication and acidification due to the deposition of nitrogen oxides as well as contamination with heavy metals (from tire wear and tear).

Key cost drivers for most air pollution costs and all modes is the receptors' density close to the emissions source, which is a proxy to the population exposed to transport related pollutants. For road transport other important cost drivers are the emission standards of the vehicle, which depend partly on the age of the vehicle. Emissions of a road vehicle then depend on vehicle speed, fuel type and the related combustion technology with its specific applicable end-of-pipe exhaust gas cleaning technology, the load factor, vehicle size, the driving pattern and the geographical location of the road.

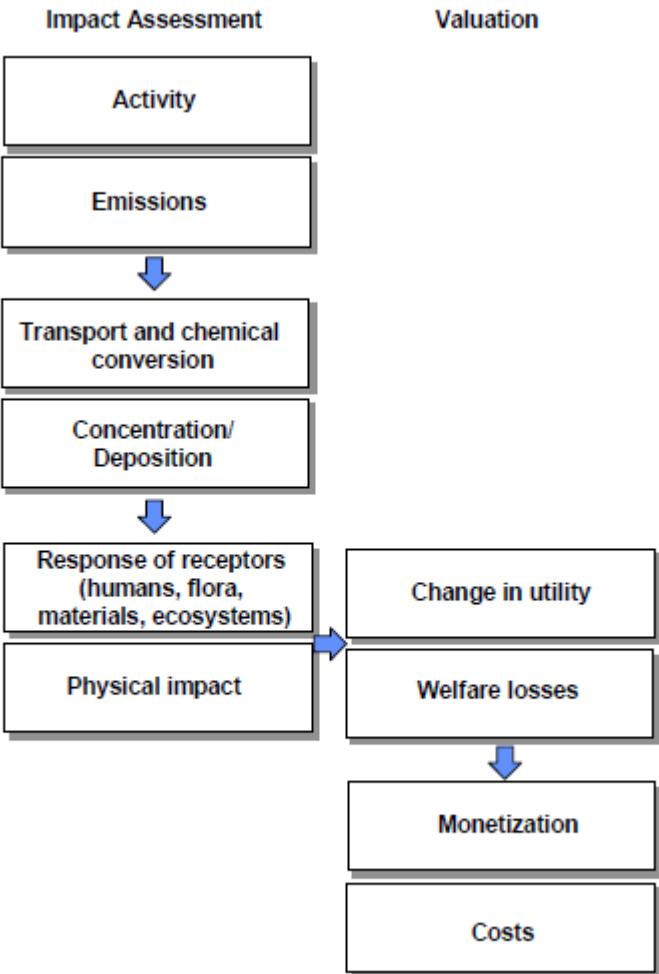
In rail transport vehicle speed, fuel type, the load factors, the power plant mix for electricity generation as well as geographical location of power plants are key cost drivers.

In air transport the type of engine and the engine mode are the most important cost drivers.

For inland waterways and maritime transport key cost drivers are engine type, vessel type, fuel quality, operation mode and (for inland waterways) driving direction (upstream or downstream).

As air pollution cost is a core external cost category, a quite considerable amount of studies on methodology as well as studies on total, average and marginal air pollution costs can be found. Within European research projects the Impact Pathway Approach established within the ExternE project (ExternE, 1997; Friedrich and Bickel, 2001) and

CAFE CBA (2005) are commonly used tools. The ExternE approach aims at estimating marginal costs for different traffic situations. The strength of this approach is its consistency and the consideration of different detailed input variables. Nevertheless, it is rather costly in order to derive average and representative figures at national level. Figure 2.23 gives an overview on the most important steps of the Impact Pathway Approach established within ExternE.



Source: HEATCO, 2005.

Figure 2.23 The Impact Pathway Approach for the quantification of marginal external costs caused by air pollution (source: HEATCO, 2005)

### **2.8.1.2. Focus on CO<sub>2</sub> Emission Models**

CO<sub>2</sub> is often considered as the most damaging consequence of transport air pollution. In 2005, 73% of the European freight inland transport was done by road (Eurostat 2007). Between 1995 and 2005, goods transport in the EU grew by 31.3% and this growth is predicted to continue. In this scenario, CO<sub>2</sub> emissions from the road sector are today 30% higher than in 1990 and transport is the only sector of the economy where emissions are predicted to increase in the future (WEO, 2008). From these values it is easy to understand why such emissions have been deeply analyzed and a number of models to calculate them have been produced: reduction of carbon emissions produced by road transport is one of the main objectives of Green Logistics. A particular attention is put on trucks, which play a fundamental role in transport logistics while being among the most polluting modes.

CO<sub>2</sub> emission models have been developed firstly in the USA starting from 1978, with a model called MOBILE developed by the Environmental Protection Agency with the scope of estimating highway vehicles emission factors. From that point onwards, a series of other models were proposed also at European level.

#### **2.8.1.2.1. Average Speed and Micro-Scale Models**

The models can be grouped into two main categories (Mtalaa *et al.*, 2009):

- *Average Speed models*: they are the most commonly used models. Total emissions are calculated as a product of activity data provided by the user and speed-dependent emission factors calculated by a specific software. They work on the basis of specific emission/consumption factors for vehicle/engine technologies for particular traffic conditions. They usually form the basis of local air quality calculations, and work characteristically on the scale of a town. For instance, the software application of COPERT 4 methodology (Gkatzoflias *et al.*, 2007) has been developed for the compilation of national inventories on a yearly basis. However, it has been shown that the methodology can also be used with a sufficient degree of certainty at a higher resolution too, i.e. for the compilation of urban emission inventories with a spatial resolution of 1x1 km<sup>2</sup>

and a temporal resolution of 1 hour. Another example is the EMFAC (2007), which is the latest version of the California mobile source emissions model. It is an officially approved regulatory model, which calculates emission inventories for motor vehicles operating on roads in California by combining vehicle emission rates with local specific activity data. The basic application is to generate emission factors for on-road motor vehicles at a county or at a state level. EMFAC is also capable of estimating regional emissions;

- *Micro-scale models*: these kinds of models use detailed speed profiles (second by second) of a vehicle to calculate fuel consumption and emissions for the individual vehicles at specific trips (Frey *et al.*, 2007). One of these emission models is the PHEM (Passenger car and Heavy duty Emission Model) developed at Graz University (Hausberger *et al.*, 2003). These models take into account vehicle kinematics through detailed parameters such as speed and acceleration. They allow calculations on a local scale (Smit *et al.*, 2008; Silva *et al.*, 2006), but can also be integrated for regional or national inventories. They allow vehicle characteristics to be altered individually and thereby to simulate expected future trends.

#### **2.8.1.2.2. Application of Emission Models**

Different forms of application of an emission model can be defined, the most important are:

- *Emission forecasts*: these are applications where fine spatial and temporal resolution is not required, and trends are generally more important than absolute emission levels. Thus, speed-dependent emission factors can adequately simulate reality. In order to come up with reliable emission factors, for each driving mode (e.g. urban driving) the corresponding average speed should be derived using appropriate measurements and assumptions;
- *Air quality models*: applications for a urban region, which are comparatively detailed, require emission inventories with an average spatial resolution of 500x500m (Wang *et al.*, 2009). On such a scale, emissions in individual streets are not of great interest since they are averaged over a number of similar streets.

Hence, speed-dependent emission factors seem to be sufficient. What is of particular importance in such simulations is an accurate knowledge of the distance travelled with cold engines in each part of the simulated area and for each hour of the day, as well as the impact of these cold starts on emissions. Attention should therefore focus on these issues in addition to effect of the altitude of the region and the gradient of streets in specific parts of the area;

- *Small-scale applications*: the calculation of emissions on the level of a single street is associated with a high degree of uncertainty . The representativeness of all input data (driving profile, emissions, etc.) is crucial, and the outcome for some individual streets may be considerably different from the average simulated emissions in streets of the same type. In such cases, in addition to the average speed, the vehicle kinematics on that street may have a significant influence, and simple speed-dependent emission factors may therefore be inadequate. Where driving behavior and dynamics are of major interest (e.g. the impacts of changes in the driving behavior have to be assessed) disaggregated approaches are recommended. However, instantaneous models do not predict consistent trends. Furthermore, what should be noted is that models based on modal emission measurements indicate that speed fluctuation is indeed relevant, but average speed itself is still an important influencing factor (Smit *et al.*, 2008).

### **2.8.2.        *Climate Change Costs Valuation***

Climate change costs have a high level of complexity due to the fact that they are long term and global and that risk patterns are very difficult to anticipate. As a result, there are difficulties to value the damages to be allocated to national transport modes. Therefore a differentiated approach (looking both at the damages and the avoidance strategy) is necessary. In addition, long term risks should be included as well.

Climate change or global warming impacts of transport are mainly caused by emissions of the greenhouse gases of carbon dioxide (CO<sub>2</sub>), nitrous oxide (N<sub>2</sub>O) and methane (CH<sub>4</sub>). To a smaller extent emission of refrigerants (hydrofluorocarbons) from Mobile Air Conditioners (MAC) also contribute to global warming. In the case of aviation also

other aircraft emissions (water vapor, sulphate, soot aerosols and nitrous oxides) at high altitude have an impact on global warming.

### **2.8.2.1. Key Areas of Assessment**

The key areas of assessment in the literature and the models regarding the social costs of climate change are here listed:

- *Sea level rise* leads to costs of additional protection, or otherwise loss of dry land and wetland loss. The balance will depend upon future decisions about what protection is justified. Costs of protection are relatively well known and included in nearly all models, but other costs (e.g. rising sea levels increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands) are more uncertain and often excluded (or only partially captured in terms of valuation). Populations that inhabit small islands and/or low-lying coastal areas are at particular risk of severe social and economic effects from sea-level rise and storm surges. This raises the issue of migration (e.g. for those living on small island states). These costs depend on diverse social and political factors (so called socially contingent effects) but they are not captured in the current valuation models;
- *Energy use impacts* will depend on average temperatures and range, but there will be a combination of increases and decreases in demand for heating (both in terms of overall energy supplied, and to meet peak demands). Benefits from increased winter temperatures that reduce heating needs may be offset by increases in demand for summer air conditioning, as average summer temperatures increase. The models can capture these effects, although the reference scenario is difficult to project;
- *Agricultural impacts* depend on regional changes in temperature and rainfall, as well as atmospheric carbon dioxide levels (and fertilization). The key impacts will be crops changes in the cultivated area and yields. These effects depend on many factors and in some areas the space suitable for cultivation and potential yields will increase. Climate variability, as well as mean climate change, is an

important consideration. Adaptive responses will be important: choice of crop, development of new cultivars and other technical changes, especially irrigation. Most valuation studies capture the direct impacts, but it is important to note these do not fully determine damages: they will also depend on changes in demand and trade patterns driven by socio-economic factor, but also complex responses to climate variability, pests and diseases, etc;

- *Water supply impacts* depend on changes in rates of precipitation and evapo-transpiration and demand changes, including those driven by climate change. The water demand of biological systems is affected by various climatic factors, including temperature and humidity. Water supply systems are usually optimized to meet (currently) extreme supply/demand conditions and the costs of shortage can be very high. Climatic variability is therefore important in determining damages. Climate change will exacerbate water shortages in many water-scarce areas of the world. There is the potential for water scarcity and severe socially contingent damages, which are not quantified at present. Water supply is included in some models, though coverage is often partial;
- *Health impacts* include both an increase in (summer) heat stress and a reduction in (winter) cold stress, though as these are in opposite directions the net mortality impact (global) of direct temperature changes may be quite small. Direct health impacts from temperature changes are included and valued in many studies. The area amenable to parasitic and vector borne diseases, such as malaria, will expand and impacts could be large. The inclusion of disease burdens has been advanced through specific studies, and some models include partial coverage of such effects. Socially contingent damages to health (via other impacts such as food production, water resources and sea level rise) in vulnerable communities are difficult to estimate but could be very large, and these are not included in any of the valuation modelling frameworks. Overall, climate change is projected to increase threats to human health, particularly in lower income populations, predominantly within tropical/subtropical countries;
- *Ecosystems and biodiversity impacts* are amongst the most complex and difficult to evaluate. Ecological productivity and biodiversity will be altered by climate change and sea-level rise, with an increased risk of extinction of some vulnerable species. Most of the major ecosystem types are likely to be affected, at least in parts of their range. Some isolated systems are particularly at risk,

including unique and valuable systems (e.g. coral reefs). Recent evidence has also identified acidification of the oceans, which is an observable consequence of rising CO<sub>2</sub> levels in the atmosphere, with potentially large impacts on marine ecosystems and fluxes of greenhouse gases between the ocean and the atmosphere. The analysis of ecosystems effects is one of the most problematic areas, in terms of a comprehensive or reliable assessment of the impacts of climate change on ecosystems. Most studies do not capture ecosystems effects fully – with valuations relying on *ad hoc* estimates of species loss and contentious valuation studies;

- *Extreme weather events* are also likely to increase, with heat waves, drought, floods, and potentially storms, tropical cyclones and even super-typhoons. However, the frequency and severity of extreme events may not be linearly dependent on average climate. Climate variability will also be important and there is no consensus on how this will change. Impacts and damages will also depend on the location and timing of the hazard and adaptive responses. For example, cyclone damages to property will tend to rise with wealth, but mortality effects may fall considerably. Extreme events are excluded from all but a few studies in relation to valuation;
- *Major events*, such as the risk of major effects or major climate discontinuities, are the most uncertain category. As a consequence, such events are not captured in any of the valuation models.

### **2.8.3.        *Noise Costs Valuation***

Noise costs consist of costs for annoyance and health. Annoyance costs are usually economically based on preferences of individuals (by stated or revealed preference methods), whereas health costs (especially due to increased risk of heart attacks) are based on dose response figures. Since marginal noise costs decrease with increasing traffic volumes, the definition and measurement of costs is quite crucial and needs differentiation.

Noise can be defined as the unwanted sound or sounds of duration, intensity, or other quality that causes physiological or psychological harm to humans. As said, two types of negative impacts of transport noise can be distinguished:

- *Costs of annoyance*: transport noise imposes undesired social disturbances, which result in social and economic costs like any restrictions on enjoyment of desired leisure activities, discomfort or inconvenience (pain suffering), etc;
- *Health costs*: transport noise can also cause physical health damages. Hearing damage can be caused by noise levels above 85 dB, while lower levels (above 60 dB) may result in nervous stress reactions, such as change of heart beat frequency, increase of blood pressure and hormonal changes. In addition, noise exposure increases the risk of cardiovascular diseases (heart and blood circulation). Finally, transport noise can result in a decrease of subjective sleep quality. In addition, it is recommended to take vulnerable groups, like children and elderly, into account. The negative impacts of noise on human health result in various types of costs, like medical costs, costs of productivity loss, and the costs of increased mortality.

It can be assumed that these two effects are independent, i.e. the potential long term health risk is not taken into account in people's perceived noise annoyance.

For air transport an additional negative impact of transport noise can be identified. In many cases governments establish 'cordons sanitaires' around large noise sources such as airports. In these cordons sanitaires land use is restricted; for example, it may not be permitted to build new houses. This restricts use of land within this area compared to a situation without noise and indirectly also limits choices elsewhere, which leads to welfare losses. These costs are only partly related to actual flight movements. Also other aspects, like land prices and future potential flight paths, influence these costs.

Marginal noise costs due to maritime shipping and inland waterway transport are assumed to be negligible, because emission factors are comparably low and most of the activities occur outside densely populated areas.

For the estimation of noise costs data on the number of exposed people is needed. Nevertheless, for many European countries exposure numbers for road and rail are not yet available and this makes the evaluation of noise costs really difficult.

#### **2.8.4. Accident Costs Valuation**

External accident costs are those social costs of traffic accidents which are not covered by risk oriented insurance premiums. The most important accident cost categories are material damages, administrative costs, medical costs, production losses and the so called risk value as a proxy to estimate pain, grief and suffering caused by traffic accidents in monetary values. Mainly the latter is not covered properly by the private insurance systems.

The most important cost drivers in road transport are, besides vehicle kilometers, vehicle speed, type of road, drivers' characteristics (such as driving behavior, experience, speeding), traffic speed and volume, time of day (day/night) and interaction with weather conditions. The maintenance level of the infrastructures, the degree of infrastructure capacity use and the level of segregation between road lanes play also an important role together with technological developments in vehicles (active and passive security measures) as well as in infrastructures (i.e. traffic management).

Main cost drivers in rail transport are traffic volumes, weather conditions, level of maintenance and level of segregation between systems, especially between road and rail and between different type of trains. Hereby the type of level crossing with road infrastructure is an important cost driver (the less protected the higher the risk of accidents).

For aviation the level of maintenance of aircraft and guiding systems, weather conditions and the education and training level of the pilots are the key cost drivers.

For inland waterways and maritime transport information on accident costs is almost entirely lacking.

##### **2.8.4.1. Bottom-up or Top-down Approach for Accident Costs**

As it was previously introduced, two kinds of approaches (bottom-up or top-down) can be defined for calculating external costs. The bottom-up approach aims at estimating marginal accident costs depending on traffic volumes. The magnitude of the costs depends on the risk elasticity (correlation between traffic levels and accidents) and on the assumption of risk values. Considering the fact however, that traffic volumes and

type of infrastructure are only two cost drivers amongst many others, not all aspects of the externality are covered. The top-down approach (IWW/INFRAS) estimates total and average accident costs considering national accident statistics and insurance systems. It focuses on material damages and administrative costs (usually covered by the insurance premiums), medical costs (including other insurance systems), production losses and societal valuation of risks (usually external). This approach compares the total social costs with covered and uncovered parts by risk insurance. It considers mainly the production losses and the value of human life as external. Since only parts of total accident costs are considered, the bottom-up approach leads to lower values than the top-down approach.

#### **2.8.4.2. *Accident Costs Externalities and Risk Anticipation***

A crucial question arises when considering accidents external costs: which part of accident costs is external and up to which level risk anticipation should be considered? The answer to this question depends on two assumptions. Firstly, the difference between individual and collective risk behavior; secondly, the allocation of insurance premiums. For both assumptions different views are possible. Rational behavior suggests that individuals should be able to anticipate their own risk. However it is questionable if there is a difference between a willingness-to-pay to reduce the own risk or the risk for others (such as relatives and friends). If there is a significant difference, self accidents with fatalities would have rather low external costs, since ‘only’ the costs for relatives and friends are relevant. If there is no difference, the willingness-to-pay is collective and there is no difference in external costs levels between self accidents and accidents with other actors involved, or in other words: the willingness-to-pay for the own risk is similar than the willingness-to-pay of relatives and friends. As regards the allocation of risk insurance premiums, two views are to be considered. The first view focuses on transport individuals and does only consider risk dependent premiums, such as *bonus-malus* systems, etc. The other view focuses on the total transport systems considering the total cost recovery. Within this approach, all insurance premiums (as well not transport related ones, such as health care insurances) are considered to cover accident costs. Thus the values of the second approach are considerably lower.

The bottom-up approach combined with the assumption of full risk anticipation leads to the lowest values, whereas the top-down approach with a risk oriented allocation of individual insurance premiums leads to rather high values. Nevertheless, there is no scientific consensus on a best practice approach.

#### **2.8.4.3. *Human Capital and Comprehensive Approach***

Crash cost studies may be also categorized based on the scope of impacts that are considered. In this case, two general perspectives can be found:

- the *Human capital method* measures only market costs (property damage, medical treatment, and lost productivity);
- the *Comprehensive approach* adds non-market costs, including pain, grief, and reduced quality of life, as reflected by people's willingness-to-pay for increased safety (i.e. reduced risk of crashes and reduced crash damages), or willingness-to-accept increased crash risk and damages. It is a more appropriate measure of the true cost to society of crashes, and the appropriate value to use when assessing crash prevention.

There is some variability in these cost values since analyses results depend on how research is conducted and on the economic and demographic attributes of the population under consideration (for example, values are generally considered higher for people in the prime of life than for people who are older and so can expect to live fewer years).

Moreover, crash rates are affected by a large number of factors, such as roadway design, traffic speeds, traffic density, vehicle mix and speed variation: this makes their evaluation even more difficult.

#### **2.8.5. *Congestion Costs Valuation***

Congestion costs consist of incremental delay, driver stress, vehicle costs, crash risk and pollution resulting from interference between vehicles in the traffic stream, particularly as a road system approaches its capacity (Hau, 1992).

Congestion arises from the mutual disturbance of users competing for limited transport system capacity. The external costs caused by congestion are affected by specific factors: the most important are vehicle size (larger and heavier vehicles cause more congestion than smaller, lighter vehicles because they require more road space and are slower to accelerate) and vehicle speed (congestion costs per vehicle-mile increase with speed because faster vehicles require more “shy distance” between them and other objects).

Congestion costs actually consist of internal and external components. Internal or private congestion costs are those increasing time and operating costs experienced by an operator when approaching or exceeding system capacity. External congestion costs are those costs experienced by all other system users due to the entrance of this operator into the system. External congestion costs are commonly not taken into account by transport users and decrease social welfare.

On access-regulated infrastructures, the presence of ‘big players’ can significantly decrease the share of congestion costs that are external, because those costs imposed on other users of the same company are internal to this company. Congestion externalities are thus higher for small companies (Johnson and Savage, 2006). In the extreme case of only one operator, e. g. in the case of national railway carriers, external congestion costs might become zero (INFRAS/IWW, 2004). In this case only scarcity costs are present, expressing the insufficiency of infrastructure capacity.

#### **2.8.5.1. *Effects of Congestion and their Cost***

Depending on the mode of transport, type of users, infrastructure characteristics, local travel time and activity alternatives, excess demand can cause several effects:

- *Travel time increase* constitutes the most important component of congestion. Applying standard valuations of travel time losses, this category commonly accounts of 90% of economic congestion costs. The Value of Time (VOT) or Value of Travel Time Savings (VTTS) can be distinguished between trip purposes, modes and journey length in passenger travel and mode and commodity type in freight transport;

- *Vehicle provision and operating costs*, including depreciation, driving personnel and increased wear and tear under congested travel patterns are highly important for commercial transport. Nevertheless, they are commonly included in the values attributed to travel time increases;
- *Disamenities in crowded systems* are relevant for passenger transport and appear on congested roads as well as in public transport systems. The Value of Travel Time under crowded conditions is thus increased by roughly 50% compared to normal travel conditions;
- *Additional fuel costs* arise from the fact that fuel consumption of vehicles under stop-and-go conditions and of planes in holding stacks are above fuel consumption in free flow traffic. Commonly this category consists of 10% of congestion costs;
- *Reliability*: the higher valuation of delay time compared to standard in vehicle time commonly relates to the unreliability of travel times caused by congestion. In particular in freight transport this is considered much more of a problem than the pure increase of average travel times. Specific indicators like the buffer time index (Schrank and Lomax, 2005) aim at describing the recovery margins which travelers and shippers consider keeping their desired arrival time under various traffic conditions;
- *Scarcity of slots* is a particular phenomenon on access regulated infrastructures, i.e. on railway networks, airspace and airports. Scarcity costs denote the opportunity costs to service providers for the non-availability of desired departure or arrival times. The value of scarcity effects strongly depends on market conditions and internal cost structures of the service provider. Auctioning processes or the application of operational models are thus commonly recommended to value them. Besides the costs of scarce slots, additional costs such as delay costs (due to unstable service conditions, in form of additional operating and time costs) can arise. The current debate is on whether both elements can be part of a capacity fee and how to deal with the different valuation of displaced services from both a social and an entrepreneurial perspective (Nash *et al.*, 2006);
- *Positive externalities* of improved or additional services inflicted by new users but providing benefits to passengers or shippers already using the system are

commonly entitled as Mohring-effect. These positive externalities may balance or even over-compensate for some congestion and scarcity costs.

### **2.8.5.2. *Bottleneck Congestion and Flow Congestion***

According to the type of infrastructure facility, congestion effects can be separated into two types (AFFORD Project, 2000):

- *Bottleneck congestion* appears at road junctions, railway stations, ports and airports. Additional user costs are driven by the capacity and load-dependent processing time of the facility, including queuing effects. The kilometers travelled by vehicles are irrelevant for this type of congestion. In road transport, bottleneck effects are most relevant in urban networks;
- *Flow congestion* denotes the exceeding of carrying capacities of links. On the macroscopic level this type of congestion can easily be described by speed-flow diagrams, micro simulation models face the challenge of the partial dependency of vehicle speeds on each other.

Real networks commonly face a mixture between bottleneck and flow congestion (Parry et al., 2007).

According to the type of infrastructure facility congestion, different types of measures are necessary. The much higher importance of flow congestion on interurban roads calls for distance-dependent internalization measures, while access charges may suite better in urban areas, ports or airports.

### **2.8.5.3. *Congestion Cost Indicators***

According to literature contributions, the most appropriate approach for quantifying congestion costs, although difficult to perform, is to calculate the marginal delay caused by an additional vehicle entering the traffic stream, taking into account the speed-flow relationship of each road segment. Another approach is to determine the user fee needed to reduce demand to design capacity, based on travelers' willingness-to-pay for road use. A third approach is to calculate unit costs of current expenditures on congestion

reduction projects. In theory these three methods should produce similar values, assuming that roadway capacity is expanded based on vehicle delay costs as reflected in vehicle users' willingness to pay, but in practice they often provide different results. In addition, necessary data is often limited, making accurate congestion costing difficult.

For monitoring purposes of transport system quality, different delay or excess cost indicators are commonly used. Their concept is to compute the average user costs or travel times above a certain threshold level of the minimum acceptable quality standard. Nevertheless, this concept does not allow a distinction between private and external congestion costs. Congestion can also be expressed by qualitative measures, such as Level-of-Service indicators. Such information is, however, not so helpful for price as it is hard to express it in monetary terms.

Comparing the various methodologies used for calculating congestion external costs, there is consensus on the basic approach valuing the time losses based on speed-flow characteristics (interurban road transport), bottleneck and queuing functions (urban road and aviation) and on applying opportunity cost approaches for scarce tracks and slots (rail and aviation). The evidence for congestion costs on road networks is much more elaborated than for congestion and scarcity in scheduled transport, in particular for regulated rail networks. Nevertheless, the difference between the proposed values for road is quite significant, depending on the type of infrastructure, the speed-flow characteristics and the input values such as the value of time.

Different congestion indicators represent different perspectives and assumptions, which can favor certain solutions over others. For example, roadway *LOS* and the *Travel Time Index* only consider motorists' delays. *Percent Travel Time* declines if uncongested vehicle travel increases, for example, due to increased sprawl. These indicators ignore congestion cost reductions to travelers who shift modes and reduced travel distances, and so are unsuited for evaluating the congestion reduction benefits of alternative modes, mobility management strategies and smart growth policies. Indicators that reflect *per capita* rather than *per vehicle* impacts are more suitable for evaluating total congestion costs. Table 2.5 summarizes the most commonly used congestion indicators.

Indicator	Description	Comprehensive?
Roadway Level Of Service (LOS)	Intensity of congestion at a particular roadway or intersection, rated from A (uncongested) to F (most congested).	No
Travel Time Rate	Ratio of peak period to free-flow travel times, considering only recurring congestion delays.	No
Travel Time Index	The ratio of peak period to free-flow travel times, considering both recurring and incident delays (e.g., traffic crashes).	No
Percent Travel Time In Congestion	Portion of peak-period vehicle or person travel that occurs under congested conditions.	No if for vehicles, yes if for people.
Congested Road Miles	Portion of roadway miles congested during peak periods.	No
Congested Time	Estimate of how long congested "rush hour" conditions exist	No
Congested Lane Miles	The number of peak-period lane miles with congested travel.	No
Annual Hours Of Delay	Hours of extra travel time due to congestion.	No if for vehicles, yes if for people.
Annual Delay Per Capita	Hours of extra travel time divided by area population.	Yes
Annual Delay Per Road User	Extra travel time hours divided by peak period road users.	No
Excess Fuel Consumption	Total additional fuel consumption due to congestion.	Yes
Fuel Per Capita	Additional fuel consumption divided by area population	Yes
Annual Congestion Costs	Hours of extra travel time multiplied times additional monetized travel time and fuel costs.	Yes
Congestion Cost Per Capita	Additional travel time costs divided by area population	Yes
Congestion Burden Index (CBI)	Travel rate index multiplied by the proportion of commuters subject to congestion by driving to work.	Yes
Avg. Traffic Speed	Average peak-period vehicle travel speeds.	No
Avg. Commute Travel Time	Average commute trip time.	Yes for commuting
Avg. Per Capita Travel Time	Average total time devoted to travel.	Yes

Table 2.5. Congestion cost indicators  
(source: Litman, 2009)

### 2.8.6. Valuation of other Cost Categories

As already mentioned, research on external costs often focuses mainly on the most important cost categories such as noise costs, air pollution costs, accident costs or climate change costs. Other external cost categories are often neglected. There are several reasons for that, such as:

- the complex impact patterns and uncertain valuation approaches for the other environmental costs such as nature and landscape, soil and water pollution costs;
- the lack of direct relation to infrastructure use and thus to infrastructure pricing, such as costs for infrastructure related nature and landscape and urban areas;

- the difficult allocation to the transport system, such as costs of up- and downstream processes and costs of energy dependency.

Methodologies for calculating minor cost categories have been developed only in very few studies, therefore the calculation methods are far from being sophisticated and fully reliable.

Specifically, the costs for nature and landscape as well as the costs for soil and water pollution are the very complex impact patterns of the natural ecosystems. This causes the knowledge about the detailed impact patterns and dose-response relationships to be less developed than for other cost categories. Negative impacts of transport activities on the natural environment can be often proven. However, the detailed relationship between activity and impact can hardly be quantified. As a consequence, damage costs can often not be quantified and the calculation has to be done with second best approaches such as the estimation of repair cost based on specific local situations.

### **3. European Strategies Towards Transport Sustainability**

#### **3.1. Introduction**

Transport generates negative externalities involving a significant cost to society: it gives rise to environmental impacts, such as accidents, noise, congestion. In contrast to the benefits, the costs of these effects are generally not borne by the transport users. Without policy intervention, these so called external costs are not taken into account by the transport users when they make a transport decision: transport users are thus faced with incorrect incentives, leading to welfare losses. Internalizing external costs means making such effects part of the decision making process of transport users. According to the welfare theory approach, internalization of external costs by market-based instruments may lead to a more efficient use of the infrastructures, reduce the negative side effects of transport activity and improve the fairness between transport users. Internalization of external cost of transport has been an important issue for transport research and policy development for many years in Europe and worldwide. A substantial amount of research projects, most of which supported by the European Commission, suggest that implementing market-based instruments inspired by the economic theoretical concept of marginal social cost pricing could yield considerable benefits.

Fair and efficient transport pricing has been advocated in a number of policy documents issued by the European Commission, notably the 2006 mid-term review of the White paper on the European Transport Policy. In this paper it is remarked that transport users have to pay costs that are directly related to the use of their mode of transport (fuel, insurance, etc.): such costs are considered *private* in the sense that they are paid directly by the user. However, it is underlined that transport users also generate negative externalities that involve a cost to society, such as delays to other drivers as a result of congestion, health problems caused by noise and air pollution and, in the longer term, effects of greenhouse gas emissions on climate change. Nevertheless, users do not bear those costs directly (*external costs*). Such costs are real, even if they do not always have an explicit market value: they refer to expenditures on police and infrastructure management, hospital charges, public health spending and loss of quality of life. They

are generally borne by the State and its citizens. The sum of the private and external costs of transport gives its *social* cost. Only a price based on the total social costs generated by the transport user, states the European Commission, will help to give the right price signal and take account of the services used and the consumption of scarce resources. However, for that price signal to be effective, transport users must be price sensitive. Sometimes this is not possible for specific reasons, such as the lack of credible alternatives, insufficient competition with regard to a particular mode of transport, insufficient incentive to innovate and switch to clean vehicles, etc.

Internalization is a necessary step in itself, but it must be accompanied by other measures intended to create greater elasticity of demand, i.e. greater sensitivity to price variations, to make the supply of certain services more attractive or to speed up technological innovation. In order to reduce the external costs, a strategy is therefore needed that includes various other elements in addition to internalization, elements such as providing infrastructure, encouraging technological innovation, competition policy, legislation and setting standards.

### **3.2. *Internalization of External Costs as a Policy Request***

At European level, the evaluation of the external effects of transport is required in an internalization prospect: as remarked previously, the internalization of the external effects aims at making such effects part of the decision making process of transport users. This can be done directly through regulation, i.e. command and control measures, or indirectly through providing better incentives to transport users, namely with market-based instruments (e.g. taxes, charges, emission trading). Combinations of these basic types are possible: for example, existing taxes and charges may be differentiated, e.g. to Euro standards. Internalization of external costs by market-based instruments is generally regarded as an efficient way to limit the negative side effects of transport. Nevertheless, it requires detailed and reliable estimation of external cost: this is the starting and most critical point of the whole analysis.

In effect, estimation and internalization of external costs of transport have been important issues for European transport research and policy development for many years. The European Commission has raised the issue of internalization in several

strategy papers, such as the Green Book on Fair and Efficient pricing (1995), the White Paper on Efficient Use of Infrastructure, the European Transport Policy (2001) and its midterm review of 2006. Following a number of research projects, the approaches of the European Commission are based on the economic theoretical concept of marginal social cost pricing. The White Book of the Overall Transport Strategy (Time to Decide, 2001) and the midterm review (Keep Europe Moving, 2006) underline the need of fair and efficient pricing considering external costs. Research projects have shown that internalization of external costs by pricing measures can be an efficient way to reduce the negative impacts of transport. In general it may:

- improve transport efficiency (e.g. efficient use of scarce infrastructures, energy and environmentally efficient rolling stock, efficient use of different transport modes);
- guarantee fairness between transport modes, that means obtaining fair prices considering the overall performance and potentials of the different transport modes;
- improve safety and reduce environmental nuisances in the transport sector.

### **3.3.            *The Background: a Global Commitment***

#### **3.3.1.        *The Kyoto Protocol***

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change. It was ratified with the aim of becoming the chief instrument for tackling climate change, as it contained the undertaking entered into by most of the industrialised countries to reduce their emissions of certain greenhouse gases by an average of 5%. Nonetheless, a large number of industrialised countries failed to achieve the objective of stabilising greenhouse gas concentrations at these levels.

The major feature of the Kyoto Protocol is that it set binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions. Recognizing that developed countries are principally responsible for

the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol was meant to place a heavier burden on developed nations under the principle of “common but differentiated responsibilities.”

The Protocol was adopted in Kyoto, Japan, on 11<sup>th</sup> of December, 1997. The detailed rules for the implementation of the Protocol were adopted at COP7 in Marrakesh in 2001, and are called the “Marrakesh Accords.” On 31<sup>st</sup> of May, 2002 the European Union ratified the Kyoto Protocol. Following its ratification by Russia, the Protocol entered into force on 16<sup>th</sup> of February, 2005. Several industrialised countries, though, refused to ratify the Protocol, including the United States.

The Kyoto Protocol tackled emissions of six greenhouse gases:

- carbon dioxide (CO<sub>2</sub>);
- methane (CH<sub>4</sub>);
- nitrous oxide (N<sub>2</sub>O);
- hydrofluorocarbons (HFCs);
- perfluorocarbons (PFCs);
- sulphur hexafluoride (SF<sub>6</sub>).

This document represented an important step forward in the effort to tackle global warming as it included binding, quantified objectives for limiting and reducing greenhouse gases.

Overall, the parties which ratified the Protocol undertook to reduce their greenhouse gas emissions by at least 5% below 1990 levels during the period 2008 to 2012, the EU Member States collectively should have reduced their greenhouse gas emissions by 8% between 2008 and 2012. The Protocol suggested various means of attaining these objectives:

- stepping up or introducing national policies to reduce emissions (greater energy efficiency, promotion of sustainable forms of agriculture, development of renewable energy sources, etc.);
- cooperating with the other Contracting Parties (exchanges of experience or information, coordination of national policies in a bid to tackle work effectively through cooperation mechanisms, namely emission permits, joint implementation and a clean development mechanism).

Under the Treaty, countries had to meet their targets primarily through national measures. However, the Kyoto Protocol offered them an additional means of meeting their targets by way of three market-based mechanisms:

- *Emissions trading* – known as “the carbon market”: allowed the countries involved in the program to buy reduction units from other countries involved in the program too, in order to respect the emission targets;
- *Clean development mechanism (CDM)*: allowed the countries involved in the program to develop emissions reduction projects in countries not involved in the program and to use them in order to respect the emission targets;
- *Joint implementation (JI)*: allowed the countries involved in the program to develop emissions reduction projects in countries involved in the program too and to use them in order to respect the emission targets.

These mechanisms were meant to help stimulate green investments and to help Parties meet their emission targets in a cost-effective way. Under the Protocol, countries’ actual emissions had to be monitored and precise records had to be kept of the trades carried out. The Kyoto Protocol was also designed to assist countries in adapting to the adverse effects of climate change. It was meant to facilitate the development and deployment of techniques that could help increase resilience to the impacts of climate change.

### **3.3.2. *Beyond Kyoto***

The Kyoto Protocol was generally seen as an important first step towards a truly global emission reduction regime that would have stabilized GHG emissions, and was meant to provide the essential architecture for any future international agreement on climate change. Nevertheless, in 2007 the IV Climate Report and the World Energy Outlook by the International Energy Agency clarified the ineffectiveness of the Protocol: while the aim should have been a reduction of global emission of at least 50% in the following 30 years in order to decrease CO<sub>2</sub> concentration, in effect an increasing consumption of fossil combustibles in Asia, South America and USA was recorded. This increased consumption would have generated an increase in CO<sub>2</sub> global

emissions of 60% within 2030. Basically, the Protocol had failed. In the same year, in Bali, the Conference on Climate Changes had defined a road map in order to get ready for the ratification of a new treaty which would have gone beyond Kyoto and would have finally involved USA, China and other development economies in a shared commitment.

Many experts thought that this ratification would have been agreed and signed at the 15th "Conference of the Parties to the United Nations Framework Convention on Climate Change" (COP15) which took place in Copenhagen in December, 2009. Nevertheless, in the end at the Convention no formal agreements were taken, but only voluntary commitments on a national basis were proposed, without deadlines nor verifications. This failure generated big worries in the scientific community which became afraid that the climate situation might have soon started to become uncontrollable.

In December 2010 a new Conference of the Parties (COP16) took place in Cancun: despite of the negative basis represented by the previous failures, this conference was surprisingly successful.



Figure 3.1. COP16 logo

COP16 has drawn a concrete project for the climate and environmental protection: a decrease in the emissions from 25 to 40% by the end of 2020 (compared to 1990 values) and a 100 billion dollars package per year for the clean technologies transfer and the tropical forests preservation are the two most significant successes of the conference. The main aim of the congress consisted in developing a global environmental consciousness and an international commitment before the expiry of the Kyoto Protocol, in 2012. In this process, the most difficult task consisted in convincing and involving in the commitment all those strategic countries (first of all USA and China) which had not accepted nor applied any of the principles stated in Kyoto. From this point of view, COP16 has been a success: even though no formal commitments have been signed, all the 194 countries taking part in the congress have agreed on a common line. In particular, China has accepted the transparency criteria on the emissions controls which represented for the USA a fundamental precondition for the negotiation. Moreover, all the countries have opened to the possibility of defining binding commitments within 2020. Even the most radical countries (including India) have embraced a multilateral position and have given the availability to create more efficient mechanisms for the transfer of clean technologies. COP16, in the end, has represented an important boost towards a common environmental and social commitment which should be definitely shared among all the most strategical countries to be successful.

### **3.4. *Current Actions at European Level***

#### **3.4.1. *Trans-European Networks Programme***

The idea of Trans-European Networks (TEN) emerged by the end of the 1980s in conjunction with the proposed Single Market. It made little sense to talk of a big market, with freedom of movement within it for goods, persons and services, unless the various regions and national networks making up that market were properly linked by modern and efficient infrastructure. The TEN-T Guidelines envisage the establishment of a single, multimodal network as the ultimate policy objective, covering both

traditional ground-based structures and equipment (including intelligent transport systems) to enable safe and efficient traffic. Increasingly, they also involve the deployment of innovative systems that not only promise benefits for transport but also have substantial potential for industrial innovation. The construction of Trans-European Networks represents thus an essential element for economic growth and the creation of employment within the European boundaries. The European Union has aimed to promote the development of Trans-European Networks as a key element for the creation of the Internal Market and the reinforcement of economic and social cohesion. This development includes the interconnection and interoperability of national networks as well as access to such networks. According with these objectives, the Community has developed guidelines covering the objectives, priorities, identification of projects of common interest and broad lines of measures for the three sectors concerned: Transport, Energy and Telecommunications.

#### ***3.4.1.1. Main Guidelines***

Regarding the Transport sector, the TEN project is based on the awareness that transport infrastructure is fundamental for the mobility of the people and goods and for the territorial cohesion of the European Union. The EU disposes of 5,000,000 km of paved roads (out of which 61,600 km are motorways); 215,400 km of rail lines (out of which 107,400 km electrified); 41,000 km of navigable inland waterways. The total investment on transport infrastructure on the period 2000-2006 amounted to 859 billion Euros. Most of these transport infrastructures have been developed under national policy premises. In order to establish a single, multimodal network that integrates land, sea and air transport networks throughout the Community, the European policymakers decided to establish the Trans-European transport network, allowing goods and people to circulate quickly and easily between Member States and assuring international connections. Establishing an efficient Trans-European transport network is a key element in the strategy for competitiveness and employment in Europe. If Europe is to fulfill its economic and social potential, it is essential to build the missing links and remove the bottlenecks in the transport infrastructure, as well as to ensure the sustainability of our transport networks into the future. Furthermore, it integrates

environmental protection requirements with a view to promoting sustainable development.

In view of the growth in traffic between Member States, expected to double by 2020, the investment required to complete and modernize a true Trans-European network in the enlarged EU amounts approximately to 500 billion Euros from 2007 to 2020, out of which 270 billion Euros need to be dedicated to the priority axis and projects. Given the scale of the investment required, it becomes necessary to priorities projects, in close collaboration with national governments, and to ensure effective European coordination. The European Community is supporting the TEN-T implementation through several Community financial instruments and loans from the European Investment Bank. Grants, in particular under the TEN-T budget line and the Cohesion and European Development Funds, play a major role in both project preparation and implementation phases. Grants are allocated to studies (from feasibility studies to comprehensive technical or environmental studies and costly geological explorations), helping to overcome early stage project difficulties, and to the works phase. A key issue for the future in relation to the implementation of the TEN-T policy is to rationalize the allocation of grants and to link it to the projects' European added value so as to ensure the best value for Community money. In this context, the Trans-European Transport Network Executive Agency (TEN-T EA) was created in 2006 to implement and manage the TEN-T programme on behalf of the European Commission. Projects of common interest within TEN-T differ considerably from each other in many respects: planning processes, geographical extension and cost, implementation periods and life span, as well as investment, implementing and operating structures. TEN-T policy has to cater for a broad range of approaches whereby Member States play a leading role in traditional infrastructure provision and work alongside the private sector. The nature of the network itself therefore places particular responsibility on all of the actors involved to share objectives and play their respective parts in achieving those objectives.

#### **3.4.1.2.     *Achieved Results***

Some positive changes resulting from the implementation of TEN-T policy are already visible. National rail and road networks have become interconnected at many points and

railways across borders are beginning to become interoperable. Community funding has concentrated on major high-speed rail projects, opening up a new generation of passenger traffic that can compete successfully with air and private cars. Finance has been channeled, under the Cohesion Fund, into major projects connecting countries and regions with differing levels of development, thereby helping to reduce disparities. The project has had a significant catalytic effect and has enabled some of the most challenging and complex projects (geologically, technically, financially, legally and administratively) to be taken forward. It has promoted pilot schemes for public-private partnership solutions, which allow lessons to be learnt in terms of financing and project management. TEN-T policy has also stimulated the development of intelligent transport systems. The transport sector has – in the fields of road, rail, air and waterborne – made significant progress through TEN-T supported projects at European or euro-regional level, many of which would otherwise not have been implemented or launched. TEN-T policy has begun to provide responses to issues in the field of freight transport, where expected growth (an increase of 34% between 2005 and 2020) underlines the importance of introducing real co-modal solutions to overcome problems such as congestion, rising carbon dioxide emissions, infrastructure and organizational gaps.

### ***3.4.1.3. Network Implementation***

The TEN-T priority projects cover major rail, road and inland waterway axes that traverse several Member States. Chosen in 2004 for their high relevance to transnational traffic flows, cohesion and sustainable development objectives, they were subjected to a common socio-economic evaluation. The TEN-T Guidelines are also linked with instruments to facilitate the implementation of projects identified as being of common interest. These are various financial instruments based on the relevant legislation, including the TEN Financial Regulation and the Cohesion Fund, ERDF and loans from the European Investment Bank, and also non-financial instruments, such as coordination initiatives taken by the Commission.

Even though some important results have been already achieved, so far the instruments available have not been sufficient to deliver full completion of projects of common interest within the timeframe agreed in the Guidelines. This is particularly true for the

comprehensive network. Responsibility for completing the large numbers of projects concerned rests almost entirely with the Member States, whose investment decisions are essentially driven by national objectives. Community funding under the Cohesion Fund has supported project implementation in eligible Member States, and has thus also contributed to the access function (including access to ultra-peripheral regions); TEN-T funding has only been able to address policy objectives in part. Overall, Community resources spent so far have barely enabled citizens and economic operators to "see the difference" (the European added value) of Community action in relation to the comprehensive TEN-T as a whole. Investment efforts by Member States on their respective territories are mostly seen as national investments rather than as contributions to a Community objective.

The situation has been different with priority projects, which have been at the centre of Community efforts, both financially and in terms of coordination. Although the Community financial resources available are still not sufficient to meet the needs of these projects in full, action directed towards more limited and commonly agreed objectives has been far more effective and visible. The approaching completion of some of these projects provides a concrete illustration of the potential benefits of the TEN-T policy objectives. For example, a key TEN-T priority project such as the high-speed railway line linking Paris, Brussels, Cologne/Frankfurt, Amsterdam and London has not only interconnected national networks and marked a breakthrough of a new generation of railway traffic across borders, it has also allowed citizens and business travelers to experience the benefits of free movement within Europe. The Motorways of the Sea priority project (covering infrastructure, facilities, procedures, technologies and services) is intended to foster quality and high-capacity integrated multi-modal, door-to-door transport services with a maritime leg. It is defined in the TEN-T Guidelines by way of a conceptual approach setting out objectives and procedures for identifying projects of common interest. This has helped the Community to develop a practical application of a co-modal transport solution aimed at improving accessibility and reducing emissions from road freight transport. Various Community and national instruments are available, including the TEN-T budget, which mainly addresses infrastructures in ports and hinterland connections. The complexity of procedures for obtaining public financial support and the lack of clear objectives and criteria have however hindered any broad implementation of the concept so far.

As regards intelligent transport systems, TEN-T policy has helped in particular to prepare Galileo and the Single European Sky Air Traffic Management Research (SESAR): major European projects which, once operational, are expected to make the use of transport infrastructure far more efficient. In road, rail and air transport, as in Vessel Traffic Management and River Information Services, ITS projects have been developed in a flexible way, on the basis of characteristics set out in the TEN-T Guidelines. This conceptual approach makes it possible to incorporate technological developments, market needs and cooperation initiatives between partners from different Member States and, combined with the 50% funding possibility for project preparation, has had a significant impact on the development of cross-border projects which might not have existed otherwise. This kind of flexible approach to project development, based on pre-established objectives and criteria, should also be lend itself to achieving other transport policy objectives, such as the provision of efficient (both economically and environmentally), safe, secure and high quality transport services.

#### ***3.4.1.4. Future Objectives***

TEN-T policy is constantly monitored and was formally reviewed in 2009: the Green Paper "Towards a better integrated trans-European transport network at the service of the common transport policy" published in February, 2009 opened the TEN-T policy review. Stakeholders, European Institutions and consultative bodies broadly welcomed the review and the approach proposed. Trans-European transport network policy aims to provide the infrastructure needed for the internal market to function smoothly and for the objectives of the European agenda on growth and jobs to be achieved. It also sets out to help ensure accessibility and boost economic and social and territorial cohesion. It supports EU citizens' right to move freely within the territory of the Member States. Furthermore, it integrates environmental protection requirements with a view to promoting sustainable development. 400 billion Euros were invested so far in a network that was established by decision of the European Parliament and the Council in 1996, and last amended in 2004. As said, this investment has helped to develop a number of projects of common interest, interconnecting national networks and overcoming technological barriers across national borders. There is however still a long way to go to

implement the initial plans fully, because of both the intrinsic long-term nature of the projects involved and the considerable delays in the completion of many projects.

While transport policy aims to promote economically and environmentally efficient, safe and secure transport services within the internal market and beyond, TEN-T policy needs to ensure that they operate to best effect, based on an integrated and innovative infrastructure that keeps pace with technological developments in the energy, infrastructure and vehicle sectors. It should reflect established European objectives, not only in the transport sector but also in the wider political, socio-economic, environmental and institutional context.

In addition to strengthening TEN-T's role within the European agenda, Europe's growing global role requires attention to be paid to the development of future TEN-T policy. Europe's economic growth and the creation of jobs also depend on its international competitiveness, which needs to be supported by good transport connections with other parts of the world. Good connections to all of Europe's immediate neighbors are furthermore vital from an economic, political and security point of view. At the same time, the fight against climate change requires wide measures: transport and infrastructure are areas which offer considerable potential for positive contributions. Climate change objectives should be placed at the centre of future TEN-T policy and be reflected in a truly European approach. Through a process that integrates economic and environmental objectives, being clearly oriented towards the needs of efficient freight and passenger services on a co-modal basis and involving innovation, future TEN-T policy should provide a sound basis for an effective contribution to the Community's climate change objectives.

The TEN-T Guidelines are the Community's instrument for policy definition and network planning. The projects of common interest identified in those Guidelines can be defined through their location on outline plans and/or through their characteristics. The Guidelines include two planning layers: a comprehensive network layer (outline plans for rail, road, inland waterway, combined transport, airport and port networks) and a second layer of 30 priority projects – i.e. selected projects of common interest. The comprehensive network includes altogether: 95,700 km of road links, 106,000 km of railway links (including 32,000 km of high-speed links), 13,000 km of inland waterways, 411 airports and 404 sea ports. Most of these links and nodes already exist. However, almost 20,000 km of the road links, over 20,000 km of railway links (overwhelmingly high-speed lines) and 600 km of inland waterway links remain to be

built or substantially upgraded (at an estimated cost of 500 billion Euros, according to recent estimates of Member States). "Planning" this Community network has essentially meant adding together significant parts of national networks for the different modes and connecting them at national borders. While certainly appropriate in the early days of TEN-T policy, the adequacy of this approach became progressively weaker with each enlargement. So far, TEN-T network planning has not been driven by genuine European objectives that would ensure that the whole is greater than the sum of its parts. Irrespective of Member States' sovereign responsibility in the field of infrastructure planning and implementation on their territories, the question of how national planning can be combined with a European level of planning that takes account of objectives outside each individual Member State's perspective becomes more and more relevant as the EU expands and networks become increasingly complex.

#### **3.4.1.5. *Expected Transport Demand***

The planning of future transport infrastructure is closely linked to demand forecasts – whether at national or EU level. However, while aiming to provide transport infrastructure that responds in full to future demand, planning authorities face a range of uncertainties regarding factors that drive demand, such as economic and population trends, energy prices, transport pricing and taxation, the development of urban and territorial structures, behavioral changes, and technological developments. On the policy side, demand management measures are gaining increasing importance and should also be taken into account in infrastructure planning. These include in particular infrastructure charging, the internalization of external costs and the application of intelligent transport systems.

Business-oriented development of transport services in an evolving internal market should also encourage efficient use of infrastructure, and have an impact on the development of demand. Building on a co-modal approach that involves both effective coordination across national borders and ITS applications, services of this kind are growing rapidly. EU transport policy focuses on a range of initiatives in the field, including the Freight Logistics Action Plan, the proposal for a Directive on Rail Freight Corridors and the Single European Sky policy.

Business activities may be able to grow within the existing infrastructure framework in the shorter term, but as they evolve, the transport policy response will need to evolve too, which could impact both on transport infrastructure provision and its "phasing". The future TEN-T policy needs to be sufficiently flexible to link transport policy and transport infrastructure development in the short, medium and long term.

### **3.4.2.        *The Eurovignette Directive***

The introduction of market-based instruments for internalization of external cost has been discussed for different transport modes. To some extent it is also been substantiated in EU Directives, particularly related to infrastructure cost pricing. Within the rail sector, the marginal cost oriented pricing approach is considered as a basis for track pricing (Directive 2001/14/EC). Charges may be differentiated with respect to environmental impacts as long as this does not lead to additional revenues for the infrastructure manager. Additional revenues are only allowed if in competing modes a comparable level of charging of environmental costs takes place.

For the road sector, the "Eurovignette Directive" adopted in 1999 and revised in 2006 provides a framework for the levying of tolls and user charges on heavy goods vehicles for using Europe's motorways. It allows Member States to set tolls at levels required to maintain and replace infrastructure, with some additional flexibility in mountainous areas.

The Directive harmonizes levy systems (vehicle taxes, tolls and charges relating to the use of road infrastructure) and establishes mechanisms for charging infrastructure cost to hauliers. It covers vehicle taxes, tolls and user charges imposed on vehicles intended for the carriage of goods by road and having a maximum permissible gross laden weight of not less than 12 tonnes. There are some exceptions to the vehicles included, specifically vehicles carrying out transport operations exclusively in the non-European territories of the Member States and vehicles registered in the Canary Islands, Ceuta and Melilla, the Azores or Madeira and carrying out transport operations in these territories or between these territories and Spain or Portugal.

The Directive indicates which taxes are concerned in each individual country, each Member State is responsible for adopting procedures for levying and collecting these

taxes, which are charged by the country in which the vehicle is registered. Member States may not set vehicle tax rates any lower than the minimum rates set out in the Directive. Under the Directive, Member States also have the option, in certain cases and subject to certain conditions, of applying reduced rates or granting exemptions.

The Eurovignette Directive lists the conditions to be met by States wishing to introduce and/or maintain tolls or introduce user charges. These conditions are as follows:

- imposition only on users of motorways or similar roads, bridges, tunnels and mountain passes;
- application of the principle of no discrimination on the grounds of the nationality of the haulier or the origin or destination of the vehicle;
- no checks at internal borders;
- re-examination of maximum rates for user charges every two years;
- application of the principle of proportionality of rates for user charges, based on the duration of the use made of the infrastructures;
- possibility of varying the rates depending on the categories of emissions from the vehicles and/or the time of day;
- possibility for two or more Member States to cooperate in introducing a common system for user charges, subject to compliance with certain conditions such as the fair sharing of revenue among Member States.

In addition to the taxes provided for by the Directive, Member States may apply:

- taxes or charges levied upon registration of the vehicle or imposed on vehicles or loads of abnormal weights or dimensions;
- parking fees and specific urban traffic charges;
- charges aimed at combating road congestion.

The revision to the Directive which took place in 2006 had the aim of establishing a new Community framework for charging for the use of road infrastructure. This makes it possible to improve the efficiency of the road transport system and ensure the proper functioning of the internal market. The revised Directive lays down new rules for the application by Member States of tolls or user charges on roads, including roads on the trans-European road network and roads in mountainous regions. Member States are able

to differentiate tolls according to a vehicle's emission category ("EURO" classification) and the level of damage it causes to roads, the place, the time and the amount of congestion. This makes it possible to tackle the problems of traffic congestion, including damage to the environment, on the basis of the "user pays" and "polluter pays" principles.

This Directive is a significant step towards the implementation of a European road charging policy. Nevertheless, one significant constraint is given by the requirement that revenues may not exceed related infrastructure costs. The Directive only allows a limited differentiation of charges according to capacity or environmental criteria. Only for mountainous areas a markup (up to 25%) is possible, considering the higher level of infrastructure costs.

In the Directive there is an explicit reference to the need of a further and deeper investigation in order to ensure that all impacts and obstacles to the internalization of external costs are addressed. This, states the Directive, can be done by examining the full range of external costs for all modes of transport, presenting a basis for assessing all external costs, analyzing the impacts of the internalization of external costs and, finally, preparing a strategy for a stepwise implementation of the model for all modes of transport.

### **3.4.3. *Marco Polo Programme***

The Marco Polo programme of the European Union aims at reducing traffic congestion on Europe's crowded roads and promoting environment-friendly means of transport. It is based on a simple strategy: shifting as much freight traffic as possible from roads to other modes of transport. While roads are overused, rail, sea and inland waterways often have spare capacity, and they also pollute less. Marco Polo aims at improving the environmental performance of European freight transport, by freeing the roads of an annual volume of 20 billion tonne-kilometers of freight, the equivalent of more than 700,000 trucks a year travelling between Paris and Berlin. This translates into substantial environmental, societal and economic benefits.

The programme is focused on three combined actions: development of Motorways of the Sea, congestion reduction and improvement of the geographical transport coverage.

### **3.4.3.1. *Motorways of the Sea***

Under Motorways of the Sea a series of actions are grouped which directly transfer the transport from road to sea with alternative modes, thus minimizing the distances covered by road. Such actions can involve the modification or the creation of auxiliary structures which are needed to develop an intermodal service. Motorways of the Sea represent a transport mode which is meant to be an efficient alternative to road transport: this is achieved through cabotage lines among national ports and short-range sea transport among European Union ports. Goods are transported on sea routes of high profitability and pass through infrastructures which supply the handling operations at reduced time and cost, minimizing useless waiting time while warranting safety. This will bring not only a decrease in road congestion, but also a sensible reduction in atmospheric pollution and an overall economic advantage in the goods transport.

Within the Italian transport network a series of Motorways of the Sea were defined which support the transport at national level. A transporter, instead of crossing the country from one side to the other, can take one of the various sea ways and reach the required destination. In this way he can avoid congestion, tiredness, high pollution and consumption of his own mode and he will also gain a contribution called “ecobonus”. Through such bonus the Italian Government has planned a refund of the sea ticket cost for transporters who choose the Motorways of the Sea to travel (20% for existing routes and 30% for new routes). In this way the trip by sea becomes not only faster and safer, but also more convenient. This ecobonus is given to all those providers which travel for more than 80 times a year over the same sea route; moreover, the provider has to maintain the same number of trips (or the same amount of load) in a combined regime road-sea for the 3 years after the incentive is given. Over the last years there has been a constant increase (20% per year on average) of the road traffic being transferred to the sea: the goods transported by sea were 1.5% of the total transported quantities in 2000 and rapidly reached more than 3.5%. Every year more than 1,200,000 Italian trailers travel by sea instead of road.

### **3.4.3.2. *Marco Polo Support to Successful Projects***

Marco Polo incentives also actions which reduce road traffic by developing transit points, intermodal transport, efficient handling terminals. It is fundamental, in order to make these strategies work, that collaboration and coordination among operators working with different modes are supported and encouraged.

Marco Polo programme already involved a significant number of actors all over Europe, promoting new rail and inland waterway projects. Nevertheless, many projects recognize that even if rail, short-sea shipping and inland waterways offer a greener alternative and can compete with trucks on commercial terms, the case for switching still needs to be made. The business-as-usual mentality among operators is hard to break. Some forwarders accustomed to road transport fear that change might mean unnecessary risk.

Dynamic marketing, quality service and close customer care are shown to be vital tools for Marco Polo projects. Participants in the programme also enlist innovation and imagination to help their projects succeed. A number use innovative technologies to gain a competitive edge, or enhance service quality. These include common IT management systems, GPS for cargo track-and-trace, and new-design containers to facilitate intermodal handling. Some utilize big European infrastructure projects, such as the Oeresund tunnel and bridge between Denmark and Sweden, to offer door-to-door international transport services. Others have turned the Sunday ban on heavy trucks in several EU countries to their advantage by providing weekend freight services by rail or sea. As a number of participants to the programme admit, they take a commercial risk in launching their projects. Even if the Marco Polo programme offers funding only in the start-up period, it helps in two ways. On one hand, it provides an EU stamp of approval for their project and enhances their green credentials. On the other hand, many of the projects would not have got under way, or would have had to be scaled-down, without the benefit of a Marco Polo grant. Marco Polo is user-driven: if a company has a project to transfer freight from road to rail or short-sea shipping routes or inland waterways, it may qualify for a Marco Polo grant. The project has to involve a cross-border route, the grant is performance-related. It is not required that the company shifts all its traffic off the road. Inter-modal projects, combining road, rail and waterborne transport, are eligible. The concept of transport as a door-to-door service is important. Feeder traffic

and final distribution can be handled by road, but road journeys should be kept as short as possible.

In addition to direct modal-shift projects, Marco Polo also funds projects that provide supporting services, including management systems, integrated cargo control or common IT platforms to facilitate interoperability between partners and between modes. Training projects related to intermodal transport and logistics also qualify for grants. Marco Polo actively promotes traffic avoidance, awarding grants to road hauliers and manufacturers who devise new practices (like avoiding empty runs or using more efficient packaging) to reduce the need for road transport in the first place. The grants provide financial support in the crucial start-up phase of a modal-shift project before it pays its way to viability, they cover periods of two to five years. Projects should be commercially viable once the period of the Marco Polo funding is over. Successful participation in a Marco Polo project enhances a company's green credentials. So far more than 400 companies have benefited from funding: the current programme runs until 2013, with an annual budget for grants of about 60 million Euros.

In conclusion, freight transport clogs Europe's roads. Yet its railways, sea routes and inland waterways are underused. Marco Polo EU programme is designed to promote these environment-friendly modes of transport and to shift freight from congested roads. A significant number of companies, with Marco Polo support, already launched rail, short-sea shipping and inland waterway projects as greener alternatives for handling freight. To succeed, their projects had to make economic as well as ecological sense. Many road transport users hesitate to change modes without clear economic benefit. Contributors all say projects would have been scaled back or not launched at all without Marco Polo funding during the critical start-up phase. This helped make the economic case to customers for a switch to rail, short-sea shipping routes or inland waterways. Marco Polo support added credibility to projects – a valuable marketing tool – and enhanced the green credentials of project participants, another significant benefit.

### **3.4.4. Greening Transport Package**

#### **3.4.4.1. The Project**

The Greening Transport package was approved by the European Commission on July, 2008 with the aim to move transport further towards sustainability. This three-pronged proposed Commission package seeks to steer the European transport sector towards enhanced sustainability. The package opens with a proposal for a strategy to ensure that the prices of transport better reflect the real cost to society, so that environmental damage and congestion can gradually be reduced in a way that boosts the efficiency of transport and ultimately the economy as a whole. Moreover, it presents a proposal to enable Member States to help make this happen through more efficient and greener road tolls for lorries, with the revenues to be used to reduce environmental impacts from transport and cut congestion. Third, a communication is included to reduce noise from rail freight. The package also includes an inventory of existing EU measures on greening transport.

Following this path, the package is structured in five parts:

- *Greening Transport Communication*: it summarizes the whole package and sets out what new initiatives the Commission is planning to take in this field in the immediate future;
- *Greening Transport Inventory*: it describes the large amount of EU action already taken to green transport and on which the package builds;
- *Strategy to Internalize the External Costs of Transport*: it focuses on making transport prices better reflect their real cost to society so that environmental damage and congestion can be reduced while boosting the efficiency of transport and ultimately the economy as a whole;
- *Proposal for a Directive on road tolls for lorries*: it is aimed at enabling Member States to reduce environmental damage and congestion through more efficient and greener road tolls for lorries. Revenue from the tolls would be used to reduce environmental impacts and cut congestion;

- *Rail Transport and Interoperability communication*: it sets out how to reduce the perceived noise from existing rail freight trains by 50% and the measures the Commission and other stakeholders will need to take in the future to achieve this.

Antonio Tajani, Vice-President of the European Commission responsible for transport, said "This package is about tackling pollution and climate change, and making sure the polluter and not the taxpayer pays for environmental damage. Among the results will be greener transport, fewer emissions, up to 8% less fuel consumption by lorries and fewer hold-ups for all road users. Delays, unnecessary emissions and soaring costs are bad for transport companies, for their clients and for all of us. A more efficient and sustainable transport system will in the long run be a more user-friendly and cheaper transport system".

The Strategy on the internalization of external costs sets out how this can happen in all modes of transport. Building on existing EU measures and proposals, such as those on fuel taxation and including aviation in the EU's Emissions Trading System, it considers all external costs including climate change, local pollution, noise and congestion. It is accompanied by a common framework for estimating external costs in the EU.

The Proposal to revise the Directive on the charging of heavy goods vehicle for infrastructure use (Eurovignette Directive) is a key part of the strategy. It seeks to establish a framework which enables Member States to calculate and vary tolls according to the air and noise pollution from traffic emissions and peak-hour congestion levels. This will encourage freight transport operators to buy cleaner vehicles and improve their logistics and route planning. The tolls are meant to be collected using electronic systems with any revenue being used in projects to alleviate the negative impacts of transport, such as research and development on cleaner and more energy efficient vehicles. A common method must be used in toll calculation so that tolls are transparent, proportionate and compatible with the internal market.

The Greening Transport Package proposes new steps to make road and rail freight transport more environmentally friendly, such as the Communication on Rail Noise. Furthermore, the package explains what has been done and what will be done by the Commission in all transport modes. For example, with this package approval the European Parliament and the Member States agreed formally on the Commission's proposal to include aviation in the EU's emissions trading scheme. Existing EU legislation

allows Member States to charge trains for their environmental costs. Railways are also to a large extent covered by the European emissions trading scheme (ETS).

#### ***3.4.4.2. Focus on Road Transport***

The European commission decided to address specifically the road transport sector as it is responsible for 75% of the emissions of nitrous oxide from transport and congestion costs are estimated at 1.1% of EU GDP. Lorries create a quarter of all these negative effects. This is not surprising since 72% of the tonnes kilometres of goods transported by inland transport in the EU use lorries. Moreover, road freight transport is growing steadily, and faster than GDP (annual growth was 4.9% in 2006). The growth is in particular concentrated in international traffic, which is forecasted to double between 2000 and 2020. Getting traffic off the road and onto rail, inland waterways or short-sea shipping is just one way that the environmental impacts of road transport can be reduced. Because road transport is, and will remain, the way the bulk of passengers and goods are transported, ways need to be found to make it greener and more efficient too. The proposal to allow heavy goods vehicles to be charged for using infrastructure in a greener and more efficient way is therefore an important contribution, as is ongoing work to deploy new vehicle technologies, improve infrastructure, improve fuel efficiency and promote "eco-driving".

### ***3.5. Other Initiatives***

As seen, the Greening Transport Package is not the only measure that the Commission has ever taken to "green transport": air pollutant emissions from cars, vans, lorries and buses have been dramatically reduced by the increasingly stringent EURO standards defined under EU law, which set maximum emission levels for new vehicles. New cars are already required to have CO<sub>2</sub> labels and the Commission has also proposed to limit the CO<sub>2</sub> emissions from new cars and ensure public authorities buy greener vehicles. There are also EU standards on fuel quality, including on the sulphur content, which is particularly important in the maritime sector. The Commission has also set a 10% target

for the use of sustainable biofuels in transport and transport actions feature prominently in the EU's Energy Efficiency Action Plan. In the aviation sector, there are EU measures on airports noise and the EU institutions are on the verge finalising agreement on the sector's inclusion in the EU's Emissions Trading System. The Single European Sky II package aims to reduce emissions per flight. The EU has also taken a large number of measures, culminating in the Erika package, to reduce the likelihood of oil spills from ships. Moreover, it has financed projects through the already mentioned Trans-European Networks and Marco Polo programmes which have concentrated on promoting less-polluting transport modes such as rail, inland waterways and short-sea shipping. Other actions have been taken in the field of transport and more proposals are following. For instance, the Commission's current review of the Energy Taxation Directive will probably lead to a proposal for defining a common labelled CO<sub>2</sub> element in fuel taxation (an element which is not addressed in the Greening Transport Package).

### ***3.6. Current Taxation and Future Internalization of Externalities***

Existing taxes internalise only partially and inefficiently external costs from road traffic. The tax structure is inadequately related to the main cost drivers of pollution and congestion. Levels of vehicle tax are unrelated to how often the vehicle is used. Fuel taxes are the same for heavily polluting vehicles as for "greener" ones and do not distinguish between rush hour and off-peak use. Efficient charges should vary according to the type of vehicle, the distance and the congestion levels.

Congestion charging is not about asking users to pay twice but a way to manage limited road capacity more efficiently in order to reduce the overall costs for all users. On busy roads, big and heavy vehicles contribute much more to congestion. Of course, lorries suffer like all other vehicles from congestion. Like all other users, they will also benefit from less congested and better managed roads.

The current legislation, yet, does not address two main external costs causes (among the others): accidents and damages to the environment. Regarding accidents, the European Commission states that there are two main reasons why the costs are not taken into consideration. Firstly, it says, the level of external accident costs depends to a large extent on the applicable insurance system and the costs it covers. Secondly, unlike local

pollution and congestion costs, accident costs cannot be efficiently internalized by kilometer based charges as they are very much determined by individual driver characteristics and accident history. Regarding damages to biodiversity and landscape, the Commission asserts that those are mostly fixed costs which depend on the existence of transport infrastructure more than on the use that is made of it. Therefore kilometer based road user charges do not seem to be the most appropriate instruments to internalize these costs.

Sustainable transport requires considerable investments in research and development and infrastructure. Funding is particularly needed to reduce road pollution at source through local action plans on management of air quality and environmental noise, to improve the energy efficiency of vehicles and lower emissions and to offer a wider choice of realistic alternatives for users. Using the revenues from the tolls for investment in more sustainable transport will benefit transport users from all Member States.

Passenger cars are not within the scope of any of the current directives, which apply to heavy goods vehicles only. Member States are of course free to levy tolls on passenger cars as well. But passenger car traffic is much less international than road freight transport. So according to the principles of subsidiarity and proportionality there is currently no basis for European action. However, differentiated tolls applied to lorries on the basis of the cost of the congestion and pollution they cause will reduce congestion on busy roads and thus benefit all motorists travelling on those roads.

The proposals to internalize externalities are meant to help Member States to ensure that the polluter – rather than taxpayers in general – meets costs that already exist. They will also over time actually reduce both pollution and costs, by creating incentives that promote greener and more efficient transport. In the short term, they may lead to a small increase in road haulage costs of a few percent but this will be rapidly offset by efficiency gains (less congestion, less pollution). Transport costs (road haulage cost is only a part of those costs) range from 1 to 9% of final product values. Changes in toll structure will be fully predictable by firms which will anticipate them and adapt their behaviour. Any upward impact on price of goods in the shops in the short-term is likely to be insignificant, if noticeable at all. In the medium-term the impact on prices should be downwards.

The final aim is to improve the overall sustainability of road freight transport, in the interests of all citizens and businesses, including ultimately the road freight sector itself.

For example, the sector will benefit alongside other users from reduced congestion on busy roads. High fuel prices, for example, affect all households, all motorists and all industry. This confirms again the need for a more sustainable transport system, more efficient in energy use, less dependent on fossil fuels and with a smaller overall environmental impact. The high fuel price should not be used as a pretext to postpone initiatives to prepare the ground for a more sustainable transport system. On the contrary, it is a further reason to accelerate the adaptation of our transport system and reduce its dependency on fossil fuels. Of course the process will take time and both firms and logistic operators need time to adapt their behaviour.

A heavy goods vehicle with a EURO 0 engine generates on average more than 5 times more air pollution costs than a vehicle of the same size equipped with a EURO V engine; even compared to a EURO III engine, a EURO V engine cuts average air pollution cost by more than half. Financially rewarding hauliers for using cleaner vehicles will accelerate the renewal of the vehicle fleet. Similarly, by properly reflecting the actual cost of traffic based on noise pollution and differentiating between areas with different population densities, hauliers will be given a clear financial incentive to route their vehicle on motorways and trunk roads and avoid suburban areas as much as possible, thus improving quality of life. Users will also be able to reduce the congestion costs they generate and the charges they pay by scheduling their vehicles to operate outside peak hours and to avoid busy roads at busy times. If Member States implement this, the average amount to be extra paid is likely to be in the range of 4-5 eurocents per kilometre for a EURO IV truck. But this is only a rough estimate as exact charges for specific areas will vary widely and will depend on a complex set of developing circumstances, in order to ensure full reflection of the relevant external costs and provide incentives to reduce those without going beyond what is for that. The charges will be differentiated according to the pollution class of vehicles, the location of roads (suburban or interurban) and the time periods (high and medium peak, off-peak and night). The actual amount will vary from section to section as it will depend on the exact local situation, notably in terms of congestion. Congestion costs may be added during peak hours or days. Air pollution and noise costs can be higher on suburban roads than on long distance roads due to the higher population density in suburban areas. There are also provisions to allow the recovery of higher external costs in mountainous areas. Member States will anyway be able to apply higher tolls to certain roads, if that is justified by local conditions. Tolling schemes based on congestion and pollution costs will have to be notified and approved by the

Commission before application. The exact amount of the tolls will be set by independent authorities designated by Member States. The tolls can include a cost element related to traffic based air and noise pollution. A common methodology for calculating local external costs is needed to ensure proportionality and transparency of the tolls based on the cost of pollution and congestion. It will also ensure that there is no discrimination on the basis of the nationality of the haulier. It will be applied on the basis of local data, in a transparent and comparable way. Congestion and pollution occur in all Member States, and they have all an interest in a better tool box to manage congestion and pollution. New toll rates will have no distorting impact on the relative position of the national road haulage industry of any Member State with its competitors from other Member States since, unlike taxes, tolls are paid by all hauliers irrespective of their Member State of registration. Using the revenues from the tolls for investment in more sustainable transport will benefit transport users from all Member States: the proposal made by the European Commission is that Member States use the additional revenues from tolls to finance projects such as research and development on cleaner and more energy efficient vehicles, building alternative transport infrastructure for transport users, promoting local action plans on management of air quality and environmental noise.

### **3.7. *Statistics***

The European Commission elaborated a set of statistics in order to analyze current status of transport sector:

- *Transport performance:*

Road accounts for 73% of total land freight transport performance in tonne-kilometres;

- *Transport growth :*

Road freight is growing faster than GDP (annual growth is 4.9%); the growth rate of international road freight transport is especially high (doubling is forecast between 2000 and 2020);

- *Emissions from road transport in 2005:*

72% of total CO<sub>2</sub> emissions from transport;

75% of NOx emissions from transport;

Road transport CO<sub>2</sub> emissions increased by 17% between 1995-2005;

- *Costs:*

Road transport accounts for roughly 90% of the total external costs generated by the transport sector; congestion accounts for 1.1 % of GDP (more than the EU budget); environmental costs account for around 100 billion Euros. Some studies estimated the total costs (including infrastructure and accident) at around 500 billion Euros for all the Member States.

**Modal split of inland modes in freight transport in 2006  
(in tonne-kilometres)**

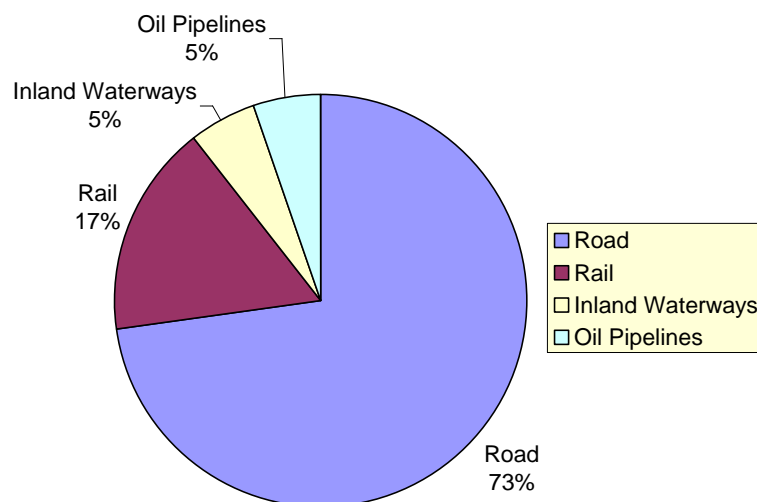


Figure 3.2. Modal split of inland modes in freight transport in 2006

### **3.8. *Future Steps***

The European Commission has already listed some initiatives it intends to come forward with in the next future:

- a regulation on greenhouse gas emissions from new vans and minibuses;
- an action plan and legislative proposal on Intelligent Transport Systems for road, in order to get these technologies onto the market and used and an urban mobility action plan, which will propose a series of short and long-term actions where there is a clear EU added value;
- a revision of the Directive on Airport Noise which is likely to increase the stringency for the types of aircraft that can be used and a revision of the environmental noise directive;
- a revision of the Energy Taxation Directive, which will ensure that it better complements the EU ETS and supports the EU's climate change and energy goals;
- a Directive on Energy Labelling for tyres and a revision of the existing CO<sub>2</sub> Car Labelling Directive;
- a proposal to address nitrous oxide emissions from aviation;
- a proposal for action at European level on greenhouse gas emissions from the maritime sector, if the International Maritime Organisation (IMO) will not make sufficient progress in developing concrete measures.



## **4. Intermodal Transport: Increased Competitiveness Due to External Costs**

### ***4.1. Introduction***

The intermodal transport represents a way of transferring the goods within a logistic network using more than one transport modes which share the same loading unit. Intermodality, thus, is based on the physical and economic integration between different transport modes in order to efficiently displace goods from an origin to a specific destination. This integration is achieved through a common unit of load which is shared by all the modes. From a practical point of view, intermodality guarantees a high transportation productivity by assigning to each mode its specific action field. For example, in the case of a transport combining road and rail, rail will give a high efficiency (and reduced costs) on long distances, while road will guarantee high flexibility in the phases of goods collection and distribution. The convenience of intermodality, which is today limited to long distances and significant volumes transported, can become much more evident in case external costs are taken into consideration in the analyses.

Intermodality requires the presence of specific terminals (ports, airports, logistic platforms) with specific equipments, in order to guarantee a rapid and efficient transfer of goods from one mode to the other; slight variations to intermodal transport include multimodality (in which there can be different loading units from mode to mode) and combined transport, in case most of the transport is made via rail or sea, while only short links are made by road.

### ***4.2. Competitive Advantage of Intermodality***

The intermodal industry is made by a vast range of modes, characterized by different cost structures, timings and reliability. Many aspects have to be considered when it comes to intermodal transport, and the transport cost is one of the most critical. Such cost includes, among the others, fuel, equipment, general and administrative costs, and

also drayage costs, which occur when more than one transport mode is used. Intermodality generates economies of scale only if all the modes are used efficiently and transfer costs are reduced at minimum.

Using all the modes efficiently means exploiting the specific advantages given by each mode by using it only when it becomes really convenient. Road transport typically has low fixed costs and allows the so-called “door-to-door” accessibility; nevertheless, it has high variable costs so it is convenient only for reduced distances. On the contrary, rail and sea have high fixed costs but low variable costs, so they are more convenient on long distances.

The development of intermodal transport has pointed out all the limits of mono-modality. The industrial production and the final consumers are requesting the logistic sector to be more and more active in the production process in order to pull down costs for stock and warehousing. Thus, transport has to guarantee quick and efficient replenishments right on time for production and distribution. No one among the traditional modes has succeeded in providing the new services that the industrial world has been requesting. In effect, modes such as rail or sea, even though they are the most economic and dispersed, cannot achieve the flexibility required by small quantities and tight leadtimes. On the contrary, air and road suffer respectively from high costs and high congestion. By taking the best out from each mode, intermodality could be able to confine each one’s negative aspects through the combination of more than one transport solution.

The crucial element of the intermodal network design comes from the need to split the total distance into partial sections, each one to be covered with the optimal mode and with a unique and standardized loading unit.

### **4.3. *Intermodal Terminals and Interports***

*Interports* are defined by the European Commission as the territorial combination of independent organisms and businesses working with goods transport (i.e. carriers, shippers, transport operators, customs) and with auxiliary services (i.e. storage, maintenance, repair) and including at least one intermodal terminal, as well as the technical and administrative services which make the infrastructure work. They can be

also defined as the systematic assemblage of integrated structures and services finalized to the swap between different transport modes and always including a rail yard that can form and receive intermodal loadings on trains and connect them to ports, airports and main roads.

Interports are typically wide structures, with the main aims of:

- *offer settlements*, in particular to transport enterprises and logistics;
- *integrate* the different transport modes (road, rail, sea, air), from both a structural and informational point of view;
- *supply services* to the settled enterprises. Services will be directed to favoring and supporting intermodal transport and products storage, controlling the shared spaces and entrances and exits from the interport, and warranting the regular functioning of the technological equipment.

Specifically, the main function of the interport consists in concentrating the flow of the goods, optimizing the routes and the deliveries, organizing the transport chain by integrated use of specific modes. For this reason, the interport is connected to different structures, such as rail structures, logistic structures, customs and service structures. The rail structure is typically composed by a rail yard (which can correspond to a shunting station), an intermodal terminal (which allows the exchange between different modes of big loading units, such as containers) and connections to warehouses (which facilitate the loading and unloading operations on the rails and the storage of the goods). The logistic structure includes warehouses and every other structure used to receive, store and ship goods on the national and international territory. Customs include buildings for the storage and transit of foreign products, offices and laboratories. Service structures include all the infrastructures which support the actual logistic functions: they have a key role in warranting the interport effectiveness.

As a consequence, due to the functions it has to assume, the interport takes simultaneously the following roles:

- *catalyst*: it accelerates the transport processes as it speeds up the flow of goods in the intermodal exchanges;

- *centralizer*: the logistic structures of the interport support the settlement of productive and/or entrepreneurial activities in its surroundings, thanks to the services offered and the proximity to important transport infrastructures;
- *collector*: the interport supplies all the services which are necessary in order to manage the logistic relationships in a Supply Chain viewpoint. Its structure permits the development of an entrepreneurial system where all the enterprises are concentrated around one single logistic pole. The integration with more than one transport mode allows to achieve a deep penetration in the territory and a barycentric position respect to the users' location;
- *optimizer*: the interport concentrates the flow of goods in order to optimize routes and deliveries; it organizes the transport chain with different modes in order to take out the maximum from each of them; it improves the overall efficiency and, at the same time, it reduces the overall economic incidence, the idling times and the risks connected to the passage from one mode to the other.

When designing an interport it is fundamental that rules safeguarding the environment are considered, in order to minimize environmental pollution from the very beginning. The role of the interport becomes more and more critical with the growth of the area served: a single interport can include hundreds of societies in its boundaries.

An *intermodal terminal* consists in the specific infrastructures (provided with the necessary equipment) where the intermodal transfer of the loading units takes place. The European Commission defines it as the place equipped for the change of transport mode and the storage of the intermodal transport units. Such terminals typically cover from 6 to 18% of the global interport surface. An intermodal terminal typically includes a number of structures, such as tracks (halt and manoeuvring tracks, loading and unloading tracks); areas for the movement of road vehicles; lifting equipment (loading/unloading lane, running lane, manoeuvring squares, storage areas, technical warehouses, gate area). In order to optimize these operations it is necessary to analyze carefully the layout of the structures which form the terminal. For example, the placement of the trucks has to consider all the other infrastructures available as well as the means of transport available.

The main functions which take place in the terminal are connected to the loading/unloading activities and the transport of the goods. Other activities that can take

place are the grouping and allocation of the loading units in the different storage areas and their classification.

Interports and terminals are strategic nodes within the intermodal network and their optimization is essential in order to achieve the efficiency of the network itself. These nodes generate both operational and environmental costs so they have to be taken into account as well when modelling the intermodal network. Being so important within the network, interports and terminals represent a key factor when managed efficiently, but on the other side they create big constraints in case they are improperly run. This is one of the main reasons that historically prevented the intermodal networks in Europe from developing: most of the interports do not have adequate infrastructures and cannot meet the efficiency and cost objectives needed by transport operators and enterprises.

#### **4.4. *Costs of Intermodal Transport***

With the current infrastructures intermodal transport becomes convenient only for significant distances. In effect, it has been calculated that only for distances exceeding 2,000 kilometers the convenience of the use of the rail transport becomes visible (Ortolani, 2007). This is strictly connected to the fact that current transport tariffs only take into consideration internal costs. In effect, if also external costs were considered, the convenience of the rail transport would raise even for much shorter distances, as rail transport generates environmental costs per unit carried which are much less significant than road transport.

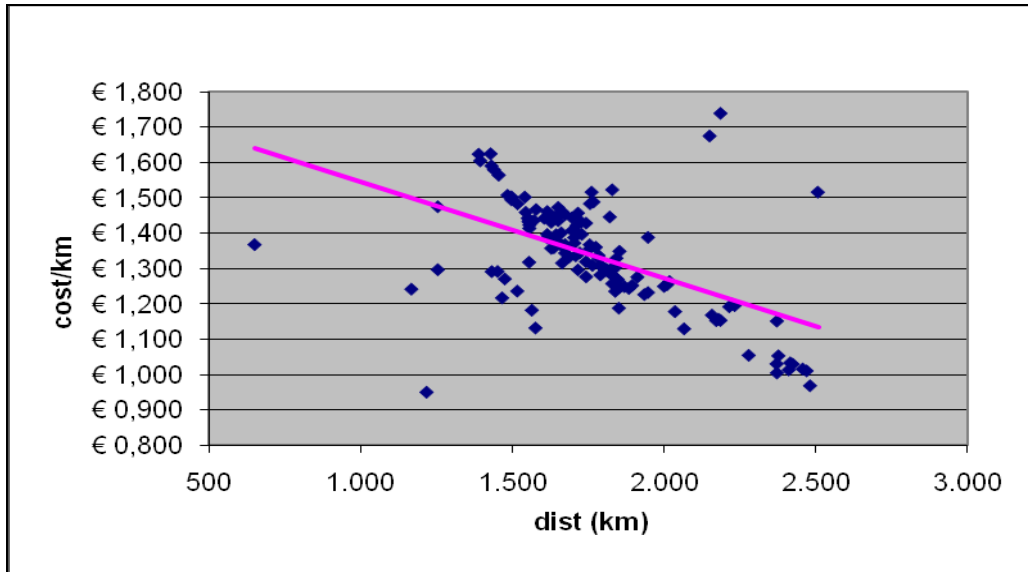


Figure 4.1. Cost/kilometer of European intermodal transport  
(source: Ortolani, 2007)

#### 4.4.1. Routes

The competitiveness of the base transport modes is a function of the distance to be covered. Nevertheless, the cost functions of the single modes (i.e. road and rail) cannot be represented simply through a linear function of covered distance (Figure 4.2)

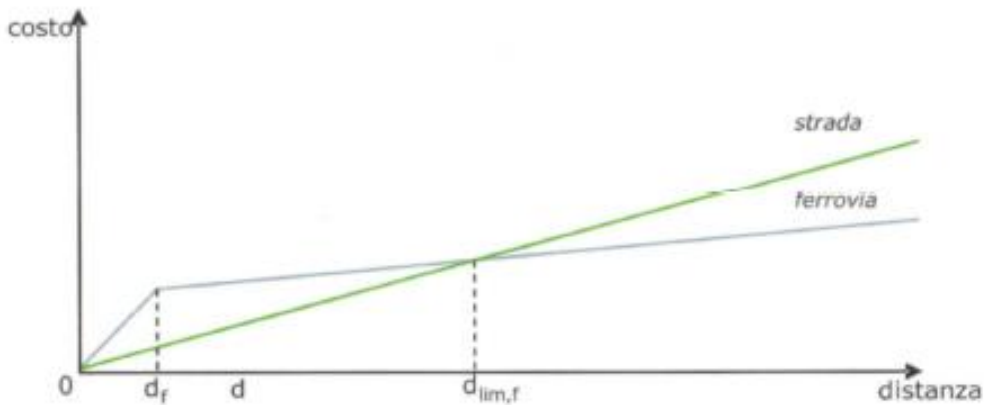


Figure 4.2. Cost/distance diagram for rail and road transport  
(source: Cantarella, 2007)

Costs are defined as follows:

$$C_f = K_{f1} * d \quad d \leq d_f \quad (4.1)$$

$$C_f = K_{f1} * d_f + K_{f2} (d - d_f) \quad d > d_f \quad (4.2)$$

$$C_s = K_s * d \quad \forall d \quad (4.3)$$

where:

$C_f$  = total travel cost for rail;

$C_s$  = total travel cost for road;

$d$  = total distance to be covered;

$d_f$  = mean distance between main rail terminals and departure and arrival points;

$K_{f1}$  = rail cost per kilometer for the access to main terminals;

$K_{f2}$  = rail cost per kilometer for the links among main terminals;

$K_s$  = road cost per kilometer.

Basically, while for road transport the cost has a linear path and goes proportionally to distance, in the case of rail there are also some additional costs to be considered. These costs are linked to the activities of entry and exit from the rail network. Nevertheless, once these costs are overcome, the rail shows lower costs per kilometer travelled ( $K_{f2} < K_s$ ). The limit value of distance called  $d_{lim,f}$  is the one after which rail becomes more convenient than road.

The combined road-rail transport (Figure 4.3) covers the access and exit routes from main rail terminals with the road transport. This guarantees a capillarity of the distribution network which could never be obtained with rail transport at a reasonable cost.

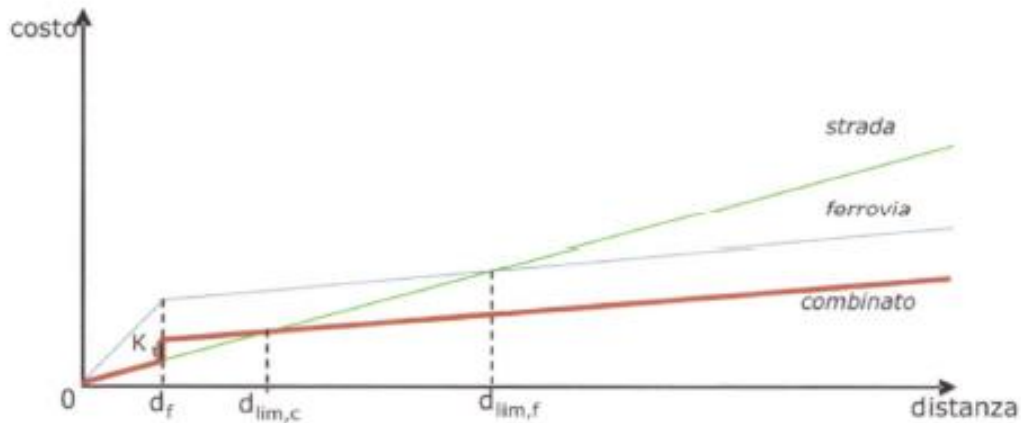


Figure 4.3. Cost/distance diagram for combined road-rail transport  
(source: Cantarella, 2007)

Under such hypotheses the cost of the combined transport can be summarized as follows:

$$C_c = K_s * d_f + K_t + K_{f2} (d - d_f) \quad (4.4)$$

where:

$C_c$  = total combined travel cost;

$K_t$  = handling cost at terminals.

Comparing equation 4.4 with formulas 4.1, 4.2, 4.3, it can be seen that competitiveness of the combined mode depends on the value of  $K_t$ , in other words on the handling cost at terminals.

The combined solution is competitive only if:

$$K_t < (K_{f1} * d_f - K_s * d_f). \quad (4.5)$$

Assuming that the mean distance between origin and intermodal terminal is  $d_f$ , Figure 4.3 shows that at that specific distance a discontinuity occurs. The value of the discontinuity is  $K_t$  and it is caused by the handling costs in the terminal. From 0 to  $d_f$  the cost of access to intermodal terminals is the one of road transport, while from  $d_f$  onwards the cost basically follows the rail one.

As a consequence, reductions on the rail and road transport costs have significant effects on combined transport as well, while reduction on the handling costs at terminals ( $K_t$ ) only has effect on combined mode. From here the necessity raises of optimizing terminals operations and also their geographical location.

A similar analysis can be made in the case of the combined transport road-sea. The variation of costs over distance for a sea shipment is similar to the one that occurs in the case of rail.

An example is shown in Figure 4.4. In this case we assume that costs for the terminal with a Roll On-Roll Off (ro-ro) handling are lower than costs for a Lift On-Lift Off (lo-lo) handling: ro-ro ships are vessels designed to carry wheeled cargo such as automobiles, trucks, semi-trailers, trailers, cars that are driven on and off the ship on their own wheels. On the contrary, in lo-lo vessels a crane is used to load and unload cargo. Moreover, we assume that transport cost per kilometer is lower than  $K_{f2}$ .

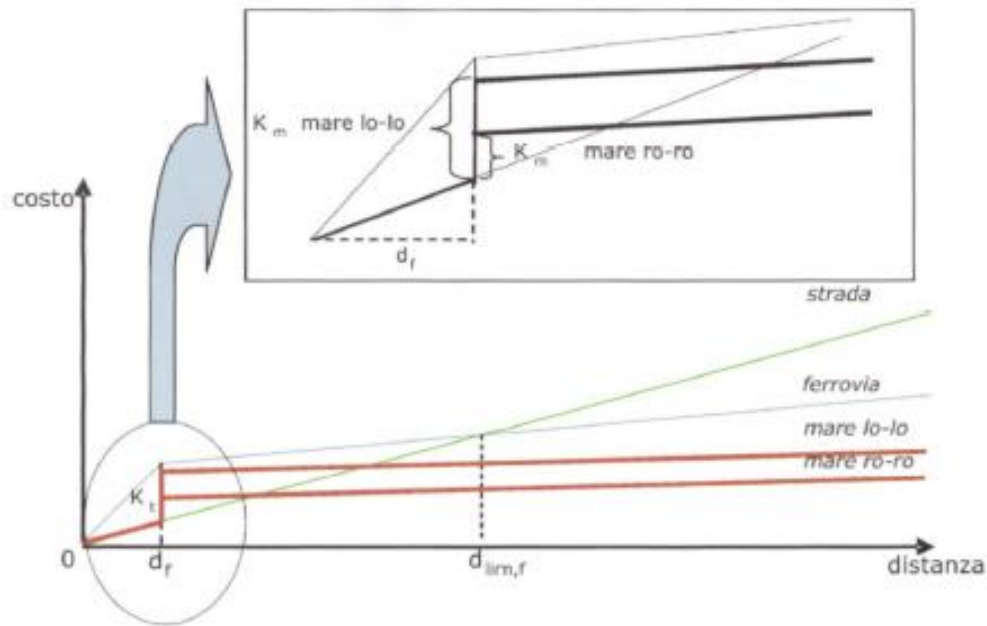


Figure 4.4. Cost/distance diagram for combined road-sea transport  
(source: Cantarella, 2007)

The complexity in the organization and management of a combined transport requires the presence of specialists in order to make all the activities (load, distribution, handling, unload) run smoothly. The most critical phases to be optimized are the load and/or distribution activities to be run with small and flexible transport, and displacements on main traits for which capacious and efficient vehicles have to be used. Nevertheless, such optimizations have to be considered also when dealing with a single mode: for example, in the case of road transport, many distribution networks use big trailers to displace the goods over long distances and small trucks to perform loading and unloading activities. The definition “complex mono-modal cycle” refers exactly to a configuration in which the distribution is performed in a single transport mode (i.e. road) but with different means (i.e. truck and trailer). Figure 4.5 shows an example of such network: in this case the transport mode is sea, while the means are the main vessel covering the longest trait and the feeders covering the loading and unloading activities and the distribution.

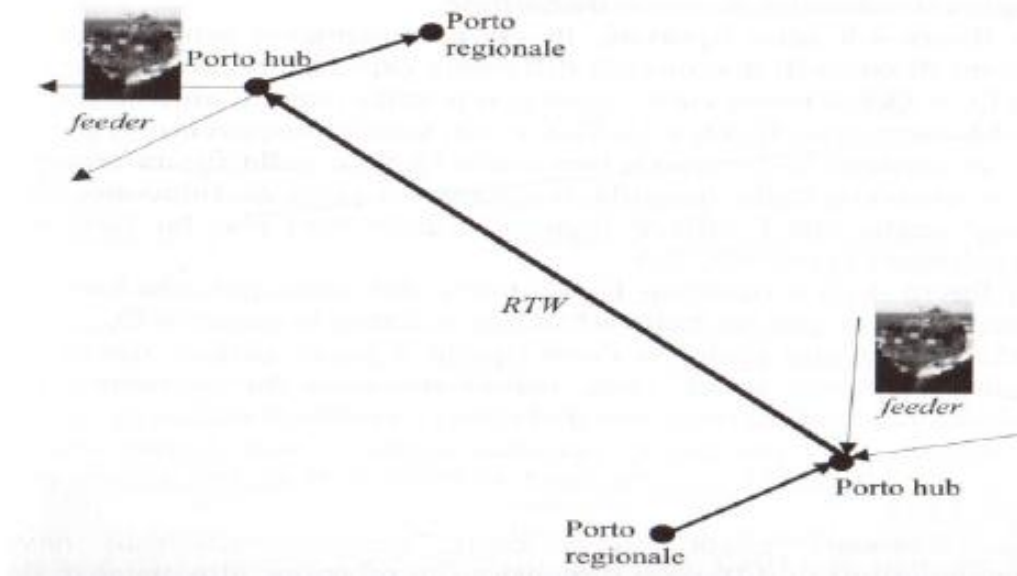


Figure 4.5. Example of complex mono-modal cycle  
 (source: Russo, 2005)

A “pluri-modal cycle”, on the contrary, consists in more than one mode and more than one mean (i.e. combined road-rail transport).



Figure 4.6. Example of complex pluri-modal cycle  
 (source: Russo, 2005)

#### **4.4.2. *Interports and Terminals***

Interports and terminals represent the core of intermodality: here the physical transfer between modes is made, coordination among actors of the different parts of the chain takes place, standardization and efficiency are mandatory in order to achieve real competitiveness.

The costs incurred in the terminals can be summarized as follows:

$$C_{handling} = C_{moving} + C_{stock} + C_{custom} + C_{moving} \quad (4.6)$$

where:

$C_{moving}$  = costs for loading/unloading the goods (crane costs). Taking as example Venice intermodal terminal, crane costs can go from 22 to 35 Euros/unit moved;

$C_{stock}$  = costs for maintaining the goods stocked, either outside (if kept inside the container) or in the terminal stores (if the goods are taken out from the container and stored inside);

$C_{custom}$  = costs due to the custom have to be considered as well if the goods come from a country not belonging to EU.

#### **4.5. *European Incentives Towards Intermodality***

As already mentioned, the distribution of goods is a fundamental condition for achieving competitiveness in Europe. Transport has to be flexible and efficient in order to sustain and lead economic growth and social and environmental development. Among the main problems underlined by the European Commission in 2001 White Paper there were the unbalanced development of the different transport modes, the road and air congestion, the effects of transportation on the environment. Moreover, in the same document the European Commission proposed a series of politics and incentives

in order to modify the existing lack of balance among modes: these politics were meant to eliminate the bottlenecks in Trans-European transport networks, to reduce noise and environmental pollution, to abate the number of road accidents.

Europe has been pushing since long for a decrease in the road transport usage in favor of other transport modes: intermodality would allow a much better and efficient utilization of the existing infrastructures. The 2001 White Paper of the European Commission did highlight the development of intermodality as a practical and effective tool in order to achieve a balanced transport system. It suggested a more intensive use of the rail transport and rivers, in order to achieve a sustainable development. Without a proper strategy, European freight transport will raise of more than a 60% within 2013, with highly negative impacts on road infrastructures, accidents, congestion, local and global pollution: Marco Polo program itself is aimed at transferring as much transport as possible from road to alternative modes, improving transport environmental performances and boosting intermodality.

#### **4.6. *Intermodality as Strategic Tool for Costs Abatement***

Even though something has already been done, much more is needed in order to let intermodality be an effective tool to achieve real gains. Appropriate incentives are needed in order to guide the market to technologies which are more and more efficient from an environmental point of view. In order to face these challenges, the European Commission has launched in 2007 a series of initiatives, underlying the need of improving the efficiency of all the transport modes, being used either alone or in a combined way. The main projects are:

- the *Action plan for the goods transport logistic*. It proposes some measures to promote efficient goods and traffic management, quality and sustainability, simplification of the administrative procedures, revision of current rules on load, weight and dimension of the vehicles;

- the *development of a rail network giving priority to goods transportation*. It has the aim of providing shorter transit times and increased reliability and reactivity of the rail transport.

Currently the rail transport in Europe is showing a fair dynamism, thanks to the increase of commercial exchanges, the road congestion, the high fuel price, the environmental worries. Nevertheless, some important problems are still there. A research conducted by UIRR (Union internationale des sociétés de transport combiné rail-route) shows that in 2006 only 53% of the trains used for an intermodal transport arrived on time. Rail has to become more and more competitive in order to effectively challenge road transport, especially under a qualitative point of view. For the consumers, quality in logistics words means lower transit times, reliability, availability of the infrastructures.

Some developments have already been done in order to develop new rail sections and international connections, and also to favour the coordination among all the international operators. Nevertheless, it is very important to focus on terminals, logistic hubs and intermediate links of the network as well. It will not be enough to have a brand new system of routes without having improved the links among these routes. This development assumes two requirements: firstly, encouraging the investments aimed at increasing the capacity of the terminals; secondly, making the access easier for all the operators which use the routes.



Figure 4.7. Potential routes to be included in the European rail network  
(source: European Commission, 2007)

- the *development of a European strategy for harbors*, indicating tools to be used in order to improve the performances of the ports as nodal points of the European transport system. Ports are essential for modal transport and contribute to the development of both the short-run sea routes and the river transport. In 2005, more than 3 billion tons of goods passed through the European ports. The European harbor system will face the challenges of an increased international transport request at the lowest cost from one side, and of an increased transport via container from the other side.

#### **4.7.           *Conclusions***

There are a number of initiatives promoted by the European Commission which act together in order to increase the efficiency and sustainability of the European distribution network. Thanks to scale economies, new routes are under design and development which can offer wide technical and economical possibilities, making intermodality an efficient and convenient solution.

The loading units will have to be standardized as much as possible, the handling operations in the terminals will have to be minimized, as well as all the administrative documentation needed. These are the requirements for achieving a simple, reliable and cheap transfer of material from one mode to the other.

Moreover, in order to increase transport sustainability it will be necessary to minimize energy consumption and noise pollution, as well as emissions, through the adoption of so-called “green corridors”, which are routes dedicated to the transport of goods and characterized by a low impact on society and environment. Essential components of these corridors are rail, sea and fluvial transport: the existing transport infrastructure will have to adapt itself in order to support the heavy growth which is forecasted in the future years for goods transport. Quality and service of the transport sector have to be improved as well, especially if alternative modes want to appear more attractive than road transport. In particular, rail transport should become more efficient, while sea and fluvial transport should be more integrated with the logistics chain.

The initiatives oriented to a European transport network are founded on co-modality, intelligent transport systems and focus the consumers’ needs. Co-modality means improving efficiency, interoperability and connectivity of road, air, sea, fluvial, road routes and their hubs, in order to achieve their full integration and to guarantee a real door-to-door service. Intelligent transport systems give the opportunity of improving transport management and increasing the utilization rate of the available infrastructures.

## **5. Literature Review**

### ***5.1. Introduction***

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.* (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 (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.

Again quoting 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.

### ***5.2. Variability in External Costs Valuation***

As stated by Litman (2009), any cost or benefit estimate incorporates some degree of variability and uncertainty. This happens also with transport costs and benefits. As a consequence, the values that can be found in any of the available reports are generic. Actual costs vary depending on factors such as location, time, vehicle condition, etc. For example, average air pollution costs may not apply to a particular situation because vehicle or exposure conditions are not average. Ideally, each cost value should be adjusted to reflect each specific application. For example, when calculating parking cost savings from reduced automobile trips in a particular area, the analyst might first use the

generic numbers available from the reports, and then adjust them based on local conditions (such as land values).

Because transport cost analysis involves new areas of research, limited data sources, and complex modelling, estimates incorporate various levels of uncertainty.

Some economic analyses only include costs that are commonly accepted and easily quantified, and dismiss difficult-to-quantify impacts as intangibles. This tends to drive decision-making toward easy-to-measure impacts (such as project costs, vehicle operating expenses, and travel time savings) at the expense of more difficult-to-measure social and environmental impacts, and concentrated, short-term impacts at the expense of more dispersed, long-term impacts. This biases the decision process in various ways. For example, it tends to favor economic objectives (because they involve market resources) over social and environmental objectives; industries (which have more financial transactions) over communities (which involve more non-market transactions); wealthier people (because they purchase more market goods) over poorer people; and the current generation over future generations. Excluding or using low estimates of relatively uncertain costs is often defended as being conservative, implying that this approach is cautious. But use of the word conservative in this context is confusing because it often results in the opposite of what is implied. Low cost estimates undervalue damages and risks, which is less cautious and conservative than using higher cost values. In practice, low estimates of indirect and non-market costs can lead to increased social and environmental damages. For example, low estimates of pollution costs reduce the justification for control measures, resulting in more emissions. Another way to deal with uncertainty is to use cost ranges rather than point estimates. This makes it possible to perform sensitivity analysis by testing how higher and lower values affect results. For example, an analyst might see whether a mobility management program is still justified if relatively low parking and congestion cost estimates are used. Some cost estimates with a relatively high degree of uncertainty are included in the reports analyzed in literature; provided that the existence of the cost can be demonstrated, there is compelling evidence that the cost is significant in magnitude, and the resulting estimate is within the expected range relative to other costs. Assuming that the variation among the uncertainty is random, the over- and under-estimates among these estimates will tend to cancel out. Including such estimates is more accurate and more conservative than setting their value at zero, which consistently underestimates total costs.

Some costs are controversial: for example, some authors refuse to recognize costs associated with climate-changing air emissions or low-density, urban-fringe development patterns. Other costs may be so small in a particular situation that they can be considered insignificant. Users should apply those that make sense in their political and geographic circumstances. However, if cost categories are excluded from quantitative analysis they can often be described qualitatively. This discussion could include information like the land use impacts and transportation diversity: social and environmental value of these impacts can be given, even if they are not quantified in monetary units.

### **5.3. *Causes of Dispersion***

The main causes of possible dispersion in the data are summarized in Quinet's work (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: here, in a fully allocated cost analysis perspective, I focused on average costs (Sansom *et al.*, 2001). 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.

Victoria Transport Policy Institute (2009) lists the following factors which should be considered when comparing transport costs estimates:

- *Purpose of the analysis*, therefore its perspective, such as whether it considers only short-run marginal costs, long-run costs, and or total social costs;
- *Categories of impacts* considered;
- *Data sources and methodologies* used to calculate costs;

- How possible *double-counting* is addressed, such as whether taxes are counted as costs or economic transfers, or whether congestion costs are summed with travel time costs;
- *Geographic scope and monetary exchange rates*, if comparing data coming from different countries;
- *Time period evaluated and inflation*;
- *Driving conditions*, such as whether the costs represent urban-peak, total urban, rural or overall average driving conditions;
- *Differences in measurement units*, such as between miles and kilometres, and between vehicle mile and passenger mile;
- *Types of vehicles* considered;
- *Types of cost estimates* (point values or ranges).

#### **5.4.            *Marginal and Average Costs***

A controversial decision which has to be taken when calculating transport costs, especially in the case of external costs, is whether marginal or average costs should be considered.

There is no univocal agreement in literature on which category better represents travel costs. A shared opinion is that depending on which is the aim of the specific analysis made, one category will be more fitting than the other. Sansom *et al.* (2001) express this price duality in terms of two different perspectives: the *Efficiency perspective* and the *Cost Coverage perspective*.

The *Efficiency perspective* is given by the comparison of marginal costs and revenues. If prices are set at the cost of an additional passenger or freight tonne kilometre, journeys for which an individual or firm's benefit exceeds the cost imposed on the rest of society will not be deterred. Conversely, travel when the benefit of individual or firm is less than the social cost imposed will be discouraged. Setting prices equal to marginal costs thus maximises economic welfare for society as a whole.

The *Cost Coverage perspective* provides a different set of evidence based on the comparison of fully allocated costs and revenues. Policymakers have a legitimate interest in the comparison between economic costs and revenues associated with the

road and rail sectors. The resource needs of these modes, or the resources that may be generated from them, need to be balanced with the resource requirements of other sectors of the economy. A comparison between the total social costs imposed by road and rail users as a whole on the rest of society and the revenues raised can support such considerations. Although many of the costs of the transport sector are joint costs (i.e. costs that cannot be uniquely attributed to a specific vehicle class or train type), the fully allocated cost approach seeks to compare social costs and revenues for each vehicle class or train type.

Nevertheless, at least in the case of external costs, the research conducted in 2004 by INFRAS/IWW reaches the conclusion that the level of marginal and average costs is comparable: marginal costs are simply much more differentiated, since they relate to different traffic situations and types of vehicles.

#### **5.4.1. *Marginal Costs for Internalization***

Giving transport users the right signals involves setting prices that do not lead to overexploitation of resources, but do not damage the transport sector, or ultimately the economy, either (European Commission, 2008). According to economics literature, “social marginal cost charging” achieves that balance. This is therefore usually proposed as the general principle for internalization. According to this approach, transport prices should correspond to the additional short-term cost created by one extra person using the infrastructure. This additional cost should include both the costs to the user and the external costs. Social marginal cost charging would therefore lead to efficient use of the existing infrastructure. As users would pay for the additional costs they generate for society, it would also help ensure fair treatment of both transport users and non-users and would create a direct link between the use of shared resources and payment on the basis of the “polluter pays” and “user pays” principles. This approach is only possible if the “polluter” does not benefit from any compensation that would cancel out the possible effects of internalization. As a consequence, marginal costs are adequate when approaching cost internalization in order to transfer costs generated by the transport activity into prices.

Nevertheless, the marginal cost approach may have certain limitations. It does not necessarily make it possible to include infrastructure costs, as is the case where fixed costs are high or traffic density is low. If necessary, it may be combined with other approaches to make sure that infrastructure is funded according to the “user pays” principle and external costs are internalized according to the “polluter pays” principle. This could also help ensure fair treatment for transport users and society as a whole. Furthermore, for some costs, such as those relating to noise, the method for estimating the marginal costs is very complex, and a pragmatic approach based on the average cost may be more feasible.

#### **5.4.2.        *Average Costs for Networks Modelling***

When it comes to network modelling, typically the requirement is to estimate the cost that would potentially raise on a specific path, under specific driving conditions. This cost will be the result of an analysis of the travel conditions and constraints, of the effects having significant impacts on the transport activity, of the historical values of cost. Still it will be a mean value, possibly the most fitting mean among all the cost values that could be assigned to the specific trip. In effect, the output that a user expects from a framework which is modelling the cost of a network is the total (average) cost for a specific trip, and not the cost incurred from an additional trip being made in the network. As a consequence, for networks modelling average internal and external costs are used. This is the approach that will be followed in the next steps and it is the basis on which the proposed calculation framework is built. Costs will be therefore calculated in next sections following a Cost Coverage perspective: the aim here is not to give indications for internalising external costs, but to find a framework which can calculate all the internal and external costs involved in a specific trip. The total cost for the trip will be calculated as the pure sum of two separate contributions, total internal transport costs (both variable and fixed) and total external transport costs. The costs will be thus an output of our assessment process, in other words they will be a consequence of a decision previously made (in terms of vehicle to be taken, volume to be carried, distance and type of road to be travelled) and not an input to it. The fully allocated cost analysis makes it possible to obtain an external cost estimate relative to a selected trip

which can be compared directly with the total internal cost of that trip. In this way the weight of both contributions can be easily calculated and the comparison of costs generated by different travel alternatives can be made.

### **5.5. *Dispersion Factors in Literature***

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 which aggregates all the different estimates. The present work is mainly focused on road transport, as it is the basis of the most widespread types of continental distribution networks. Among all the contributions analyzed in literature, a good number of studies provides real external transport cost values for road transport. Nevertheless, the values are typically estimated through empirical analysis or evaluation of research data. The different perimeters of analysis, methodologies, unit values used by the authors are the main causes of the high variability of the calculated costs. A main difference in the outcomes is given by the choice of considering urban or extra-urban transport. Moreover, the units of measurement through which the costs are estimated vary from research to research.

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.

### **5.6. *Claim for Standardization***

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 Quinet's work (2006): 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. Scientific uncertainty, in the end, is a smaller contribution of variation. Quinet concludes that, when properly applied, cost studies can provide justifiable values which are useful for economic analysis.

### **5.7.           *Approximations and Costs Included in the Analyses***

It is sometimes argued that uncertain costs should be excluded from the analyses. Litman (2009) asserts that this is analytically incorrect and skews results: it is more appropriate to use the best available estimates and apply sensitivity analysis. Quoting Ottinger (1993): “A crude approximation, made as exact as possible and changed over time to reflect new information, would be preferable to the manifestly unjust approximation caused by ignoring these costs, and thus valuing environmental damage as zero.” Low cost estimates undervalue damages and risks, resulting in less cautious and conservative decisions than higher estimates. When a cost or risk is dismissed because of uncertainty, despite reasonable evidence of its existence, the results should be described as a lower bound of estimate, and decision makers informed that total costs are likely to be higher. Costs excluded from quantitative analysis because they are difficult to measure should be described qualitatively. For example, if a transport project analysis includes no monetized estimates for sprawl costs, land use impacts should be quantified and likely costs described.

### **5.8.           *Categories of Studies***

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 costs: they do consider one or more external cost fields but do not give any quantitative or analytical indications regarding these costs, or they only give a rough overall value.

*Analytical studies* do not provide any values, but they 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: road and rail networks. As the estimated costs for the two networks differ significantly, the analysis will take into consideration separately the two cases.

## **5.9. Road Transport**

### **5.9.1. Qualitative Studies**

Qualitative studies regarding road transport networks take into account a considerable variety of costs. The most complete contribution, given by 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 (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 (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<sub>2</sub>. Nicolas *et al.* (2005) are considering analogously air pollution as the main environmental drawback of a transportation network.

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

Finally, in May, Jopson and Matthews (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 Euros 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.

### **5.9.2. Analytical Studies**

Analytical studies typically integrate the formulation of the transport cost in a global simulation model. 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 (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 (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<sub>x</sub>) 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.

### **5.9.3.        *Quantitative Studies***

Among all the contributions analyzed in literature, a good number of studies provides real external transport cost values, which are typically estimated through empirical analysis or evaluation of research data. As it is shown in Table 5.1, 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 take place 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 categories will be 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 (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 2009) during which the value of money has continuously changed. Thus, two main approximations have to be included in the analysis. The first one is bound to the need of defining a standard value for vehicle capacity in order to be able to define all cost categories on a ton basis: this value was fixed to 14.3 ton/vehicle. The second approximation comes from the need of deflating all cost values in order to evaluate them always considering the same cost of money. Nevertheless, it has to be noted that in

order to finally calculate the cost values, only the most recent contributions were considered (from 2000 onwards): this has significantly decreased the level of approximation. Table 5.1 (as well as it happens for Table 5.2) still includes all most relevant articles (even older ones) in order to give a more detailed picture of the literature which was explored.

Other cost variation factors, like the growing efficiency on energy consumption, are very difficult to estimate. For this reason, the model which will be proposed does not consider such factors, while a sensitivity analysis will be conducted in order to evaluate the impact of changes in the input values on final total costs and transportation network design.

EXTERNAL COSTS																		
Article	Nature of transport network	Reference area	Perimeter of analysis	Methodology	Emissions - Air pollution	Emissions - Greenhouse effect	Congestion	Noise	Accidents	Road Damage	Resource consumption	Roadway/land value	Land use	Water pollution	Waste disposal	Traffic services	Barrier effect	
External costs of intercity truck freight transportation (D.J. Finkenbrock, Transportation Research Part A, no. 305-326, 1999)	Freight	USA	Extra-urban	Data analysis	0,087 cent \$/tonn-mile (1994)	0,15 cent \$/tonn-mile (1994)		0,04 cent \$/tonn-mile (1994)	0,59 cent \$/tonn-mile (1994)									
The marginal external costs of urban transport (I. Meyers, S. Oelien, S. Proost, Transportation Research Part D, no. 111 - 130, 1996)	Freight	Europe	Urban	Data analysis	0,147 €/vehicle km	0,036 €/vehicle km (2005)	1,391 €/vehicle km (2005)	0,397 €/vehicle km (2005)										
A meta-analysis of Western European external costs estimates (E. Quinet, Transportation Research Part D, no. 465 - 476, 2004)	Freight	Europe	Urban and extra-urban	Literature analysis			0,094 €/tonn mile (2004)											
Estimating the cost of air pollution from road transport in Italy (R. Daniels, A. Chelari, Transport Research Part D, no. 249 - 258, 1998)	Freight	Europe (Italy)	Urban	Data analysis	98,95 cent \$/vehicle mile (1992)													
Optimal pricing of transport externalities in an international environment: some empirical results based on numerical optimization model (B. De Borger, C. Courcelle, D. Swinnen, Regional Science and Urban Economics 34, pp. 163 - 201, 2004)	Freight	Europe (Belgium)	Urban and extra-urban	Empirical analysis	0,0095 €/tonn km (2005)		0,082 €/tonn km (2005)		0,004 €/tonn km (2005)									
External costs of the Belgian interurban freight traffic: a network analysis of their internalisation (M. Beutels, F. Degrandt, J.F. Geerts, B. Jourquin, Transportation Research Part D, pp. 285 - 301, 2002)	Freight	Europe	Extra-urban	Empirical analysis	182 m€/tonn km (1995)		23,7 m€/tonn km (1995)	6,6 m€/tonn km (1995)	12,95 m€/tonn km (1995)	1,45 m€/tonn km (1995)								
An evaluation of national road user charging in England (S. Gläster, D. J. Goham, Transportation Research Part A, pp. 632 - 650, 2005)	Freight	Europe (UK)	Urban and extra-urban	Analytical model	1,02 pence/vehicle km (2000)	0,39 pence/vehicle km (2000)		0,04 pence/vehicle km (2000)	1,11 pence/vehicle km (2000)	0,48 pence/vehicle km (2000)								
Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications (Utman, T.A., Victoria Transport Policy Institute, 2009)	Freight	USA	Urban and extra-urban	Data analysis	0,243 \$/vehicle mile (2007)	0,386 \$/vehicle mile (2007)	0,115 \$/vehicle mile (2007)	0,036 \$/vehicle mile (2007)	0,1815 \$/vehicle mile (2007)	0,0924 \$/vehicle mile (2007)	0,165 \$/vehicle mile (2007)	0,112 \$/vehicle mile (2007)	0,2192 \$/vehicle mile (2007)	0,0462 \$/vehicle mile (2007)	0,0132 \$/vehicle mile (2007)	0,0396 \$/vehicle mile (2007)	0,0462 \$/vehicle mile (2007)	

Table 5.1. External road costs contributions in literature

### **5.10. *Rail Transport***

Regarding rail transport, the most meaningful contributions are represented by quantitative studies, which in most cases take into consideration some of the main cost components previously seen in the case of road transport. Nevertheless, it is more difficult to develop accurate estimates of social costs for rail transportation than for road networks: as pointed out by Forkenbrock (2001), this is mainly due to the scarceness 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, considered between years 1994 and 2005. A part from the approximation linked to the actual value of money, these data appear to be more homogeneous than the ones identified for road transport.

Article	Nature of transport network	Reference area	Perimeter of analysis	Methodology	EXTERNAL COSTS			
					Emissions - Air pollution	Emissions - Greenhouse effect	Noise	Accidents
<b>Comparison of external costs of rail and truck freight transportation</b> (D.J. Forkenbrock, Transportation Research Part A 35, pp. 321-337, 2001)	Rail	USA	Extra-urban	Data analysis	0,01 cent \$/tonn mile (1994)	0,02 cent \$/tonn mile (1994)	0,04 cent \$/tonn mile (1994)	0,17 cent \$/tonn mile (1994)
<b>A meta-analysis of Western European external costs estimates</b> (E. Quinet, Transportation Research Part D, pp. 465 – 476, 2004)	Rail	Europe	Urban and extra-urban	Literature analysis	0,009 €/tonn mile (2004)			
<b>Optimal pricing of transport externalities in an international environment: some empirical results based on numerical optimization model</b> (B. De Borger, C. Courcelle, D. Swinnen, Regional Science and Urban Economics 34, pp. 163 – 201, 2004)	Rail	Europe (Belgium)	Urban and extra-urban	Empirical analysis	0,003 €/tonn km (2005)			
<b>External costs of the Belgian interurban freight traffic: a network analysis of their internalisation</b> (M. Beuthe, F. Degrandtsart, J-F. Geerts, B. Jourquin, Transportation Research Part D, pp. 285 – 301, 2002)	Rail	Europe	Extra-urban	Empirical analysis	5 m€/tonn km (1995)	3,1 m€/tonn km (1995)	2,44 m€/tonn km (1995)	

Table 5.2. External rail costs contributions in literature



## **6. Development of Cost Models and New Analytical Formulations**

### ***6.1. Introduction***

After having defined the different cost categories, the purpose of the analysis consisted of finding an aggregate cost function. In order to do this, the different costs given by the literature were translated into a homogeneous unit of measurement (euro/kilometre) and each cost category was summarized into single coefficients representing a sensible mean, minimum and maximum value of all the examined costs. This was done by using the two approximations mentioned before, regarding the average load of a truck and the value of money.

The average truck load was estimated to be 14.3 tons. Using this factor, all the cost categories originally expressed on a vehicle basis were converted into a ton basis, also assuming a specific saturation coefficient.

Conversion factors and historical inflation values were added in order to express all the cost categories in terms of 2008 Euros. Finally, all the costs were expressed in the same measurement unit, which is €/ton per kilometre travelled.

The sensitivity analysis which will be introduced in the next section was useful to evaluate the impacts of these assumptions on the external cost evaluation and then on the network design.

Further analysis, as well as the framework development, will only consider costs relative to road and rail transport, as they represent the core of the European distribution network and they are also the modes for which the abatement of both internal and external costs would convey a significant advantage. Anyway an overview on sea freight internal costs will also be given. Nevertheless, sea freight external costs are the object of very few researches and they are usually (but mistakenly) considered negligible. Future research will definitely have to analyze these costs in deep in order to get their real value.

The final obtained function for transport costs depends on three relevant factors: travel time ( $T$ ), travelled kilometres ( $km$ ) and environmental aspects ( $EA$ ):

$$C_{tot\ freight} = f(T, km, EA) \quad (6.1)$$

As explained by:

$$C_{tot\ freight} = C_{int} + C_{ext} \quad (6.2)$$

Total freight costs are made up by two main categories: Internal Costs and External Costs. In the following sections both categories will be explored.

## **6.2. Internal Costs**

### **6.2.1. Theoretical Formulations Developed**

#### **6.2.1.1. Road Transport**

All the networks can be theoretically modeled as sequences of arcs (routes) and intersections (charge and discharge points). The total cost of a so-defined system can be modeled as:

$$CI = \sum_{i \in I} Ci + CI_{,driver} \quad (6.3)$$

where:

$Ci$  is the cost of the generic arc  $i$ , and  $CI_{,driver}$  represents the driver wage for the whole transportation.

$CI_{,driver}$  can be kept separated from the other transportation cost factors as it can be assumed that the personnel, both at the charge and discharge points, mainly performs other duties.

$CI_{,driver}$  value can be obtained as a function of travel time and stops:

$$CI_{,driver} = T_{c,m} C_a \quad [\text{Euro}] \quad (6.4)$$

where:

$T_{c,m}$  = travel time (including halts and stops time).

During daily travel, average stop time is estimated in 30 minutes every 4.5 hours of travel for all kinds of goods. For the halts the mean time goes from 2.5 hours every 10 hours of travel for perishable goods, up to 7.5 hours every 10 hours of travel for industrial goods. The halt time is computed only if total travel time exceeds 11 hours per day.

$C_a$  = hourly driver's wage.

The driver's wage will change according to transport contracts and current legislation.

The total cost for the generic transport arc ( $CI$ ) will be given by:

$$CI = CI_{,fuel} + CI_{,various} + CI_{,toll} \quad (6.5)$$

where:

$CI_{,fuel}$  = fuel cost for covering the arc, defined in the following way:

$$C_{fuel} = (v^2/a + v/b + c) \mu_{fuel} q_{fuel}$$

$v$  = travelling speed;

$\mu_{fuel}$  = fuel unitary consumption;

$q_{fuel}$  = fuel unitary cost;

$a = 122,850$  (h<sup>2</sup>/Km<sup>2</sup>);

$b = 814$  (h/Km);

$c = 0.1015$ .

$C_{i,various}$  is obtained summing the costs which are not related to the level of service of the travelled path. Specifically:

- Operational costs (tires, lubricating, maintenance, taxes, insurances);
- Extra driver's costs (overtime and transfers);
- Depreciation.

$C_{i,toll}$  are the costs incurred when fee-paying routes are covered.

Usually, in order to take into consideration the fact that the motion is non-uniform, the values of  $C_{i,fuel}$  and  $C_{i,various}$  are increased by 10% for rural arcs and by 15% for urban arcs.

### **6.2.1.2. Rail Transport**

The rail transport cost can be calculated as a function of travelled distance (and/or travel time) and loaded weight.

The total cost  $C$  (per unit of load) can be thus expressed as:

$$C = C_1 d + 1/2 [C_2 (t_m + c) d + C_3 + C_4 n + C_5 re + C_6 d] \quad (6.6)$$

where:

$d$  = distance;

$t_m$  = mean tare weight of a wagon;

$c$  = loaded weight;

$n$  = number of shuntings crossed;

$re$  = wagon utilization time;

$C_1$  = group of costs which are function of the paid weight per distance (taxes and fees, various rights and indemnities);

$C_2$  = group of costs which are function of weight and distance: movement and safety, storage, preparation, maintenance, security installations;

$C_3$  = group of costs which are function of the number of loaded wagons: registration and identification at departure and arrival, marshalling;

$C_4$  = group of costs which are function of shuntings;

$C_5$  = group of costs which are function of the wagons per utilization time: periodic maintenance, depreciation or wagon hire;

$C_6$  = group of costs which are function of the wagons per traveled distance.

The cost of the rail transport is usually expressed terms of:

- €/tonne (most widespread unit of measurement);
- €/wagon;
- €/train.

### **6.1.2.3. Sea Transport**

The operational costs for sea transport can be divided into fixed and variable costs. Fixed costs are connected to the purchase of the vessel and are typically sustained by the shipowner and fitter-out. Variable costs are the costs connected to the vessel usage, they are borne by the transporter or the provider that hires the vessel. Variable costs can be further divided into *operational costs* and *travel costs*.

*Variable operational costs* include:

- crew costs;
- repairing and maintenance;
- insurance;
- other supplies costs and administrative costs.

*Crew costs* can vary considering the nationality of both vessel and crew, average number of crew members for a vessel loading containers goes from 10 to 15 people. Crew costs can be formulated as:

$$C_{crew} = s_{crew} * N_{crew} \quad (6.7)$$

where:

$s_{crew}$  = mean salary of a crew member;

$N_{crew}$  = number of people belonging to the crew.

*Repairing and maintenance costs* depend on the maintenance activities made by the transport society in order to make the vessel travel in safe conditions.

$$C_{maint} = r_1 * C_{vessel} \quad (6.8)$$

where:

$r_1$  = percentual rate which raises proportionally to the vessel age.

*Insurance costs* cover the transporter in case of thefts, damages or third parties responsibilities. They usually amount to 1% of the total vessel variable costs.

$$C_{insurance} = a + b * w + c * NT \quad (6.9)$$

where:

$w$  = loading capacity of the vessel;

$NT$  = net tonnage;

$a$  = 15.1 [Euro/day];

$b$  = 0.027 [Euro/day TEU];

$c$  = 0.0031 [Euro/day tonne].

(source: Banca D'Italia – [www.bancaditalia.it](http://www.bancaditalia.it))

*Variable travel costs* represent the most important cost voice. They include:

- filling costs;
- harbor costs (loading/unloading activities, handling and goods stocking);
- crossing rights.

Among *filling costs*, fuel makes the biggest part. Fuel costs can be estimated by multiplying the quantity of fuel used by the price paid to purchase it:

$$C_{fuel} = C_{IFO} * IFO \quad (6.10)$$

where:

$C_{IFO}$  = fuel cost [Euro/tonne];

$IFO$  = quantity of fuel used =  $F * T_S$ ;

$F$  = daily consumption of the vessel

(it is a function of operational conditions: type of vessel, engines, speed);

$T_S$  = travel time [days].

Under the filling costs, even though it is much less relevant, the cost of diesel used for the auxiliary engines can be considered as well:

$$C_{diesel} = C_{MDO} * MDO \quad (6.11)$$

where:

$C_{MDO}$  = diesel cost [Euro/tonne];

$MDO$  = quantity of diesel used.

## 6.2.2. *Values in Literature*

### 6.2.2.1. *Road Transport*

All the factors concurring in the internal costs depend by two of the factors introduced before: travel time ( $T$ ) and travelled kilometres ( $km$ ).

$$C_{int} = f(T, km) \quad (6.12)$$

In fact, in many Supply Chain networks the total transportation cost function is minimized by combining the above two factors. To give an unique and homogeneous unit of measurement between time and kilometres a cinematic quotient can be used, being it defined as the mean speed for different parts of the travelled route. Using this assumption, a typical delivery travel can be broken up into two main paths: 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 local speed ratio ( $s_l$ ) can be used to compare the two fractions and to express both the inside urban centre path and the external urban centre travel as a function of travelled kilometres ( $km$ ).

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

$$C_{int} = f(f_1(s_l, km), km) \quad (6.13)$$

Several values of  $C_{int} = f(km)$  on international (European) and national (Italian) travels were analyzed, as it is shown in Figure 6.1.

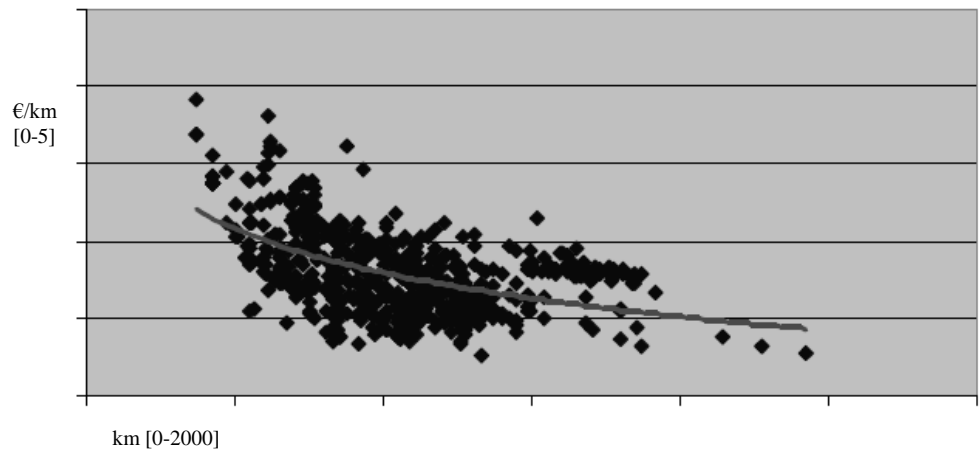
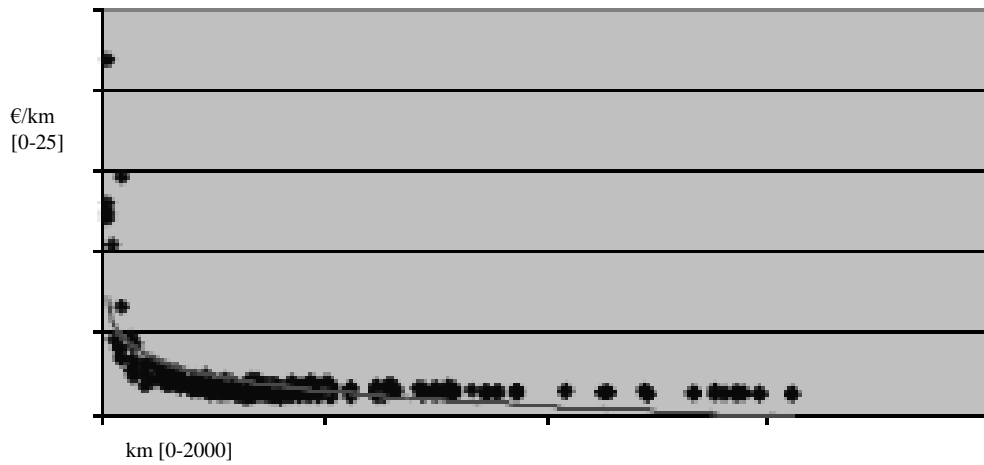


Figure 6.1. Internal road transport costs for European and Italian deliveries  
(source: Ortolani, 2007)

Finally, as an average value for road transport internal cost the most reliable value was estimated to be the one given by the Italian Ministry of Transport in a 2008 review, amounting to 0.0553 €//(ton km).

### 6.2.2.2. *Rail Transport*

The rail internal transport cost is defined using a complex listing of charges, developed by the rail cargo companies. The final cost value depends on several factors, based on transported goods, such as type of goods, transported quantities, empty containers management, available trips, frequency of deliveries. For this reason, it is very difficult to calculate an average value. In this paper, an internal rail cost has been estimated for the specific case studies and the impact of its variability on final network design and total cost has been tested with a sensitivity analysis.

### 6.3. *External Costs: New Analytical Formulations*

External costs are again function of travel time ( $T$ ) and travelled kilometres ( $km$ ). Moreover, these costs depend on the environmental aspects ( $EA$ ). Using the assumption introduced for the internal costs, we can define:

$$C_{ext} = f(T, km, EA) \quad (6.14)$$

where:

$T = f_1(s, km)$ , considering the local speed ratio;

$EA = f_2(EI, km)$ , taking into consideration the different impacts on environment (EI)

for several transports methods (road and rail).

### 6.3.1. Road Transport

The external costs function for road transport can be expressed as:

$$EA = f_2(EI, km) = (a_1 + a_2 + a_3 + a_4 + a_5 + a_6 + a_7 + a_8 + a_9 + a_{10} + a_{11} + a_{12} + a_{13}) \quad (6.15)$$

where:

- $a_1$  = emissions – air pollution coefficient;
- $a_2$  = emissions – greenhouse effect coefficient;
- $a_3$  = congestion coefficient;
- $a_4$  = noise coefficient;
- $a_5$  = accidents coefficient;
- $a_6$  = road damage coefficient;
- $a_7$  = resource consumption coefficient;
- $a_8$  = roadway land cost coefficient;
- $a_9$  = land use impact coefficient;
- $a_{10}$  = water pollution coefficient;
- $a_{11}$  = waste disposal coefficient;
- $a_{12}$  = traffic services coefficient;
- $a_{13}$  = barrier effect coefficient.

As said, this review aims to consider all significant external cost categories proposed by the current papers. As a matter of fact, most of the contributions only consider the most common cost categories, such as emissions, congestion, noise and accident costs. These costs definitely have a huge impact on the final cost estimation but considering only those values would turn in an under-estimation of the final cost.

The cost categories are assumed to be independent and additive. As a matter of fact, the same assumption is considered valid in many researches: Van Essen *et al.* in their “Handbook on estimation of external costs in the transport sector” (2009) consider the total external cost as the sum of noise, congestion, accidents, air pollution, climate

change, up- and downstream processes, nature and landscape and, finally, soil and water pollution impacts.

The values of the above coefficients were calculated starting from the evaluation of all the different estimates in literature and they are summarized in Table 6.1 (all of them are expressed in €/((ton km))).

<b>Coefficient Index</b>	<b>Coefficient Description</b>	<b><math>\underline{V}_1</math></b>	<b><math>\underline{V}_2</math></b>	<b><i>Min V</i></b>	<b><i>Max V</i></b>
$a_1$	emissions – air pollution	0.00778	0.00778	0.00050	0.02068
$a_2$	emissions – greenhouse effect	0.00789	0.00690	0.00050	0.02068
$a_3$	congestion	0.04511	0.02819	0.00375	0.10172
$a_4$	noise	0.00299	0.00224	0.00005	0.00791
$a_5$	accidents	0.00884	0.00774	0.00144	0.02537
$a_6$	road damage	0.00188	0.00141	0.00062	0.00594
$a_7$	resource consumption	0.00535	0.00067	0.00535	0.00535
$a_8$	roadway land cost	0.00364	0.00045	0.00364	0.00364
$a_9$	land use impact	0.00711	0.00089	0.00711	0.00711
$a_{10}$	water pollution	0.00150	0.00019	0.00150	0.00150
$a_{11}$	waste disposal	0.00004	0.00001	0.00004	0.00004
$a_{12}$	traffic services	0.00128	0.00016	0.00128	0.00128
$a_{13}$	barrier effect	0.00150	0.00019	0.00150	0.00150
<b><i>TOT</i></b>		<b>0.0949</b>	<b>0.0568</b>		

Table 6.1. Road transport external costs coefficients [€/((ton\*km))]

where:

$\underline{V}_1$  = mean value calculated starting from literature cost coefficients and ignoring zero values;

$\underline{V}_2$  = mean value calculated starting from literature cost coefficients and considering zero values;

*Min V* = minimum value in literature;

*Max V* = maximum value in literature.

As explained before, these values are related to a truck with average load of 14.3 tons. It is possible to estimate the coefficient also for other kinds of trucks with different average load. For example, Figure 6.2 shows the congestion coefficient for several vehicles, from 4 tons to 28 tons, and different kinds of path: urban peak, urban off-peak and rural. Each value is estimated starting from the average value of 14.3 tons truck based on average vehicle saturation, carrying capacity, path type and other specific parameters.

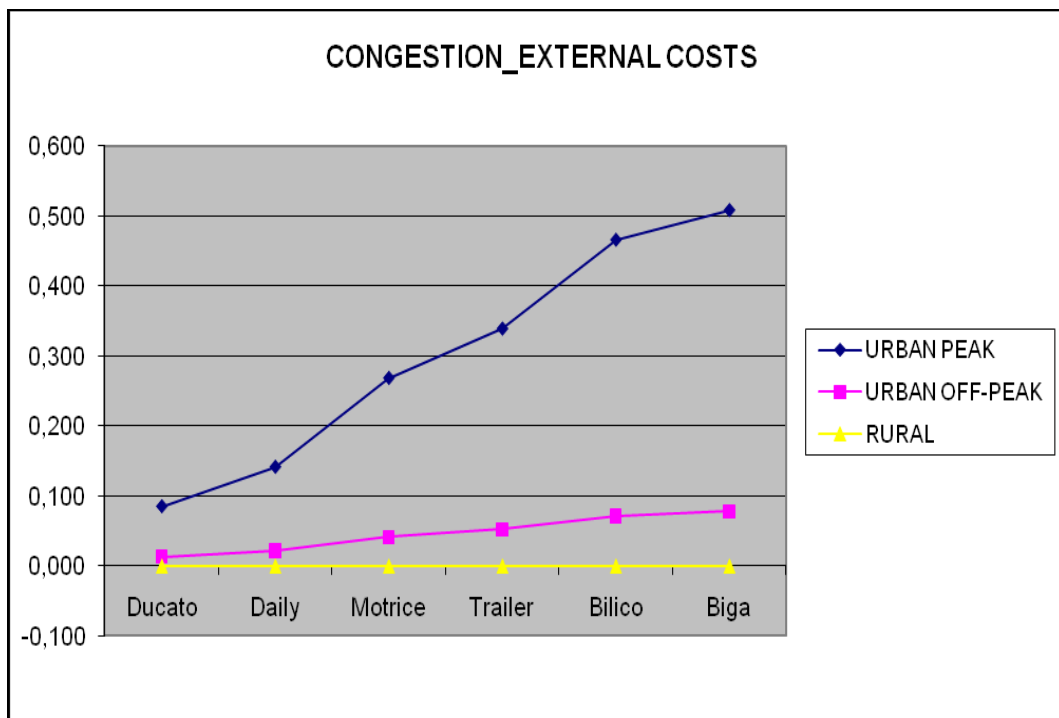


Figure 6.2. Congestion coefficients based on carrying capacity and path type  
[€/((vehicle\*km))]

### 6.3.2. Rail Transport

The external cost function for rail transport can be expressed as:

$$EA = f_2(EI, km) = (b_1 + b_2 + b_3 + b_4) \quad (6.16)$$

where

$b_1$  = emissions – air pollution coefficient;

$b_2$  = emissions – greenhouse effect coefficient;

$b_3$  = noise coefficient;

$b_4$  = accidents coefficient.

The calculated values of the above coefficients are summarized in Table 6.2 (all of them are expressed in €/ton km).

Coefficient Index	Coefficient Description	$\underline{V}_1$	$\underline{V}_2$	Min V	Max V
$b_1$	emissions – air pollution	0.00153	0.00153	0.00006	0.00300
$b_2$	emissions – greenhouse effect	0.00154	0.00154	0.00012	0.00300
$b_3$	noise	0.00181	0.00135	0.00024	0.00371
$b_4$	accidents	0.00182	0.00138	0.00103	0.00292
<b>TOT</b>		<b>0.00670</b>	<b>0.00580</b>		

Table 6.2. Rail transport external costs coefficients [€/ton\*km]

where:

$\underline{V}_1$  = mean value calculated starting from literature cost coefficients and ignoring zero values;

$\underline{V}_2$  = mean value calculated starting from literature cost coefficients and considering zero values;

*Min V* = minimum value in literature;

*Max V* = maximum value in literature.

For both road and rail cases the value which is used in the analysis per each cost category is  $\underline{V}_l$ , which is a mean value calculated starting from literature cost coefficients and ignoring zeros. In this way every cost coefficient is calculated by taking into consideration only the contributions which actually monetize that cost.

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

$$C_{ext} = f(f_1(s_l, km), km, f_2(EI, km)) \quad (6.17)$$

### **6.3.3.      *Sea Transport***

For sea transport, as well as for the aviation field, basically no literature with external costs estimation is available. This conveys the assumption (more or less explicit) that such costs are negligible. Even though surely the specific cost per product transported will be much lower in case of sea transport if compared to road, external costs are there for sea shipments as well and will grow rapidly if not addressed properly.

## **6.4. Case Studies: Application of the New Cost Models**

### **6.4.1. Cool and Food Transport Network**

The external costs formula was applied while designing the Italian distribution network of an international fast food company. Currently it is a 100% road transport network, the goods are stocked inside the vehicles and kept at three different temperature levels. The products are delivered by a number of different suppliers to two hubs and then they are distributed through over 400 restaurants of different dimensions. The conservation temperatures are respectively:  $-25^{\circ}$  Celsius for frozen products, like bread, meal and ice cream;  $+2^{\circ}$  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 address 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 (Figure 6.4). The chosen solution has been the second one, with multi-temperature vehicles. The study has been extended also to the choice of logistics partners.

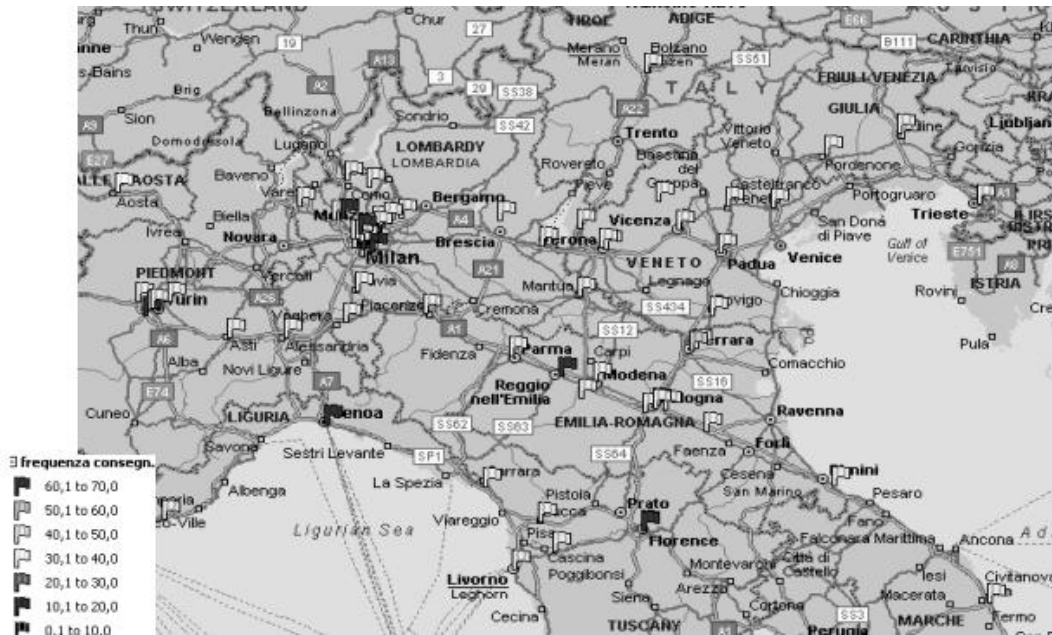


Figure 6.3. Northern Italy network (city trailer truck)

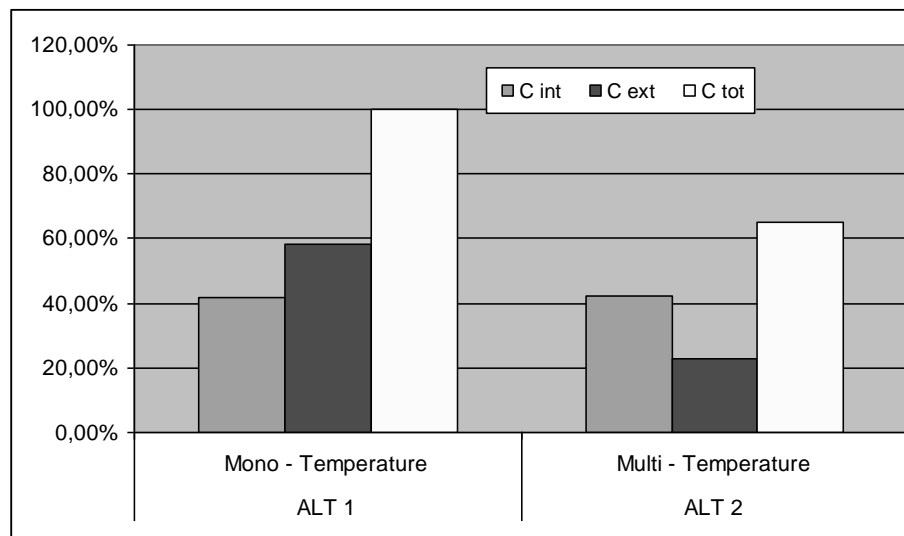


Figure 6.4. Total transport costs

The alternative with the multi-temperature vehicles resulted to be more convenient even when the added external costs caused by the refrigerators were considered in the analysis. In effect, in order to make the multi-temperature option work, specific controls

have to be used on the trucks. The multi-temperature controllers are able to manage up to three different temperature levels allowing an efficient distribution of the goods at the required temperature level, but they generate further operational as well as environmental costs. Multi-temperature controllers do not generate sensible consequences on all the external cost categories, but have specific impacts on some of them. Roadway facilities costs refer to the incremental costs of building stronger pavements, wider roads and higher design speeds and they can be generated by vehicles according to their weight, size and speed. Adding a multi-temperature refrigerator on the truck will increase the overall weight and thus increase such roadway facilities costs: the average incremental cost in the multi-temperature case was estimated to be 7% more than the base option (same truck without multi-temperature refrigerator).

Air pollution is mainly affected by five factors: vehicle type (larger vehicles tend to produce more emissions), vehicle age and condition, driving cycle, driving style, driving conditions. The only factor affected by the refrigerator's added weight is the vehicle type: its influence was estimated at a 9% increase respect to the base case.

Noise refers to unwanted sounds and vibrations. Again, five factors mainly affect the amount of noise emitted: vehicle type (heavy vehicles tend to produce more emissions), engine type, traffic speed, pavement type and condition, distance and barriers. The only factor affected by the refrigerator's added weight is the vehicle type: its influence can be estimated as 7%. Moreover, the noise produced by the refrigerator pump has to be added: it can be estimated as an incremental 2%.

Resource consumption external costs refer to costs of resources consumed in motor vehicle production and operation not borne directly by users. This primarily refers to energy. The refrigerator implies an additional energy use due to the refrigeration activity, its contribution to external costs can be estimated as an incremental 1.5%.

The refrigerators typically use chlorine free refrigerants. These refrigerants are classified as a non dangerous products (see act 1999/45/CE) and they do not contain any chemicals which could be harmful to environment and health (see act 67/548/CEE). As a consequence, no additional water pollution cost is caused by the added refrigerator.

Waste disposal external costs due to the refrigerator come mainly from the battery included in the system. Motor vehicle wastes are generally classified in 5 categories with decreasing percentages of influence: used oil (50%), antifreeze (15%), batteries (15%), antifreeze (7%), pesticide and other (7%). In this case we can assume that the

battery included in the refrigerator weights as much as the vehicle battery, causing then an additional 7% to be computed in the external costs.

#### 6.4.2. *Reverse Logistics of Industrial Liquid Wastes*

This case deals with the application of the proposed model for designing a network for picking and disposal activities of industrial liquid wastes. The network is placed in northern Italy. Given three disposal points (located near three important cities) and known the amount of production of industrial liquid wastes (measured in m<sup>3</sup>) of a series of over 6,000 firms located in several local areas (Figure 6.5), the aim of the project was to design the best transport network.

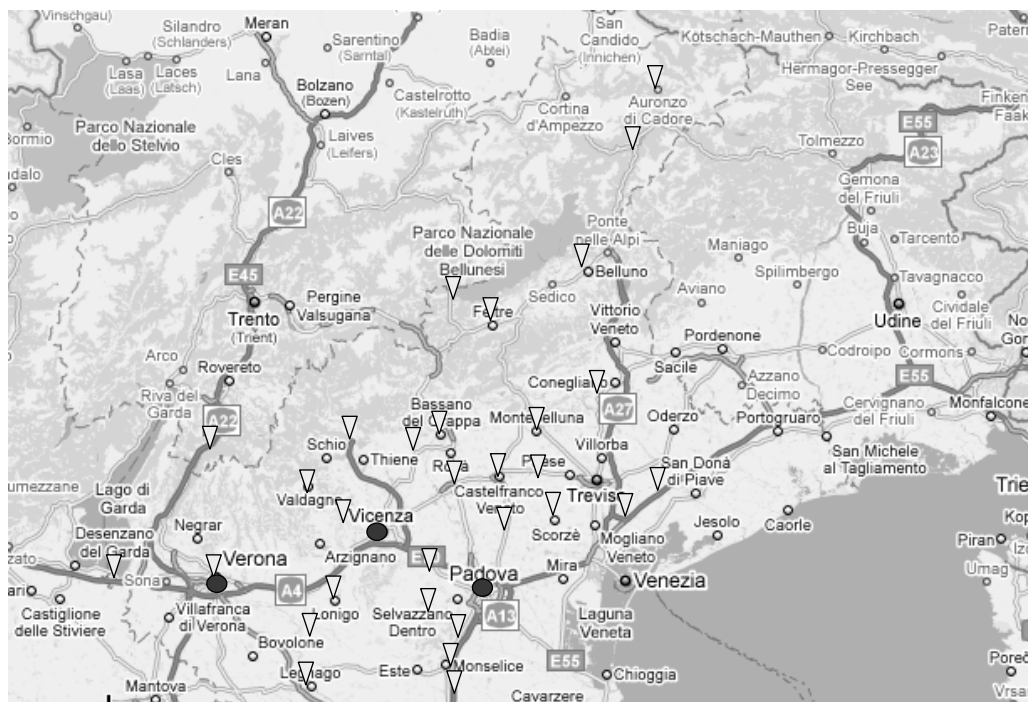


Figure 6.5. Network of analyzed firms

In this case, the transport costs have been scaled from [€/ton\*km] to [€/m<sup>3</sup>\*km]: a conversion factor  $c_v$  has been introduced.

Each container can transport 28 tonnes, corresponding to 22.5 m<sup>3</sup>, consequently the  $c_v$  factor is equal to 1.24 tonnes/m<sup>3</sup>. Using this factor, the road internal cost is about 0.0553 €/ton\*km, equivalent to 0.06884 €/m<sup>3</sup>\*km.

About the rail internal costs, the manager of the analyzed company gave this economic value: 100 €/km for a train of 24 containers, with total of 672 tons, equal to 833 m<sup>3</sup>. The unit rail internal cost is equal to 0.15 €/ton\*km, which equals to 0.1867 €/m<sup>3</sup>\*km (using the conversion factor). This high value is due to the low expected amount of transported goods. The value comes from the listing of charges of Train Cargo company employed in this case study.

It has to be noted that one of the objectives of this case study was to demonstrate that the rail transport mode might not be economically convenient if a company considers only the internal costs, but it could become interesting when the network managers evaluate also the external costs, as illustrated in Table 6.3. In fact, the optimisation process, when considering only the internal costs, carried out a 100% road transport systems and relative optimisation of routes. Nevertheless, considering also environmental aspects and external costs brought to a different optimal solution, characterized by a mix of two different transport types, both road and rail. This has been the adopted solution.

Table 6.3 shows the values of internal and external costs of the two different solutions: OPT INT reports the total costs [€/year] resulting from the optimisation considering only the internal costs, while OPT TOT is related to the global optimisation results [€/year].

<i>Cost</i>	<i>Description</i>	<i>Values</i>	
		<i>€/ (ton*km)</i>	<i>€/ (m3*km)</i>
Cint_road	Road Internal Costs	0.0553	0.06884
Cint_train	Train Internal Costs	0.1500	0.18667
Cext_road	Road External Costs	0.0949	0.11810
Cext_train	Train External Costs	0.0067	0.00834

	<i>OPT INT [€/year]</i>	<i>OPT TOT [€/year]</i>	<i>DELTA</i>
Cint_tot	248,566.44	271,240.74	9.12%
Cext_tot	426,563.39	394,827.25	-7.44%
Ctot	675,129.83	666,067.99	-1.34%

Table 6.3. Rail transport external costs coefficients [€/ (ton\*km)]

## 6.5. Sensitivity Analysis

After having run the analysis using some fixed data (referring to what we called the “base case”), a sensitivity analysis was made, simulating 1,600 different scenarios.

This analysis was run in order to test the consistency of the already mentioned assumptions :

- in the calculation of road external costs only most recent contributions were considered, while all the articles dated before year 2000 were excluded;
- similarly, in the rail external costs calculations only few important cost categories were included, as most of the ones which are relevant in the road case do not have the same importance for rail transport;
- both internal and (especially) external costs show a high variability in the values given in literature, this mainly due to the causes listed by Victoria Transport Policy research (2009);
- specific values for the average truck and rail capacity were assumed.
- 

Moreover, the sensitivity analysis was required due to the high dispersion of the data (as already remarked in previous sections and also stated in Quinet’s work). This analysis was run using Matlab® and it included variations to both internal and external costs. In particular, both internal and external unit costs were modified on the basis of the percentages shown in Table 6.4.



It has to be noted that costs of OPT INT were calculated by firstly optimizing the transport route while only considering internal costs, and then estimating the cost of such route considering both internal and external costs. OPT TOT is referred to the optimisation considering both internal and external costs.

Figure 6.6 shows, in the base case, how the percentage savings between OPT INT and OPT TOT costs vary as a function of the variations of internal and external costs for both rail and road.

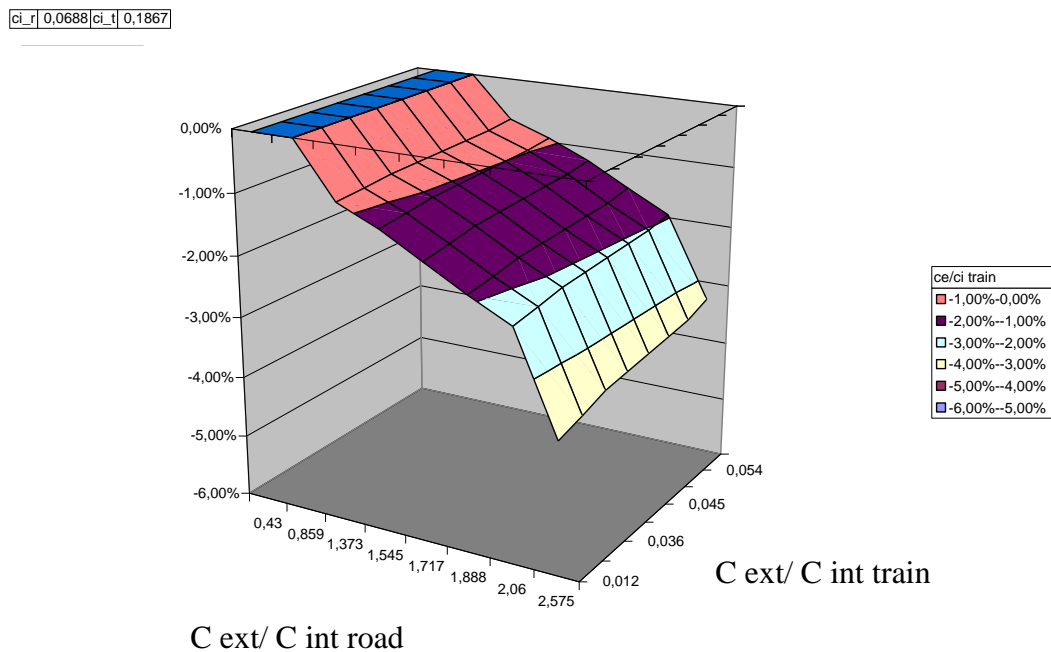


Figure 6.6. Savings variation:  $C_{ext}/C_{int\ road}$  vs  $C_{ext}/C_{int\ train}$

The axes show the ratio between road external and internal transport cost ( $x$  axe) and the ratio between rail external and internal transport cost ( $y$  axe).

It can be seen that until external road costs do not weight more than 40% respect to internal road costs, the delta between road and rail costs is almost zero: as a consequence, using rail transport would not convey any valuable advantages nor in terms of internal or even external costs. Nevertheless, if external road costs are valued to weight more than 0.43 times the internal costs, then the advantage of using rail becomes more and more consistent. A general decrease of the total transportation cost

that would be generated by rail transport respect to road can be seen, the more external road costs increase their weight on internal costs. As it was predictable, then, the more external costs are considered, the more rail freight appears to be convenient over road, as the external costs per unit and kilometre travelled imposed by rail are consistently lower respect to the same feature in road.

Figure 6.7 shows how the total volume transported by rail would vary in the base case as a function of the variations of internal and external costs for both rail and road

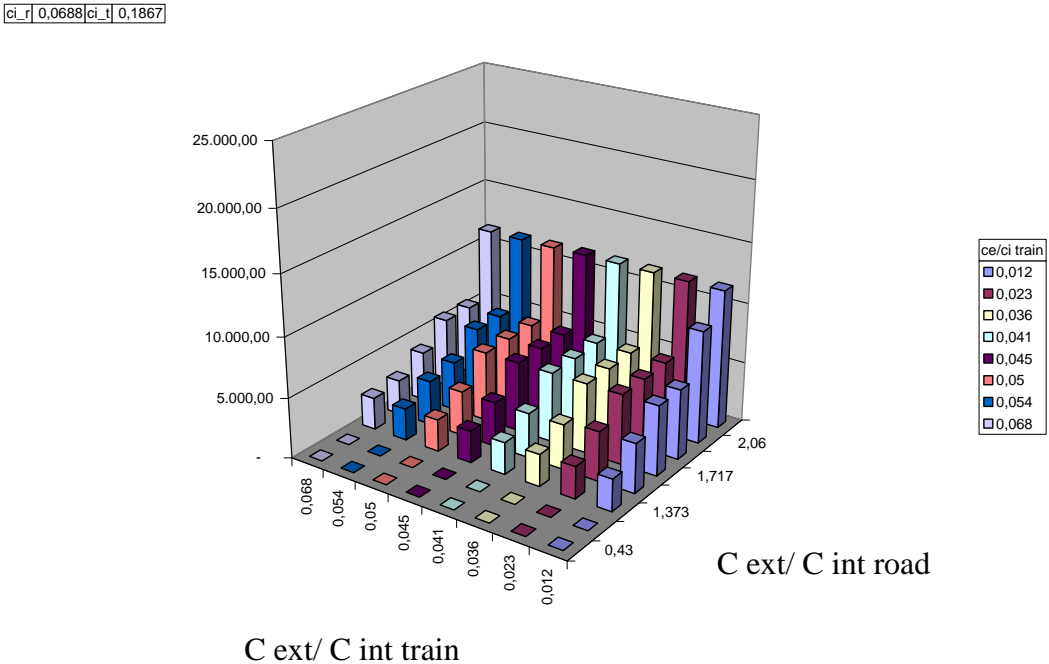


Figure 6.7. Volumes variation:  $C_{ext}/C_{int\ train}$  vs  $C_{ext}/C_{int\ road}$

The volume transported by rail is increasing as the weight of external road transport costs on internal costs increases, this coming again from the increased convenience of rail transport over road.

### 6.5.1. *Impacts of Internal and External Costs Variation*

The sensitivity analysis was run in order to evaluate how the results change once the costs in input are changing: Figures 6.8 and 6.9 show how the delta cost is changing if rail internal costs are fixed, while road internal costs are rising.

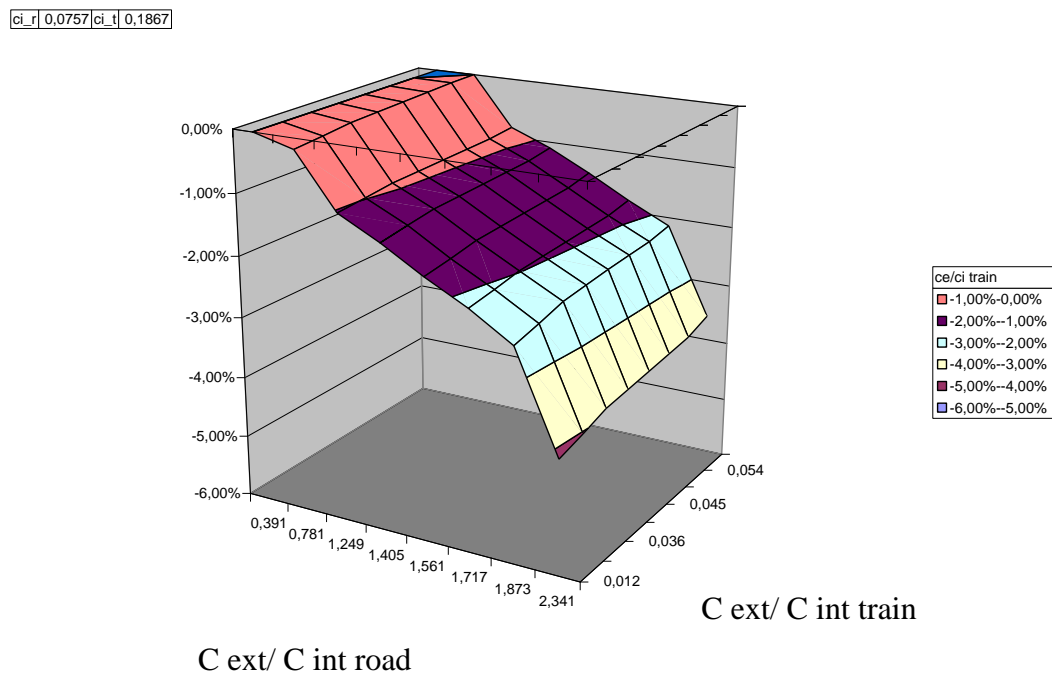


Figure 6.8. Savings variation:  $C_{ext}/C_{int\ road}$  vs  $C_{ext}/C_{int\ train}$

ci\_r| 0,1032|ci\_t| 0,1867

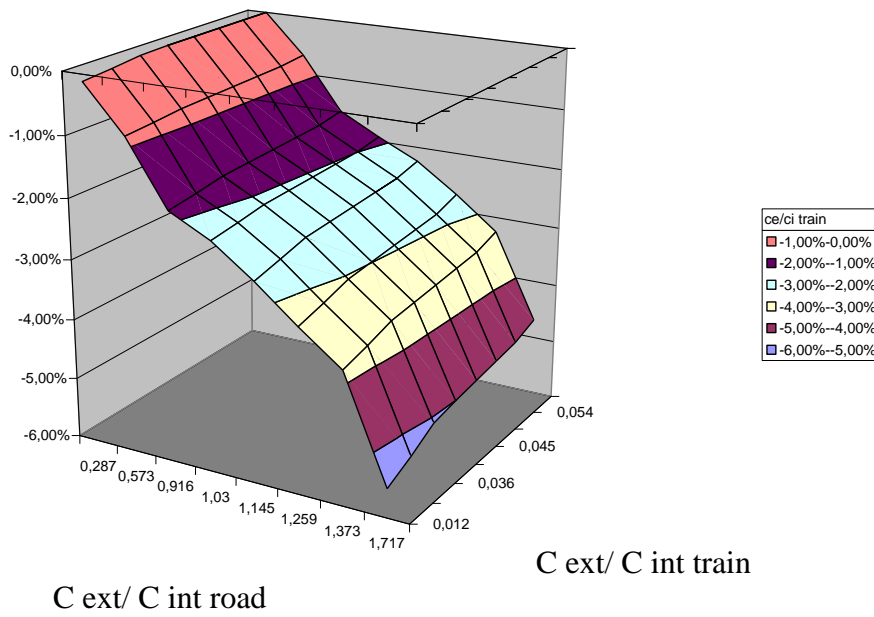


Figure 6.9. Savings variation:  $C_{ext}/C_{int road}$  vs  $C_{ext}/C_{int train}$

The more road internal costs increase, the more the pattern is marked: in case internal road transport costs are particularly high (0.1867 €/ton km), rail transport appears to be always more convenient, no matter which is the value of road external costs.

Figures 6.10 and 6.11 show how the delta cost is changing if road internal costs are fixed, while rail internal costs are rising.

ci\_r 0,0688 | ci\_t 0,2053

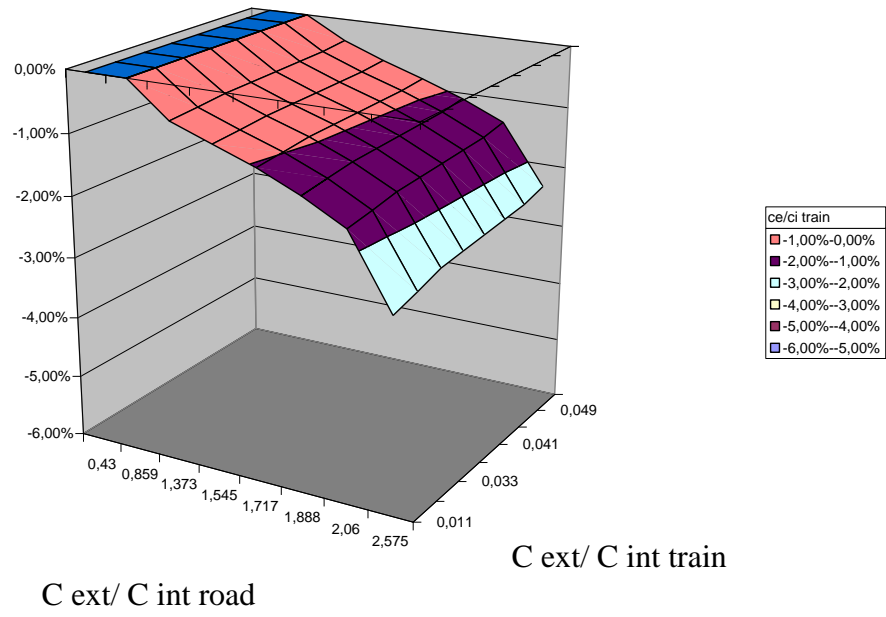


Figure 6.10. Savings variation:  $C_{ext}/C_{int,road}$  vs  $C_{ext}/C_{int,train}$

ci\_r 0,0688 | ci\_t 0,2800

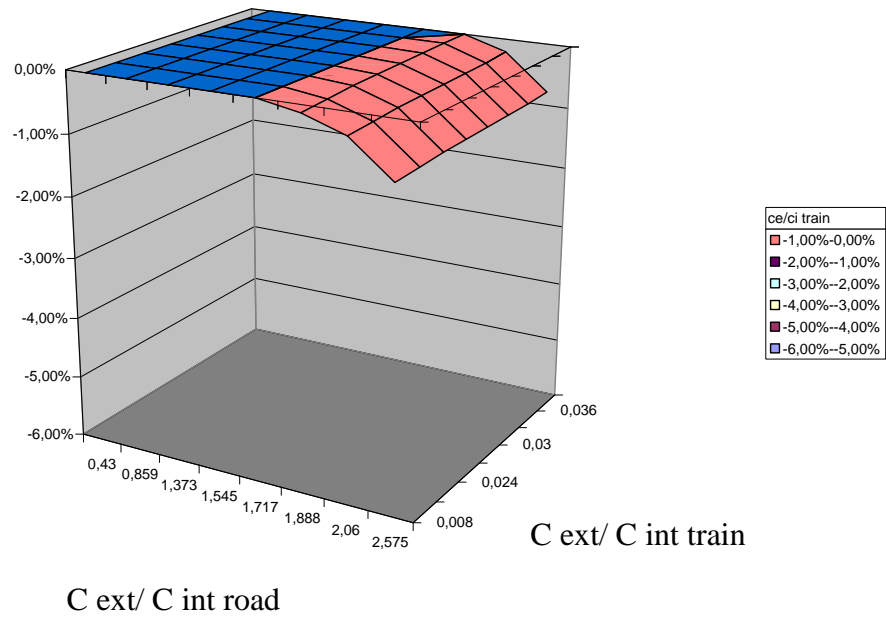


Figure 6.11. Savings variation:  $C_{ext}/C_{int,road}$  vs  $C_{ext}/C_{int,train}$

The more internal rail costs are high, the more road transport is convenient: when rail transport costs are particularly high (0.2800 €/ton km), road transport is more convenient until its external costs weight 1.5 times the internal costs.

Figures 6.12, 6.13, 6.14 and 6.15 show the same results in terms of transported volumes: once a mode becomes more convenient because its internal costs decrease (or internal costs of the alternative mode increase) then an increased volume is transported by using that mode. The variation of rail costs ratio does not affect significantly the results, while the increase of the road costs ratio brings an increase of transported volumes by rail.

ci\_r|0,0757|ci\_t|0,1867

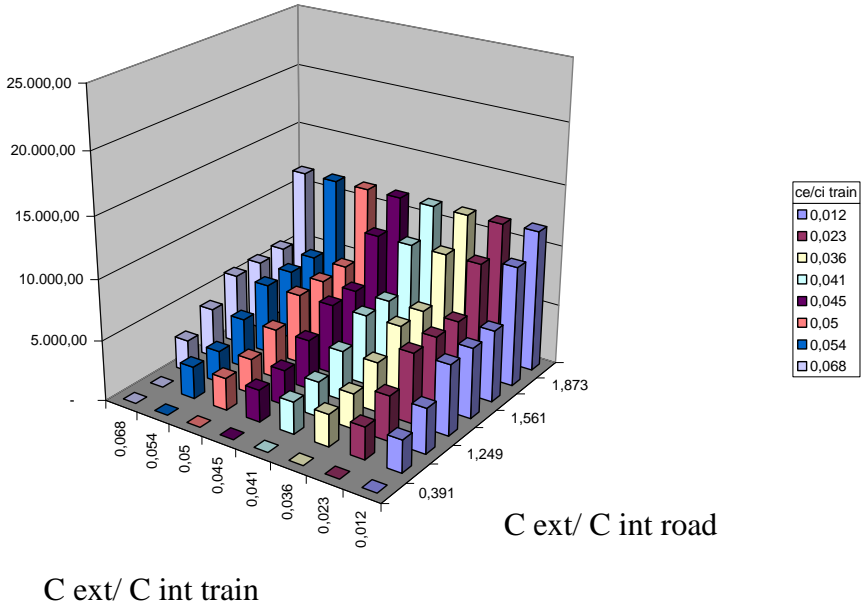


Figure 6.12. Volumes variation:  $C_{ext}/C_{int\ train}$  vs  $C_{ext}/C_{int\ road}$

ci\_r|0,1032|ci\_t|0,1867

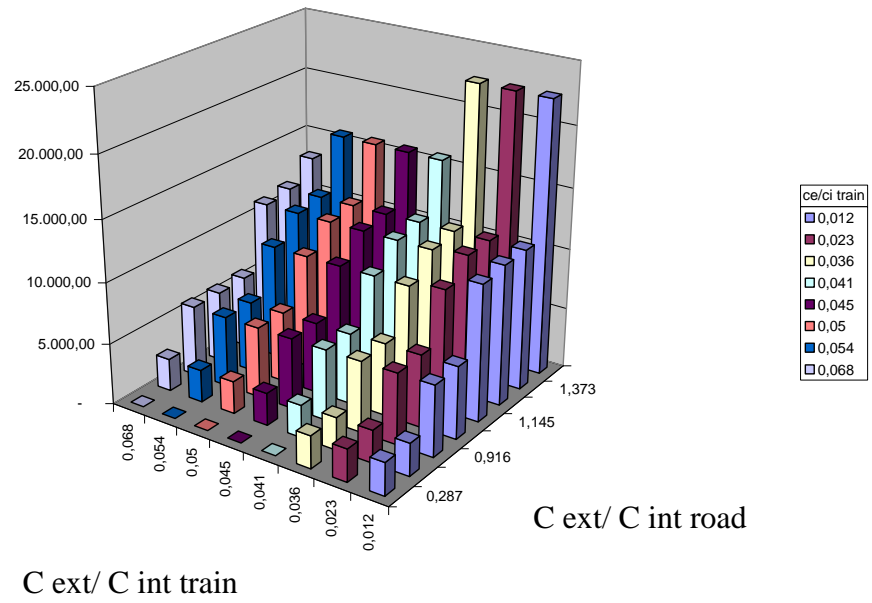


Figure 6.13. Volumes variation:  $C_{ext}/C_{int\ train}$  vs  $C_{ext}/C_{int\ road}$

ci\_r|0,0688|ci\_t|0,2053

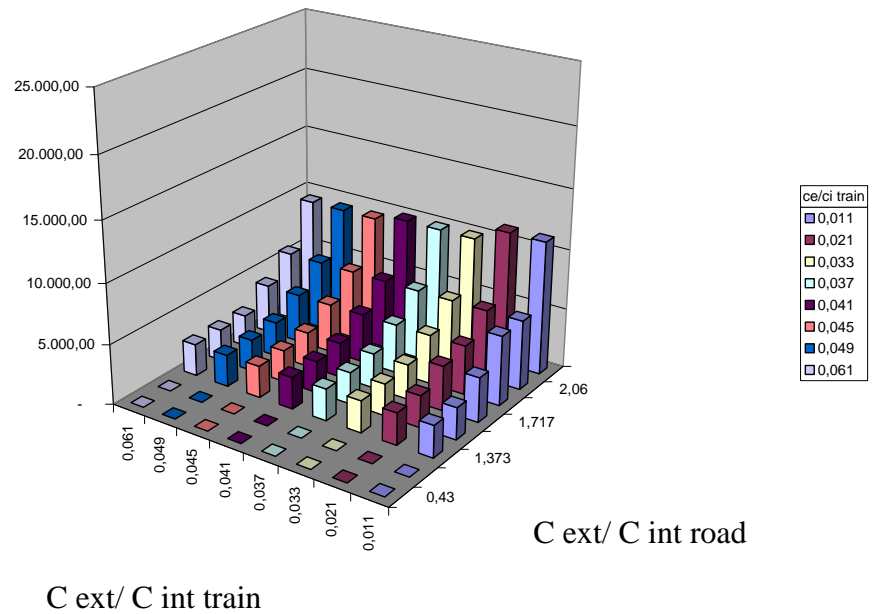


Figure 6.14. Volumes variation:  $C_{ext}/C_{int\ train}$  vs  $C_{ext}/C_{int\ road}$

ci\_r | 0,0688 | ci\_t | 0,2800

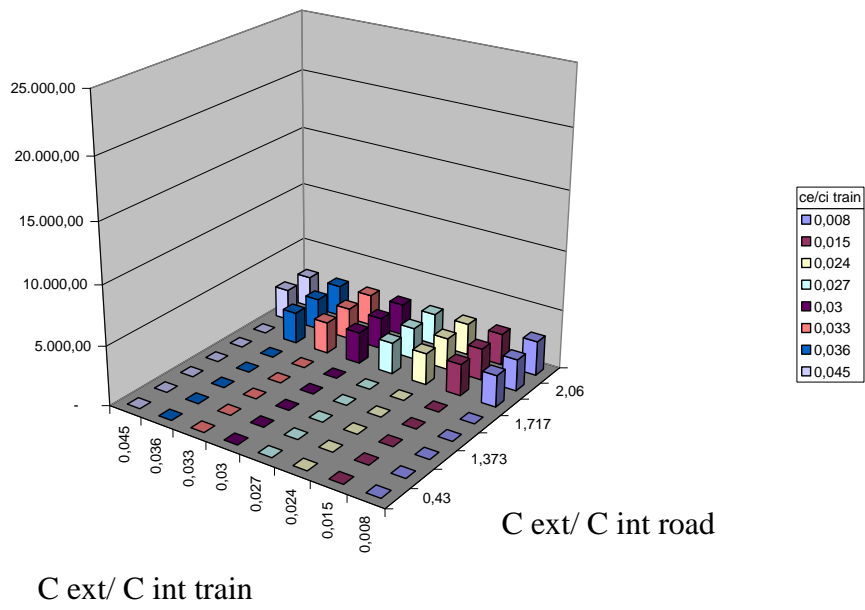


Figure 6.15. Volumes variation:  $C_{ext}/C_{int\ train}$  vs  $C_{ext}/C_{int\ road}$

## **7. Design of an Innovative Framework for Total Cost Estimation**

### ***7.1. Introduction***

The final aim of this work consists in gathering the various (and variable) literature contributions on freight transport costs and building a summarized model. The model allows an easy calculation of the overall transportation cost of a specific distribution route. Starting from a reduced number of values in input, the user can obtain in output both the internal and external transport costs which will be generated on a specific route under specific travelling conditions.

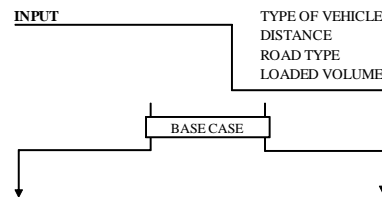
The framework uses two different approaches for external and internal costs, as they are influenced either by different factors or by the same factors but in different ways. The direct approach that can be used for calculating internal costs is completely different from the one that has to be used in case of external costs (which are much less evident and easily identifiable). Nevertheless, both approaches start from a so-called “base case”. The base case is a well defined reference case, characterized by a standard vehicle type on a standard route with a given load and saturation factor. Internal costs are calculated by adapting to the base case all the factors that contribute to the typical distribution cost calculation: vehicle purchase costs, insurances and taxes, maintenance, tyres and fuel costs. For external costs, the calculation cannot be defined with such a direct method and a cascade approach has to be used. At first both the internal and external costs for the base case are calculated. Once the cost related to the base case is defined, all the following steps of the framework are designed to gradually adapt the case to the real situation. As a consequence, the specific vehicle used replaces the standard one, the route can be varied (and with it, the internal factors involved) and, finally, the saturation of the vehicle is considered. In the end a specific cost is calculated, which takes into consideration the constraints and the specificness of the given distribution activity.

## 7.2. Design of the New Framework

Figure 7.1 shows graphically the path followed in the framework creation, starting from the base case and adding up step by step the case specifications.

### STEPS

1.



### 2.A INTERNAL COST CALCULATION

$C_{int\ tot}$

#### 2.A.1 INTERNAL VARIABLE COST

##### STEP 1

BASE VEHICLE



Pallet ratio

##### STEP 2

SPECIFIC VEHICLE



Speed factor

##### STEP 3

SPECIFIC ROAD



Volume ratio

##### STEP 4

SATURATION

#### 2.A.2 INTERNAL FIXED COST

#### 2.A.3 TOTAL INTERNAL COST

$$C_{int\ tot} = C_{int\ var} + C_{int\ fix}$$

### 2.B EXTERNAL COST CALCULATION

$C_{ext\ tot}$

#### 2.B.1 TOTAL EXTERNAL COST

##### STEP 1

BASE VEHICLE



Pallet ratio

##### STEP 2

SPECIFIC VEHICLE



External factors matrix  
Road type matrix

##### STEP 3

SPECIFIC ROAD  
SPECIFIC EXTERNAL COST FACTORS



Volume ratio

##### STEP 4

SATURATION

3.

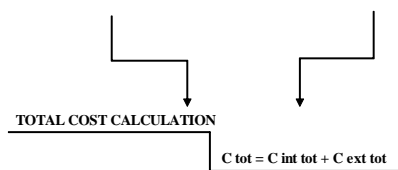


Figure 7.1. Graphical path of calculation framework

### 7.2.1. *Input*

The values to be given in input to the framework are the following ones:

- Type of vehicle

The types of vehicle were classified by using common Italian vehicles references, and identifying them with the number of pallets which can be loaded on each one. For simple reference, the vehicles were nominated as Base vehicle (10 pallets vehicle, used as base case) and Vehicles 1 to 5, each one of them characterized by a specific capacity.

<i>Vehicle</i>	<i>Capacity (# of pallets)</i>
Vehicle 1	6
Base Vehicle	10
Vehicle 2	19
Vehicle 3	24
Vehicle 4	33
Vehicle 5	36

Table 7.1. Vehicles considered in the analysis

Depending on the number of pallets to be carried, the user can choose the most suitable vehicle among a pre-defined list including the above means.

- Distance

The user has to indicate the distance (in kilometers) between the starting and the arrival point of the distribution route. At this stage no distinguishing between urban or rural route is required.

- Road type

As both internal and external transport costs vary with traffic and road conditions, information on the nature of the travel conditions is required. The user has to indicate which percentage of the total distance is likely to be covered

in a rural environment, which one on urban streets in off-peak conditions and, finally, which one in urban streets in peak conditions.

- Loaded volume

It refers to the total volume (in cubic meters) which needs to be carried by the chosen vehicle.

Starting from this value, the system calculates the volumetric saturation coefficient by dividing the loaded volume by the maximum available volume on the vehicle.

## **7.2.2. *New Calculations for Costs Evaluation***

Calculations follow a different path in case of internal and external costs. As a consequence, they will be treated separately.

### **7.2.2.A *Internal Cost Calculation***

Internal transport costs are calculated starting from a base internal cost value given by the Italian Transport Ministry in the Internal Transport Cost 2008 handbook. This value refers to a 33 pallets vehicle travelling on a rural route and amounts to 1.539 €/km. Mean speed for this vehicle is 80 kms/hour and saturation is 100%. This internal cost value is made up by a variable amount (approximately 1 €/km for the base case) plus a fixed amount (0.5 €/km). The variable amount will be calculated case by case through a set of coefficients and hypotheses (explained in the next paragraph), while the fixed amount will be added as it is per each travelled kilometer for every possible route.

As a consequence, the total internal cost will be obtained summing the internal variable cost for the specific route plus the internal fixed cost.

All the cost values considered in the internal costs calculation (both fixed and variable costs) are listed in Table 7.2.

**INTERNAL COSTS**

<b>FACTORS</b>	<b>FUNCTION OF VEHICLE TYPE?</b>	<b>FUNCTION OF ROAD TYPE?</b>	<b>FUNCTION OF DISTANCE?</b>	<b>FUNCTION OF SATURATION?</b>
1. Vehicle purchase	yes - proportional to vehicle dimensions (# of pallets that can be loaded)	no	no	no
1.1 Purchase				
1.2 Purchase taxes				
2. Insurance	yes - proportional to vehicle dimensions (# of pallets that can be loaded)	no	no	no
2.1 Civil Responsibility Tax				
2.2 Fire and theft				
2.3 Insurance taxes				
3. Vehicle taxes	yes - proportional to vehicle dimensions (# of pallets that can be loaded)	no	no	no
3.1 Ownership tax				
4. Tyres	yes - proportional to vehicle weight (# of pallets that can be loaded)	yes - depending on mean speed of different road types	yes - proportionally	yes - proportional to vehicle weight
4.1 Tractor				
4.2 Semitrailer				
5. Fuel	yes - proportional to vehicle weight (# of pallets that can be loaded)	yes - depending on mean speed of different road types	yes - proportionally	yes - proportional to vehicle weight
5.1 Industrial price				
5.2 Fuel tax				
6. Repairing and Maintenance	marginally	marginally	marginally	marginally
6.1 Manpower				
6.2 Replacements				
6.3 Lubricants				
7. Road tolls	no	yes	yes	no
8. Driver wage	no	no	marginally	no

Table 7.2. Internal cost values

**7.2.2.A1 Internal Variable Cost**

As said, the internal variable cost is calculated starting from a base internal cost value: this base cost is converted into a specific cost through proper coefficients which are included step by step in the analysis and which depend on the values in input. The specific cost is calculated by taking into consideration the type of vehicle used, the road type, the loaded volume and, consequently, the saturation factor. Vehicle type is identified through a volume ratio (or pallet ratio): specifically volume carried by the specific vehicle on volume carried on the base vehicle. Road type is identified by a speed ratio which takes into account the fact that different road conditions will allow different mean speeds. Table 7.3 shows the mean speeds for the considered vehicles under different road conditions.

<i>Vehicle</i>	<i>Mean speed - URBAN PEAK</i>	<i>Mean speed - URBAN OFF PEAK</i>	<i>Mean speed - RURAL</i>
Vehicle 1	35	60	100
Base Vehicle	35	60	100
Vehicle 2	30	50	90
Vehicle 3	30	50	90
Vehicle 4	20	40	80
Vehicle 5	20	40	80

Table 7.3. Mean speed under different road conditions (km/hour)

Distance is not taken into account in the framework with a specific coefficient as the final costs are calculated on a total traveled distance basis. Finally, saturation is considered through a factor which divides the effective load on the specific vehicle (in terms of cubic meters) by the maximum possible load on that vehicle.

In this way, starting from the base case (10 pallets vehicle travelling in rural conditions), it is possible to calculate the cost for a specific vehicle in rural conditions (step 1) and then for a specific vehicle in specific road conditions (step 2). Finally, once the cost is calculated, the saturation factor is used in order to scale the cost by considering that the vehicle is not usually fully loaded.

### 7.2.2.A2 *Internal Fixed Cost*

As stated previously, the internal fixed costs amount to 0.5 €/km, independently from the route taken.

### 7.2.2.A3 *Case Study A: Internal Cost Calculation*

The framework was tested on a considerable amount of cases. As an explanatory example we will consider here the case of a Vehicle 3 type (a trailer) loaded with 19 m<sup>3</sup>, travelling for 15% of the total distance (which amounts to 130 kms) on a urban way in peak conditions, for 20% of the total distance on a urban path in off peak conditions and for the balance 65% in a rural environment. Given the total volume that can be loaded in such a vehicle (24 pallets), the saturation factor is 55%.

Table 7.4 shows the input values of the example.

<i>INPUT VALUES</i>	
<i>VEHICLE</i>	TRAILER
<i>DISTANCE</i>	130 kms
<i>TRIP</i>	15% urban peak 20% urban off peak 65% rural
<i>LOADED VOLUME</i>	19,00 m <sup>3</sup>
<i>SATURATION FACTOR</i>	55%

Table 7.4. Values in input

Starting from these values the assumption table is filled (Table 7.5).

<i>ASSUMPTIONS</i>					
	<i>plt</i>	<i>m3</i>	<i>Cint RURAL scaled €/ (km*m3)</i>	<i>Cint URBAN OFF-PEAK scaled €/ (km*m3)</i>	<i>Cint URBAN PEAK scaled €/ (km*m3)</i>
<i>Vehicle 1</i>	6	8,64	0,079	0,132	0,225
<i>Base Vehicle</i>	10	14,4	0,056	0,093	0,159
<i>Vehicle 2</i>	19	27,36	0,039	0,071	0,118
<i>Vehicle 3</i>	24	34,56	0,036	0,064	0,107
<i>Vehicle 4</i>	33	47,52	0,032	0,063	0,101
<i>Vehicle 5</i>	36	51,84	0,031	0,061	0,098
<i>INTERNAL TRANSPORT COST (BASE CASE)</i>					
			RURAL	0,803 €/km	
			URBAN OFF-PEAK	1,338 €/km	
			URBAN PEAK	2,294 €/km	
<i>MEAN SPEED (BASE CASE)</i>					
			RURAL	100 km/h	
			URBAN OFF-PEAK	60 km/h	
			URBAN PEAK	35 km/h	
<i>VOLUMES</i>					
				1 plt	
				1,44 m3	

Table 7.5. Assumptions

The framework starts from the basic internal transport cost which is given in literature and amounts to 1.539 €/km in case of rural transport for a 33 pallets vehicle (Ministero dei Trasporti e della Navigazione, 2008). The variable part of this value (1 €/km) is then scaled through the pallet ratio in order to get the value for our base case (10 pallets vehicle) in a rural condition. From the literature contributions the scale ratios in order to obtain the urban peak and off peak costs starting from the base case are given for the 10 pallets vehicle (Litman, 2009) and again, through the pallet ratio, they are calculated for the specific case. As a consequence, internal costs for all three travel conditions are calculated: by multiplying each cost by its travel condition percentage the total variable cost is calculated. Finally, the internal fixed cost is added and the sum of the two

contributions gives the total internal cost, which amounts in this case to 0.092 €/km\*m<sup>3</sup>\*vehicle (corresponding to 228.24 €/ vehicle).

### **7.2.2.B External Cost Calculation**

An extensive literature investigation (Ortolani C., Persona A., Sgarbossa F., 2009) has led to the definition and quantification of the most relevant external cost values that raise during transport activity.

The values, divided among the different external costs factors, are summarized in Table 7.6.

<b>EXTERNAL FACTORS</b>	<b>€/ (vehicle*km)</b>
ACCIDENTS	0,014
CONGESTION	0,005
EMISSIONS - AIR POLLUTION	0,024
EMISSIONS - GREENHOUSE EFFECT	0,051
NOISE	0,003
ROADWAY FACILITIES	0,009
RESOURCE CONSUMPTION	0,013
ROADWAY LAND VALUE	0,009
LAND USE	0,021
WATER POLLUTION	0,004
WASTE DISPOSAL	0,000
TRAFFIC SERVICES	0,003
BARRIER EFFECT	0,004

Table 7.6. External cost factors

These costs are valid for a 6 pallets capacity truck travelling in urban, off peak condition and being fully loaded (100% saturation). In order to calculate the external costs for the specific case some steps are followed.

The starting point is again represented by the cost calculated for a so-called base case. This cost comes from a deep analysis of the contributions in literature that define and estimate the external transport costs.

Step 1 consists, thus, in defining this total external cost for the base case, as result of the literature investigation: this is done through the values summarized previously in Table 7.6.

Step 2 consists in calculating external costs for the specific vehicle considered. This is achieved by scaling the total cost by the loaded volume ratio (volume that can be loaded in base case on volume that can be loaded in specific case). As a consequence, the cost for the specific vehicle travelling in urban, off peak condition and being fully loaded is calculated.

Step 3 takes into consideration the road type and the external factors involved. As a matter of fact, different travel conditions can involve either different cost factors or the same factors but with different weights. As a consequence, two matrixes are considered: the External Factors Matrix associates to each travel condition only the factors which are involved; the Road Type Matrix calculates the effect of the costs on the total distribution route by considering the given percentages of rural, urban peak and urban off peak travelling. A critical point here is represented by the necessity of associating correctly the cost factors to the travel conditions. As a matter of fact, the impact of a specific cost factor can vary significantly under different travel states: this aspect has been deeply investigated by Litman in one of his latest works, named *Transportation Cost and Benefit Analysis: Techniques, Estimates and Implications*. This study conducted in 2009 at the Victoria Transport Policy Institute analyzes the full impacts of external transport costs by taking into account also variations due to different travel conditions (specifically rural, urban peak and urban off-peak states).

Table 7.7 shows Litmans' findings on external cost variations under different travel conditions for the case of a light-duty truck.

		<i>TRAVEL CONDITIONS</i>		
		<i>URBAN PEAK</i>	<i>URBAN OFF-PEAK</i>	<i>RURAL</i>
<i>EXTERNAL COSTS</i>	<i>ACCIDENTS</i>	0,055	0,055	0,055
	<i>CONGESTION</i>	0,13	0,02	0
	<i>EMISSIONS - AIR POLLUTION</i>	0,112	0,094	0,007
	<i>EMISSIONS - GREENHOUSE EFFECT</i>	0,222	0,202	0,181
	<i>NOISE</i>	0,013	0,013	0,007
	<i>ROADWAY FACILITIES</i>	0,035	0,035	0,021
	<i>RESOURCE CONSUMPTION</i>	0,06	0,052	0,044
	<i>ROADWAY LAND VALUE</i>	0,034	0,034	0,034
	<i>LAND USE</i>	0,083	0,083	0,0415
	<i>WATER POLLUTION</i>	0,014	0,014	0,014
	<i>WASTE DISPOSAL</i>	0,0004	0,0004	0,0004
	<i>TRAFFIC SERVICES</i>	0,02	0,013	0,007
	<i>BARRIER EFFECT</i>	0,023	0,015	0,008

Table 7.7. External transport costs under different travel conditions, expressed in US Dollars per vehicle mile  
(source: Litman, 2009)

Finally, by multiplying the obtained cost value by the saturation factor (Step 4) the total external cost is calculated. This cost will be specific in terms of vehicle considered, route covered and actual saturation.

### **7.2.2.B1 Case Study B: External Cost Calculation**

In order to calculate the external cost for the Vehicle 3 example all previous steps are followed (see Matrixes 7.1, 7. 2, 7.3 and 7.4) and finally total external cost amounts to 45.70 € for the trip.

<b>TRAILER</b>	
<b>EXTERNAL COSTS</b>	<b>€/(vehicle*mile)</b>
ACCIDENTS	0,089
CONGESTION	0,032
EMISSIONS - AIR POLLUTION	0,152
EMISSIONS - GREENHOUSE EFFECT	0,327
NOISE	0,021
ROADWAY FACILITIES	0,057
RESOURCE CONSUMPTION	0,084
ROADWAY LAND VALUE	0,055
LAND USE	0,134
WATER POLLUTION	0,023
WASTE DISPOSAL	0,001
TRAFFIC SERVICES	0,021
BARRIER EFFECT	0,024

Matrix 7.1. External cost values per Vehicle 3 (Euros/vehicle\*mile)

<b>EXTERNAL COSTS</b>	<b>TRAVEL CONDITIONS</b>		
	<b>URBAN PEAK</b>	<b>URBAN OFF-PEAK</b>	<b>RURAL</b>
ACCIDENTS	0,15	0,2	0,65
CONGESTION	0,15	0,2	0
EMISSIONS - AIR POLLUTION	0,15	0,2	0,65
EMISSIONS - GREENHOUSE EFFECT	0,15	0,2	0,65
NOISE	0,15	0,2	0,65
ROADWAY FACILITIES	0,15	0,2	0,65
RESOURCE CONSUMPTION	0,15	0,2	0,65
ROADWAY LAND VALUE	0,15	0,2	0,65
LAND USE	0,15	0,2	0,65
WATER POLLUTION	0,15	0,2	0,65
WASTE DISPOSAL	0,15	0,2	0,65
TRAFFIC SERVICES	0,15	0,2	0,65
BARRIER EFFECT	0,15	0,2	0,65

Matrix 7.2. External factors weight values per Vehicle 3

EXTERNAL COSTS	TRAVEL CONDITIONS		
	URBAN PEAK	URBAN OFF-PEAK	RURAL
ACCIDENTS	0,089	0,089	0,089
CONGESTION	0,210	0,032	0,000
EMISSIONS - AIR POLLUTION	0,181	0,152	0,011
EMISSIONS - GREENHOUSE EFFECT	0,359	0,327	0,293
NOISE	0,021	0,021	0,011
ROADWAY FACILITIES	0,057	0,057	0,034
RESOURCE CONSUMPTION	0,097	0,084	0,071
ROADWAY LAND VALUE	0,055	0,055	0,055
LAND USE	0,134	0,134	0,067
WATER POLLUTION	0,023	0,023	0,023
WASTE DISPOSAL	0,001	0,001	0,001
TRAFFIC SERVICES	0,032	0,021	0,011
BARRIER EFFECT	0,037	0,024	0,013

Matrix 7.3. Factors cost on given trip (Euros/vehicle\*mile)

EXTERNAL COSTS	TRAVEL CONDITIONS		
	URBAN PEAK	URBAN OFF-PEAK	RURAL
ACCIDENTS	0,013	0,018	0,058
CONGESTION	0,032	0,006	0,000
EMISSIONS - AIR POLLUTION	0,027	0,030	0,007
EMISSIONS - GREENHOUSE EFFECT	0,054	0,065	0,190
NOISE	0,003	0,004	0,007
ROADWAY FACILITIES	0,008	0,011	0,022
RESOURCE CONSUMPTION	0,015	0,017	0,046
ROADWAY LAND VALUE	0,008	0,011	0,036
LAND USE	0,020	0,027	0,044
WATER POLLUTION	0,003	0,005	0,015
WASTE DISPOSAL	0,000	0,000	0,000
TRAFFIC SERVICES	0,005	0,004	0,007
BARRIER EFFECT	0,006	0,005	0,008

Matrix 7.4. Weighted cost on given trip (Euros/vehicle\*mile)

### 7.2.3. *Output: Total Cost Calculation*

The output of the framework is a simple cost value obtained by adding up the total internal and external transportation costs calculated as explained in previous passages:

$$C_{tot} = C_{int\ tot} + C_{ext\ tot} = C_{int\ var} + C_{int\ fix} + C_{ext\ tot}.$$

This value can be either considered as a total amount per trip (if multiplied by the traveled distance) or as a specific value (€ per travelled kilometer).

In Vehicle 3 example the calculated total cost amounts to 274 €/km, where 16.68% of the total cost is external (see Table 7.8).

<b>OUTPUT</b>		
	€/km*m3*vehicle	€/vehicle
<i>C int tot</i>	0,092	228,24
<i>C ext tot</i>	0,019	45,70
<i>Ctot</i>	0,111	273,94
<i>% C ext</i>	16,68%	16,68%

Table 7.8. Total values in output

### 7.3. *Case Studies: Real Application of the Created Framework*

In order to test the framework further, it was applied to a number of real cases. The distribution networks and constraints of two big Italian companies (here named Company A and Company B) were considered and the costs that would have risen under different scenarios were calculated using the framework.

#### 7.3.1. *Case Study: Company A*

Company A is a world-leading manufacturer of domestic appliances. Historically a major producer of portable heaters and air-conditioners, the company has expanded to

include nearly every category of small domestic appliances in the food preparation and cooking, as well as household cleaning and ironing segments. The company's products include microwave ovens (Company A is one of the largest manufacturers of microwave ovens in Europe under its own brands names and as an Original Equipment Manufacturer supplier) as well as table-top and built-in electric and gas ovens, coffee machines, indoor grills, food processors, irons, and vacuum cleaners and other floor care products. In addition to its small domestic appliance production, Company A also designs and manufactures central heating and air conditioning systems for home, institutional, and industrial sectors. In all, Company A operates 13 production facilities and 30 international subsidiaries supporting sales to 75 countries worldwide: its distribution network is extremely widespread especially at European level. Nevertheless, the Italian market still represents the most strategic market, so a special attention is applied on the deliveries within the country.

The case study considers a trip to be made using a trailer delivering 24 m<sup>3</sup> (saturation = 69%) from the logistic hub of the company (located in Mignagola – Treviso) to a distribution point in located Parma. Total travelled distance is 265 kilometres, the trip is meant to be done mostly in a rural environment (80%), with a small distance travelled in urban off peak conditions (5%) and the balance (15%) in urban peak conditions.

<i><b>INPUT</b></i>	
<i><b>VEHICLE</b></i>	<i><b>TRAILER</b></i>
<i><b>DISTANCE</b></i>	265 kms
<i><b>TRIP</b></i>	15% urban peak 5% urban off peak 80% rural
<i><b>LOADED VOLUME</b></i>	24,00 m <sup>3</sup>
<i><b>SATURATION FACTOR</b></i>	69%

Table 7.9. Company A case study: values in input

The cost calculated through the framework amounts to 511 €/vehicle, as it is shown in Table 7.10.

<b>OUTPUT</b>		
	€/km <sup>3</sup> *m <sup>3</sup> *vehicle	€/vehicle
<i>C int tot</i>	0,067	424,03
<i>C ext tot</i>	0,014	87,50
<i>Ctot</i>	0,080	511,52
<i>% C ext</i>	17,11%	17,11%

Table 7.10. Company A case study: values in output

The cost that the company is paying to its logistics provider for this travel amounts to 490 €/vehicle. Basically the cost calculated by the framework exceeds the amount actually paid by the company by 4%. This difference can be seen as the external costs unpaid amount. In effect external costs are, by definition, those costs which are not absorbed (at least, not completely) by the part that runs the transport, but are paid by the whole society. Nevertheless, the internal calculated cost itself is lower than what is paid by the company: the logistics provider's revenue will make the difference between the operational cost raised and the amount paid.

### 7.3.2. *Case Study: Company B*

Company B is a manufacturer and worldwide supplier of men, women and children's hosiery, underwear and beachwear. The company is directly represented in more than 25 countries, manufactures in more than 5 countries, owns 800 stores and has licensed 1,200 franchised stores across the globe. Maintaining four brands, the company's activities cover many areas, from design and manufacturing, through wholesale distribution, to retail operations and franchising. Such an intricate model involves a complex distribution and transport network as well. The Italian market is highly strategic for the company and the distribution within the national boundaries is critical. In this case the distribution cost for a trip from the finished goods store (placed in Castagnaro – Verona) to one of the main selling points (located in Lonato - Brescia) is calculated.

The total distance to be covered is 95 kilometres: 85 kilometres in a rural environment and the balance in urban – off peak conditions. The vehicle used is again a trailer, with 81% saturation (18 m<sup>3</sup> loaded).

<b>INPUT</b>	
<b>VEHICLE</b>	TRAILER
<b>DISTANCE</b>	95 kms
<b>TRIP</b>	0% urban peak 11% urban off peak 89% rural
<b>LOADED VOLUME</b>	28,00 m <sup>3</sup>
<b>SATURATION FACTOR</b>	81%

Table 7.11. Company B case study: values in input

In this case the total cost amounts to 151 €/vehicle.

<b>OUTPUT</b>		
	€/km*m <sup>3</sup> *vehicle	€/vehicle
<b><i>C int tot</i></b>	0,046	122,15
<b><i>C ext tot</i></b>	0,011	28,50
<b><i>Ctot</i></b>	0,057	150,65
<b><i>% C ext</i></b>	18,92%	18,92%

Table 7.12. Company B case study: values in output

The cost paid by the company to the logistics provider for this trip is 144 €/vehicle. Again, the difference between the two values represents the unpaid amount of external costs which this trip will generate.

### **7.3.3.        *Comments on the Cases***

In both cases, the overall costs which were calculated using the framework exceed the actual, operational cost paid by the companies to their forwarders. This highlights immediately the fact that there are certain unpaid amounts which are linked to the presence of external costs. In both cases, besides, the amount of total internal costs calculated by the framework is lower than the amount paid by the company of a 16% and 18% respectively. This is perfectly consistent with the analysis as average forwarders' revenues amount to 16% of the operative cost incurred: basically, the amount that the company is paying is the total internal cost of the trip plus the forwarder reward. In both cases, though, external costs have big impacts, with a weight which is on average the 18% of the total cost. Being so significant, such costs cannot be ignored. On the contrary, finding strategies in order to minimize them becomes more and more important.

As these costs are influenced by a considerable number of factors, it is necessary to identify on which of these factors to act in order to effectively minimize the external cost. For this reason an additional sensitivity analysis was run: through this analysis it was possible to understand which are the factors that have a major influence on the final result. These are the most critical factors to consider whenever a cost minimization strategy takes place.

### **7.4.        *Sensitivity Analysis***

The sensitivity analysis was run on the results given by the framework in order to test the input values and assumptions and to highlight which factors have a significant impact on the output of the model. The main assumptions I made while building up the framework are the ones here listed:

- in the calculation of road external costs only most recent literature contributions were considered, as the articles dated before 2000 were excluded;
- both internal and - especially - external costs show a high variability in the values given in literature, this mainly due to the causes listed by Victoria

Transport Policy research (2009) and confirmed by previous research on the theme (Ortolani C., A. Persona, F. Sgarbossa, 2009) as well as by Quinet's work (2004);

- specific values for the average truck capacity and saturation were assumed;
- the internal base transport cost is made up by both a variable and a fixed amount; while the external transport cost is completely variable.

The analysis was run using Minitab® and in particular its Design Of Experiments (DOE) tools: 4,600 scenarios under different vehicle, loading and road conditions were simulated and the results were summarized in a series of graphs. Through these graphs it is possible to point out which are the mutual effects among all the factors in input and how each factor (as well as the combination of all the factors) impacts on the final result.

Table 7.13 shows the input factors and their levels, which were combined in the different scenarios in order to obtain the final results. The factors which have been altered are: Max Volume (which refers to the maximum capacity of the vehicle, so basically identifies the vehicle type); Saturation Factor (which determines the actual volume which loaded on the vehicle); Travelled Distance (total distance to be covered); % Urban Peak, % Urban Off Peak, % Rural. The last three values, which refer to the driving conditions, were combined in each scenario in order to verify the condition that their sum is 100%.

<b><i>Factors</i></b>	<b><i>Levels</i></b>
<i>Max Volume (m3)</i>	8.64 - 14.10 - 27.36 - 34.56 - 47.52 - 51.84
<i>Saturation Factor</i>	0.1 - 0.2 - 0.5 - 0.7 - 0.9 - 1
<i>Travelled Distance (km)</i>	50 - 100 - 200 - 300 - 400 - 500 - 600 - 700 - 800 - 900 - 1000 - 1100 - 1200 - 1300 - 1400 - 1500 - 1600 - 1700 - 1800 - 1900 - 2000
<i>% Urban Peak</i>	0.1 - 0.2 - 0.4 - 0.6 - 0.8 - 1
<i>% Urban Off Peak</i>	0.1 - 0.2 - 0.4 - 0.6 - 0.8 - 1
<i>% Rural</i>	0.1 - 0.2 - 0.4 - 0.6 - 0.8 - 1

Table 7.13. Sensitivity analysis: factors and levels in input

### 7.4.1. Factors Effects on Total Internal Costs

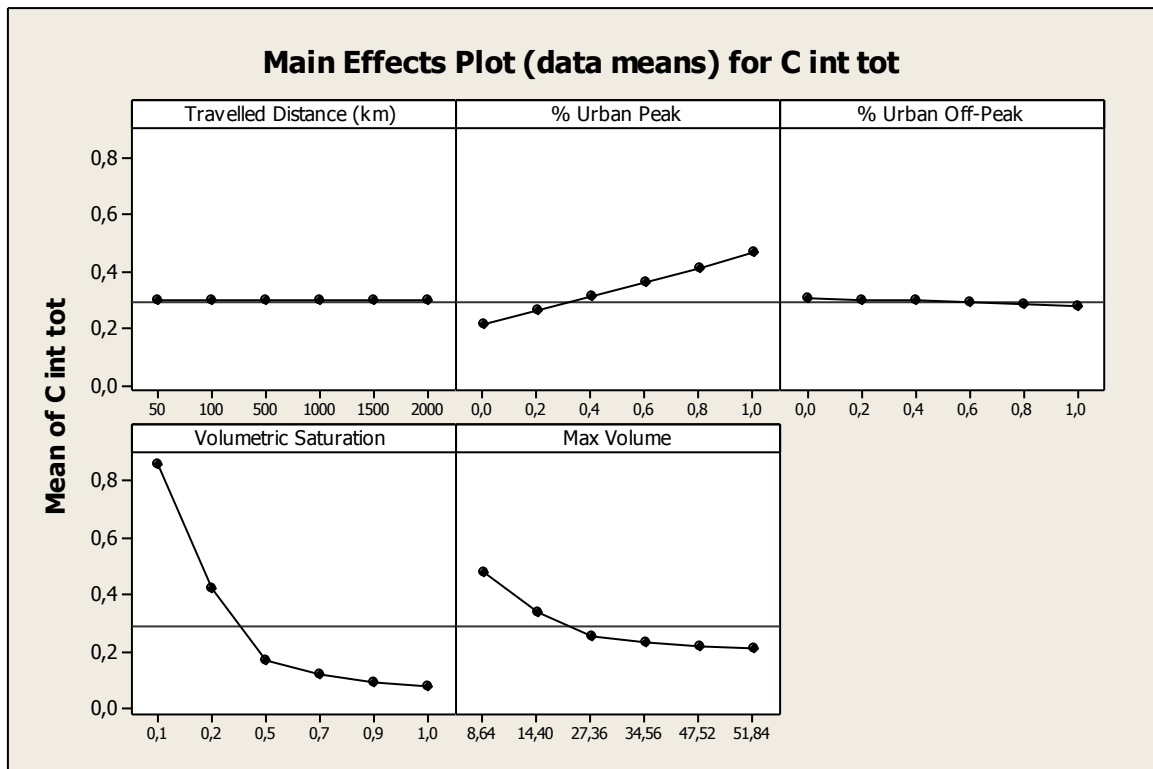


Figure 7.2. Factors effects on C int tot

- Internal costs are not function of distance as they are specific costs ( $\text{€}/(\text{km} \cdot \text{vehicle} \cdot \text{m}^3)$ ), so they do not depend on the travelled kilometres;
- The variation of the urban peak percentage has a significant influence on C int: these costs increase proportionally to that percentage increase. This is due to the reduced speed maintained in case of urban peak transit, which makes the travel time (and, as a consequence, the internal costs) increase;
- The variation of the urban off peak percentage, on the contrary, has an extremely reduced influence on C int. As a consequence, big variations on internal costs will only be there in the transition from rural to urban peak transit: being the two extreme conditions, they are characterized by completely different travel speeds;

- As the volumetric saturation increases, the internal costs incidence decreases considerably. This confirms the advantage of loading the vehicle up to a level which is as close as possible to the total available capacity;
- The vehicle type (here represented by the maximum volume that can be loaded) has an important impact on the internal costs incidence. In effect, internal costs weight decreases (with a damped effect) as vehicle dimensions increase.

#### 7.4.2. Factors Effects on External Costs

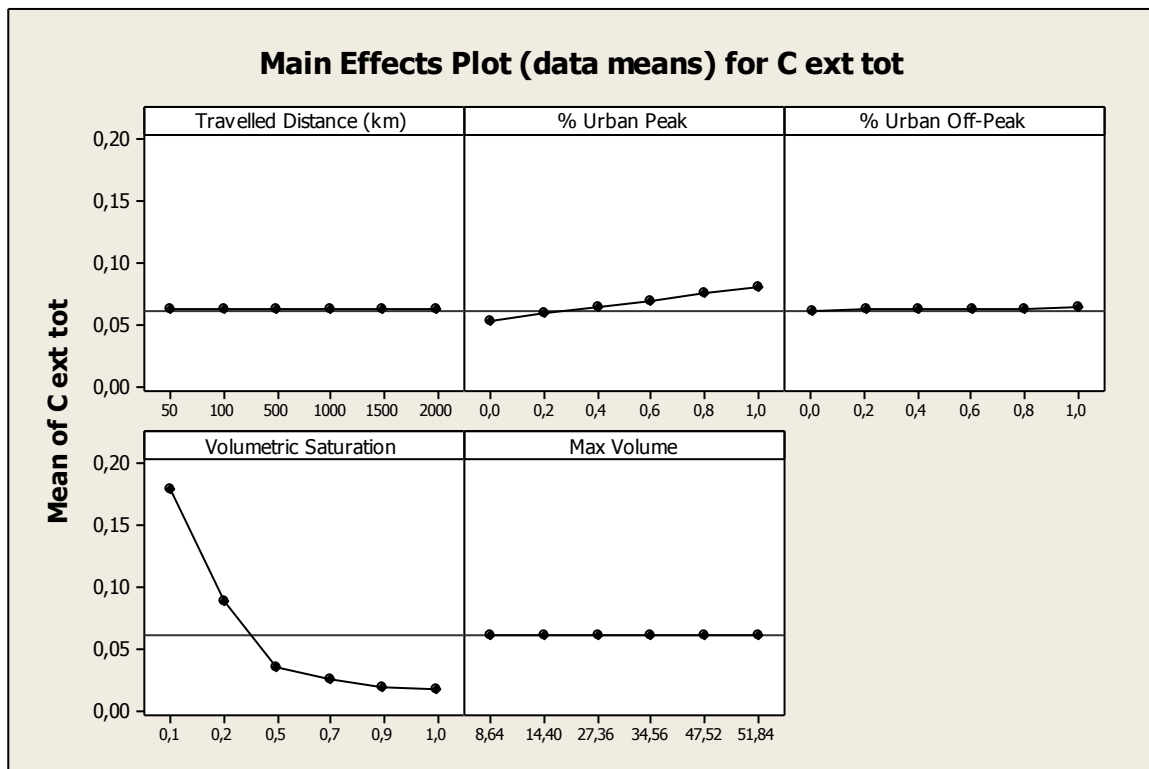


Figure 7.3. Factors effects on Cext

- Again, external costs do not depend on travelled distance: they are specific costs ( $\text{€}/(\text{km} \cdot \text{vehicle} \cdot \text{m}^3)$ );
- The variation of urban peak percentage has an influence on Cext, even though it is much less visible than the case of internal costs. This is due to the fact that

only some of the factors that take part in the external costs depend on the travel speed and specific congestion (i.e. emissions, noise, increased probability of causing or suffering accidents);

- On the contrary, the variation of urban peak percentage has a minor influence on  $C_{ext}$ : big variations in the costs will be there only in the transition from rural to urban peak transit;
- As the volumetric saturation increases, the external costs incidence varies sensibly. Again, there are considerable benefits in filling the vehicle capacity;
- The type of vehicle used has basically no influence on external costs: the external costs per  $m^3$  are substantially fixed even though the vehicle type varies.

### 7.4.3. Factors Effects on the Percentage of External Costs on Total Cost

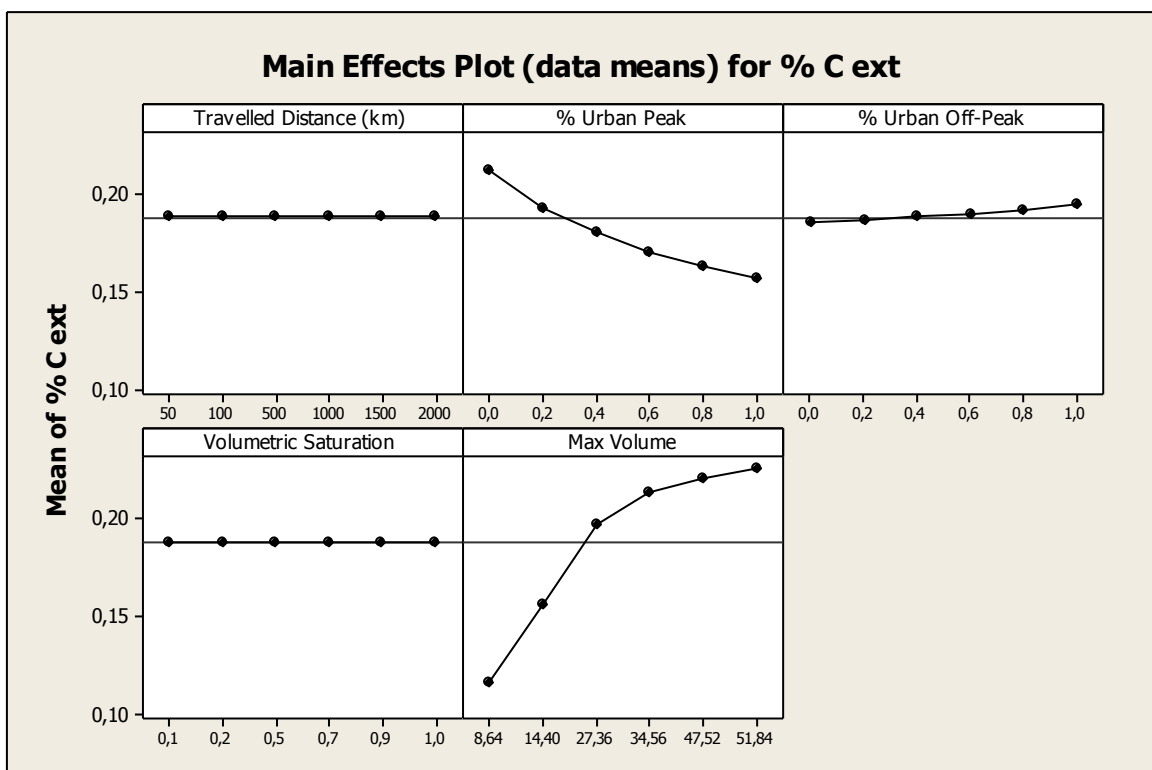


Figure 7.4. Factors effects on %  $C_{ext}$  on total cost

- The travelled distance does not generate any variations in the incidence of the external costs on the total cost. In effect, even in this case we are considering specific costs (per kilometre travelled);
- The variation of the urban peak percentage has a considerable impact on the external costs. In detail, as the urban peak percentage increases, the incidence of the external costs on total costs decreases. This is due to the fact that even though external costs increase with the urban peak percentage growth, this rise does not equal the internal costs increase. Internal costs, in effect, mount with a much sharper progress: as a consequence, the growth of the total costs presents a decrease of the external costs weight on the overall value;
- The variation of the urban off peak percentage shows a limited influence on external costs weight. In effect the variation of this factor on both internal and external costs was negligible. As the urban off peak percentage increases, anyway, the effect of the external costs increases slightly;
- The increase of the volumetric saturation has no impact on the external costs influence on total costs: this comes from the fact that both internal and external costs vary in the same way with the vehicle saturation (both decrease with the same progress as long as saturation increases);
- The vehicle type has a great influence on the weight of external costs on the total cost. This is due to the fact that as the vehicle dimensions increase, internal costs decrease quite rapidly, while external costs remain fixed. As a consequence, their weight on the total cost increases considerably.

#### 7.4.4. Factors Effects and Interactions on Total Internal Costs

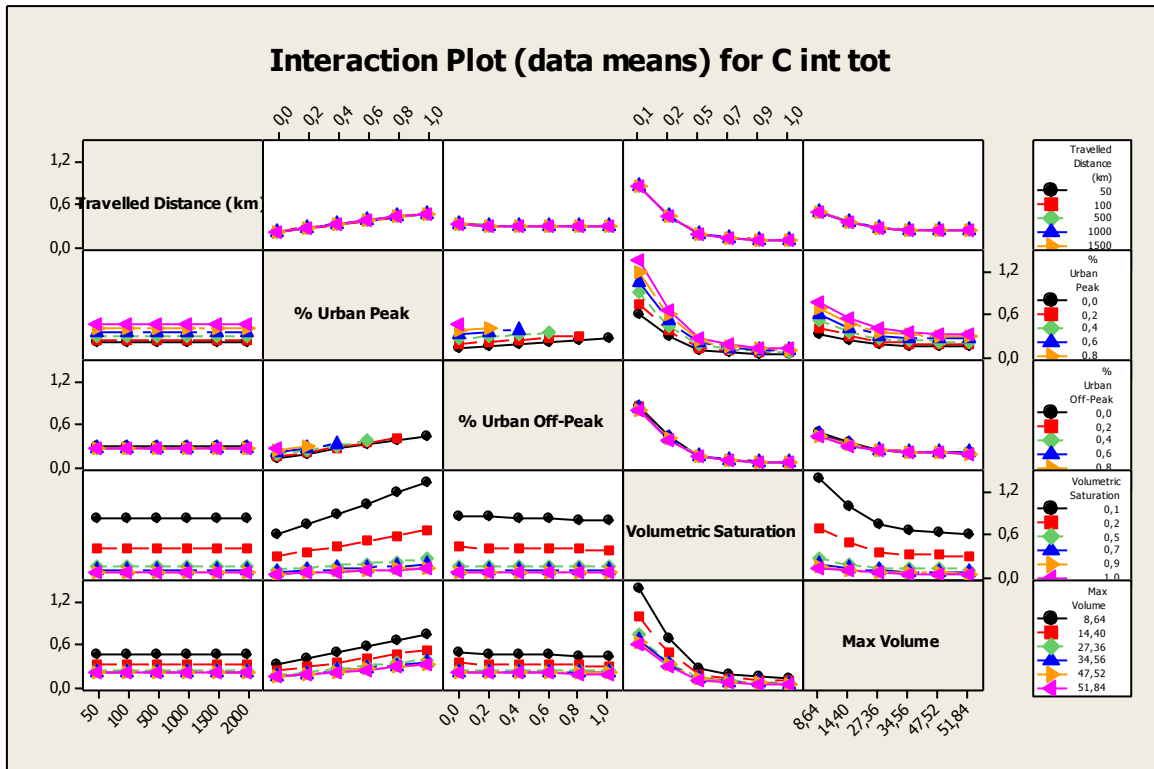


Figure 7.5. Factors effects and interactions on Cint tot

- As we are considering specific costs (per travelled kilometre) distance does not have either impacts on the costs nor significant interactions with the other factors. The specific costs vary with the variation of urban peak percentage, volumetric saturation, vehicle dimensions and (much less) urban off peak percentage, but they remain fixed with the travelled kilometres;
- Regarding the interaction between urban peak percentage and volumetric saturation, in case the vehicle is poorly saturated (less than 50%) the specific cost (which is already high) grows up as urban peak percentage increases. In case of higher saturation, the urban peak percentage does not have a substantial effect on the cost variation. Basically while going from a very low saturation to a half loaded vehicle the internal costs decrease very quickly (and they are highly influenced by the urban peak percentage), while once the saturation

factor reaches 50% the costs tend to decrease with a much smoother effect and also the urban peak percentage has a minor influence;

- There is an interaction (even if it is less marked) also between vehicle dimensions and urban peak percentage: as long as vehicle dimensions decrease and urban peak percentage increases, costs tend to increase. The impact of the urban peak percentage is stronger in case of small vehicles but it is anyway there for any kinds of mode;
- On the contrary, the interaction between urban off peak percentage and volumetric saturation is almost zero. This is due to the fact that the effect of the urban off peak percentage itself on the internal costs is negligible. As a consequence, the course of the factors interactions follows the effects brought by the volumetric saturation: once it increases, internal costs decrease for all types of vehicle;
- Regarding the interactions between urban off peak percentage and vehicle dimensions, the effect is the same: the costs follow the course given by the vehicle type (as the vehicle dimensions decrease the costs increase, regardless of the urban off peak percentage);
- The relationship between vehicle dimensions and saturation is meaningful: internal costs are high in case of low saturation, especially for small vehicles. As saturation increases the costs decrease considerably, but the dependence upon the vehicle dimensions is less pronounced. As a consequence, between these two factors the volumetric saturation is the one whose even small changes cause the major variations in the total internal cost.

### 7.4.5. Factors Effects and Interactions on External Costs

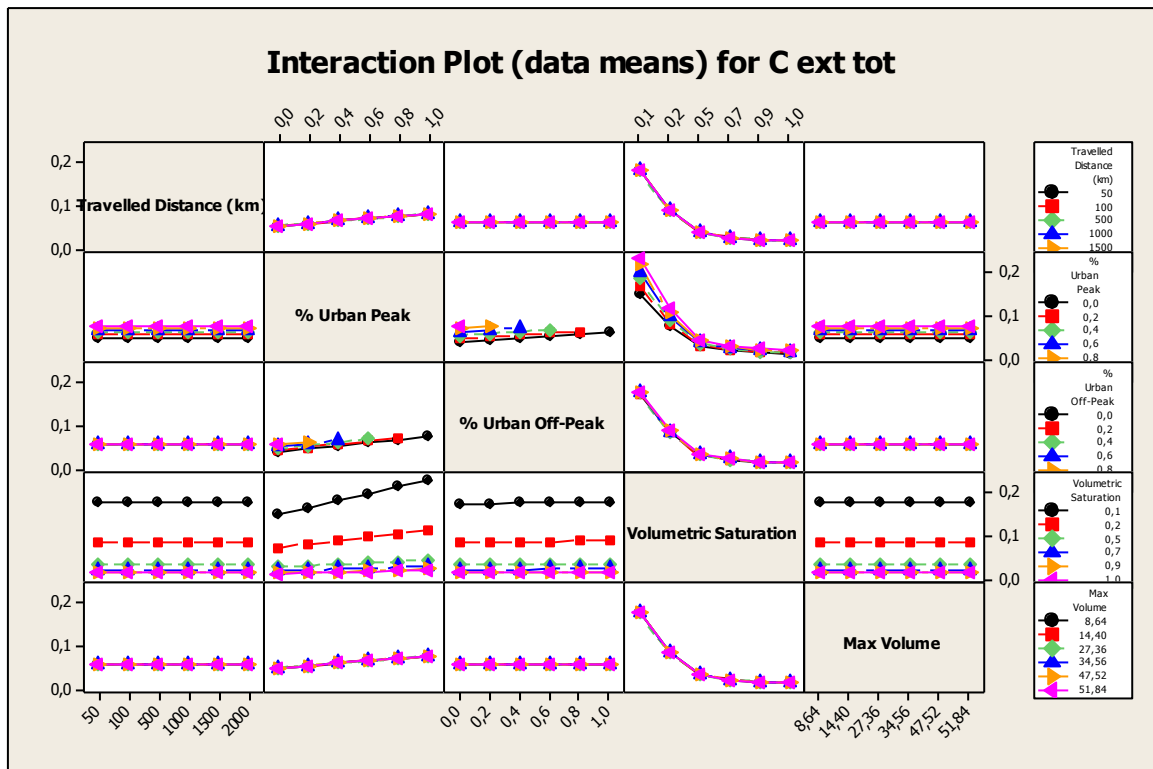


Figure 7.6. Factors effects and interactions on Cext

- As specific costs (per travelled kilometre) are considered, distance factor has no impact on the cost or significant interactions with the other factors;
- In case the vehicle saturation factor is low (less than 50%), the external costs increase significantly as the urban peak percentage increases. The path is similar to what was discussed in the case of internal costs;
- In this case, no interaction exists between vehicle type and urban peak percentage. As discussed previously, in effect, the external cost per  $m^3$  is substantially fixed, even if the vehicle type varies;
- The interaction between urban off peak percentage and volumetric saturation is again negligible, considering also the minor effect of urban off peak percentage on external costs;

- The interaction between urban off peak percentage and vehicle dimensions does not have a significant effect either;
- In the case of external costs not even the relationship between vehicle dimensions and saturation is significant; as the specific cost does not depend on the vehicle type, the external costs course is guided mostly by saturation. As said, as the vehicle saturation increases, the external specific cost will decrease considerably.

#### 7.4.6. Factors Effects and Interactions on the Percentage of External Costs on Total Cost

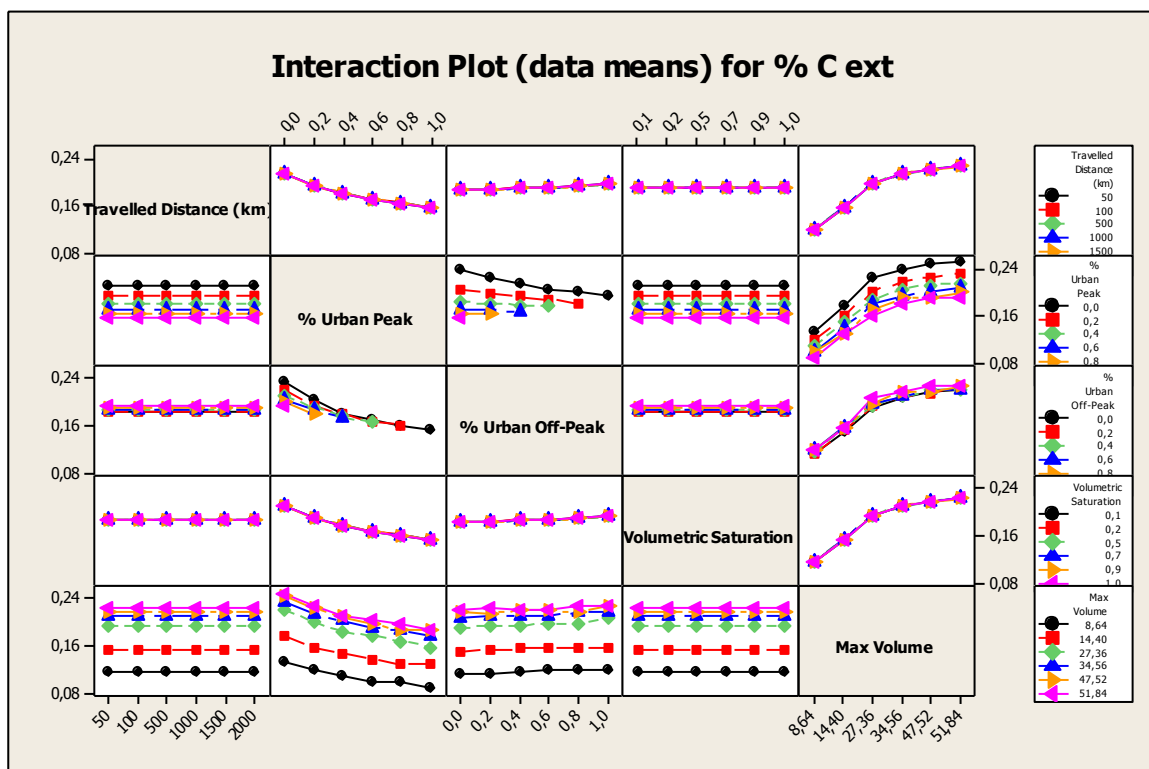


Figure 7.7. Factors effects and interactions on % Cext on total cost

- As the travelled distance does not have any effects either on internal or external specific costs, it does not even have an impact on the external costs percentage on total costs;
- The specific cost increases sensitively as the urban peak percentage increases for both external and internal costs with very similar paths, as a consequence both urban peak percentage and volumetric saturation do not show influences on the external cost percentage (which remains fixed even though the absolute cost values vary);
- A well defined interaction between vehicle type and urban peak percentage exists: with the vehicle dimensions increase and the urban peak percentage decrease, the external costs percentage value rises. This is due to the fact that while the external cost value remains fixed even though the vehicle dimensions change, the internal cost decreases together with the vehicle dimensions increase and the urban peak percentage decrease;
- The interaction between urban off peak percentage and volumetric saturation is negligible;
- Regarding the interaction between urban off peak percentage and vehicle dimensions, the external costs percentage rises as long as the vehicle dimensions increase (because the external costs do not vary, while the internal costs decrease). No significant effect is given by the variation of the urban off peak percentage;
- Finally, the relationship between vehicle dimensions and saturation shows that the percentage of external costs on total costs increases with the rise of the vehicle dimensions (because external costs do not depend on vehicle dimensions, while internal costs decrease as dimensions become bigger). On the contrary, the percentage of external costs does not vary with saturation because both internal and external costs do vary with the same trend as long as saturation changes.

### 7.4.7. Standardized Effects on Total Internal Costs

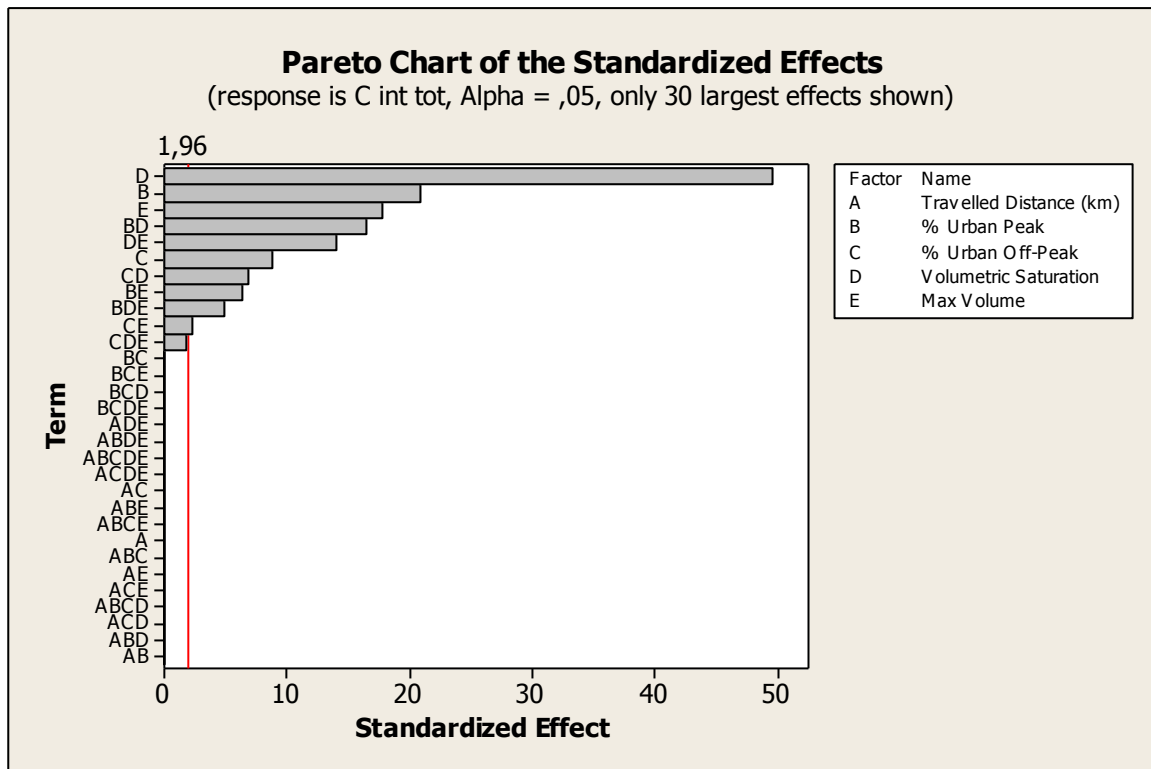


Figure 7.8. Standardized effects on Cint tot

The factors having a major impact on the internal cost (variable and fixed) are: volumetric saturation, percentage of urban peak travel and vehicle dimensions. Their interactions have a significant effect as well, while percentage of urban off peak transit only has a marginal effect.

7.4.8. *Normal Probability Plot of Total Internal Costs*

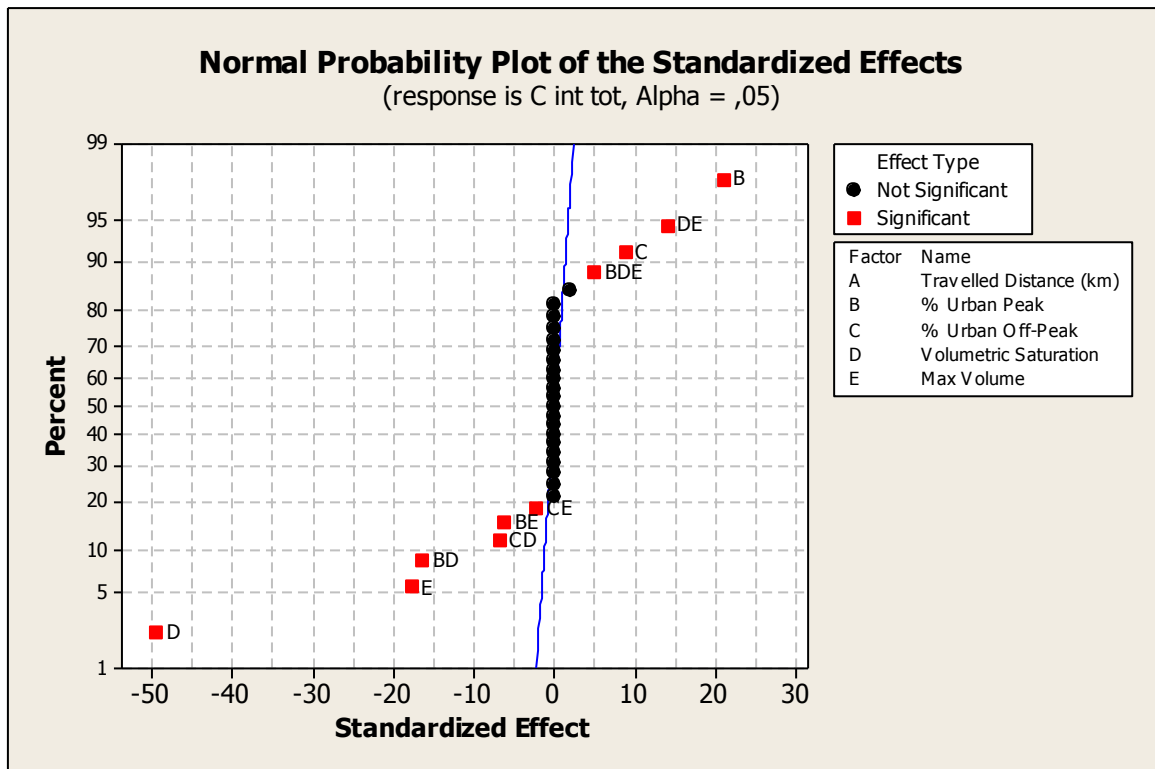


Figure 7.9. Normal probability plot – Cint tot

Regarding the two most significant factors, in the case of internal costs they are the volumetric saturation (internal costs decrease when saturation increases) and the urban peak percentage (internal costs increase when urban peak transit increases).

### 7.4.9. Standardized Effects on External Costs

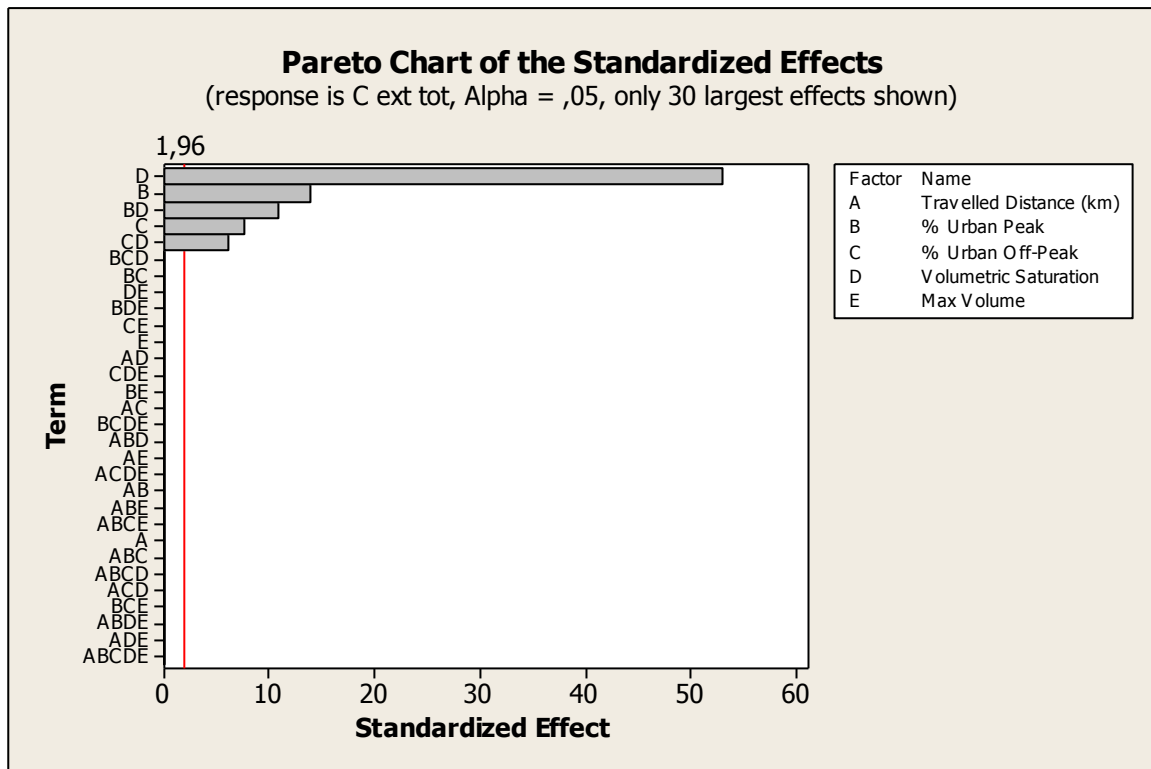


Figure 7.10. Standardized effects on Cext

The most meaningful factor in the case of external costs is the vehicle saturation, followed by the urban peak percentage which anyway has a much less relevant influence.

7.4.10. *Normal Probability Plot of External Costs*

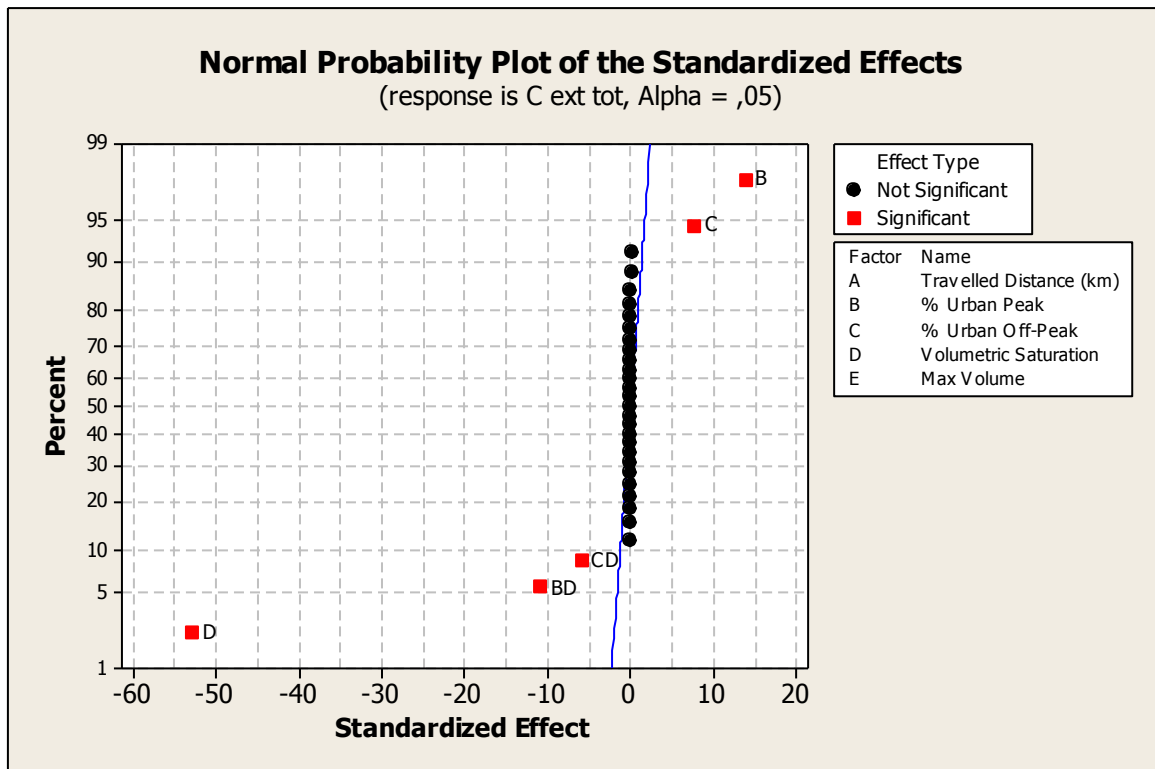


Figure 7.11. Normal probability plot - Cext

Again the predominance of the volumetric saturation can be noticed (external costs decrease when vehicle saturation increases).



7.4.12. *Normal Probability Plot of the Percentage of External Costs on Total Cost*

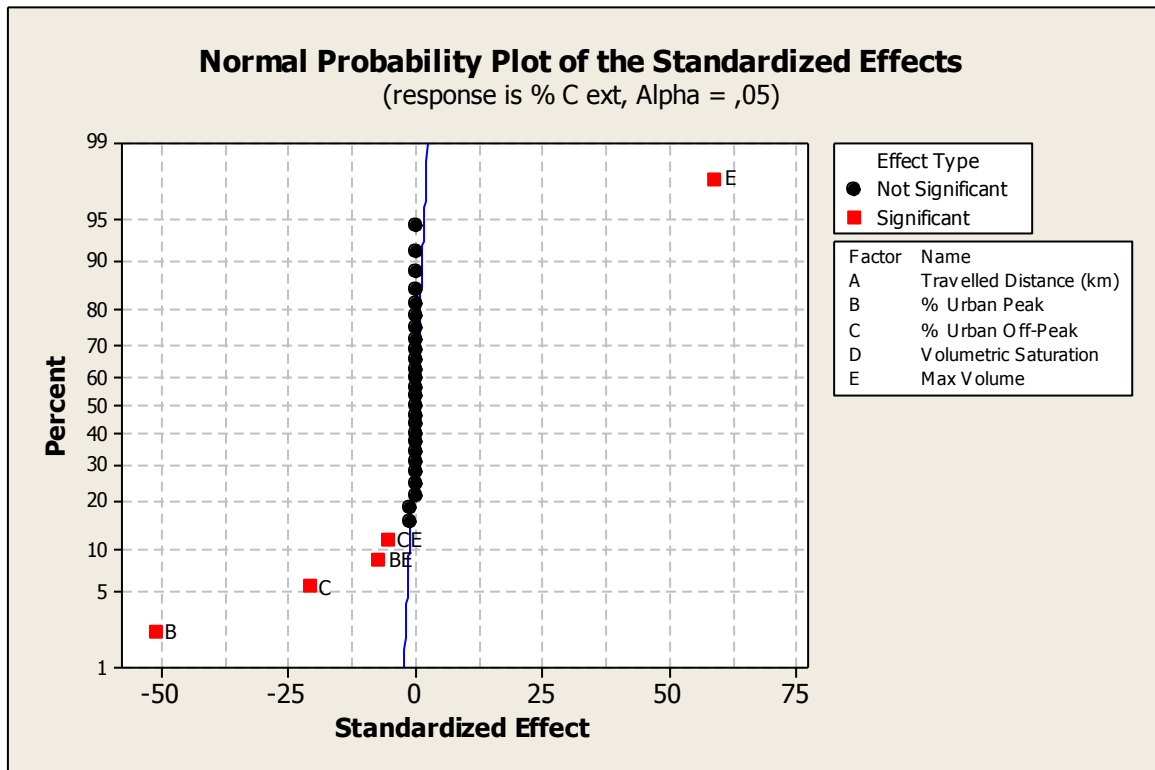


Figure 7.13. Normal probability plot – % Cext

As stated previously, the most significant effects are the vehicle type and the urban peak percentage. The factors show opposite trends: when the vehicle dimensions increase the external cost percentage rises, while when the urban peak percentage increases the external cost percentage decreases.

#### **7.4.13.        *Comments on the Sensitivity Analysis***

The sensitivity analysis has highlighted the most meaningful factors affecting both internal and external cost values. Internal costs are highly influenced by volumetric saturation, percentage of urban peak travel and type of vehicle used. The most significant factor is the volumetric saturation: internal costs decrease significantly when saturation increases. The percentage of travelled distance in urban peak conditions has a big impact as well: internal costs increase when urban peak transit increases. In the case of external costs, there is one significant factor, which is vehicle saturation: external costs decrease when vehicle saturation increases. As a consequence, for the overall costs saturation is definitely the most important factor: the more the vehicle is loaded, the less the overall cost will impact on each loading unit. Another important factor (having a significant impact especially on internal costs) is the type of route chosen: if a long way is covered in urban roads in highly congested conditions, the overall cost will increase significantly.

#### **7.5.            *Conclusions***

Starting from an extensive literature review which was conducted in previous research (Ortolani C., A. Persona, F. Sgarbossa, 2009), I developed a framework in order to properly estimate both operational (internal) environmental (external) costs generated by any freight transport. The tests run on the framework, including the application to two real cases, showed that it gives reliable results which slightly overestimate the prices currently paid to logistics providers, which in effect do not take into account any of the environmental costs. The sensitivity analysis which was finally applied to the results showed that the factors having a major impact on the final cost are the volumetric saturation of the vehicle (which has a big influence on internal costs), the vehicle dimension (which affects mostly external costs) and the percentage of kilometres covered in a urban environment in highly congested conditions on the total travelled distance, which has a significant effect on both internal and external costs.

## CONCLUSIONS AND FUTURE RESEARCH

Operational costs generated by the transportation activity are typically well defined and computed in the logistics providers' rates: they include vehicle purchase costs, insurance and taxes, tyres consumption, fuel, ordinary and extraordinary maintenance, general road tolls and driver wages. Nevertheless, the pure computation of the travel operational costs does not reflect the overall burdens that the transportation activity generates on society: there is a full set of impacts (such as gasses and particles emissions, noise, congestion, accidents) which costs are not reflected into transport prices. These are the environmental costs, and for not being fully reflected into prices they are not borne by the part which benefits from the transport itself, but by the whole of society.

The starting point of the present work has been the analysis of the main contributions in literature which are not only defining the transportation cost from an operational point of view, but also considering the indirect and external cost effects of the transport itself. Starting from this solid base, the core of this thesis is represented by the development of an analytical framework which makes it possible to calculate internal as well as external transportation costs generated by any specific trip. The application of this framework to real industrial cases has demonstrated how significant the impact of external costs is.

Chapter 1 opens with an overview on Supply Chain and sustainability. Sustainability has become the latest challenge faced by Supply Chain management. The push towards the so-called "green side" of the Supply Chain comes from a series of concurrent effects. First of all, the increased pressure placed on firms via increasing environmental legislation. Especially at European level, a long series of actions has been taken in order to boost social and environmental consciousness in all the industrial fields. This has made many firms start to worry about the environmental effects of their behavior, as these effects may lead to an increased fiscal pressure. Then, environmental impacts of the industrial activities are the object of an ever-increasing attention paid by consumers: they have become more aware and educated about environmental issues. Firstly because of the increasing exposure of environment related topics, such as acid rain, greenhouse effects and desertification; secondly because of the appearance of eco-certificates,

which help the consumers to identify eco-friendly products. These effects have led to the development of the concept of Green Supply Chain Management, which has been defined as “integrating environment thinking into Supply Chain management” (Srivastara, 2007).

The chapter analyzes also the consequences of the environmental focus on the transport field: an efficient transport system is considered as the lifeblood of a successful economic system, but at the same time it represents one of the most polluting activities that the industry is generating.

Chapter 2 focuses on the costs incurred due to transportation. Internal costs, on one side, are the costs connected to the operational activities which are necessary in order to allow the physical movement of the goods from one point to another. External costs, on the other side, are the costs linked to the environmental impacts generated by the distribution activity. This chapter analyzes in detail all the cost voices included under each category, as well as best practices for cost evaluation. As a matter of fact, the various costs differ a lot from one another, so the process used for calculating them cannot be the same in all cases. This is especially valid for external costs, for which methods going from contingent valuation up to compensation rates can be used.

Chapter 3 analyzes the strategies adopted by the European Union towards sustainability. The evaluation of external costs and the adoption of a feasible strategy for their internalization are becoming important requests at policy level. One of the basements of the legislation on environmental sustainability at international level is the Kyoto Protocol, promulgated in 1997 but still not accepted or only partially adopted by many industrialized countries. The European Union has gone forward after this protocol with a long series of initiatives and projects. The chapter analyzes past and current regulations, as well as future projects in order to achieve sustainability in the transport sector.

Chapter 4 focuses on intermodal transport. It explains how the introduction of externalities in the cost evaluation clearly shows the competitive advantage of intermodality. At present intermodal transport is underdeveloped in Europe due to the scarcity of infrastructures and the high critical distances which would make the use of rail transport become more convenient than road at an operational level. Nevertheless,

when it comes to environmental costs, the impacts that rail transport imposes to environment and society per kilometer travelled are much lower than those imposed by road distribution. As a consequence, it is demonstrated that if those costs are properly considered and total costs are calculated, intermodal transport becomes more convenient than road even for reduced distances, given the availability of proper transport infrastructures, terminals and interports. The chapter analyzes the functions to be used for cost calculation in case of intermodality and their outputs.

The following chapters represent the main part of the research: Chapter 5 presents the results of the extensive literature analysis. The contributions are classified into three main categories: qualitative, analytical and quantitative studies. The research shows how dispersed data regarding full transport cost are, underlying the necessity of defining reliable cost categories, 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, in the case of external costs it is necessary to consider not only immediate impacts, but also future effects, including a dynamic vision of the long term situation. 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. All the main causes of dispersion are analyzed and discussed in deep and the assumptions made in order to obtain a final, comprehensive value for each cost voice are explained. Moreover, a research made by Quinet (2006) is presented: the author reaches the conclusion that the main differences among costs 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 units 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. Scientific uncertainty, in the end, is a smaller contribution of variation. Quinet concludes that, when properly applied, cost studies can provide justifiable values which are useful for economic analysis.

In Chapter 6 the analytical model for internal and external costs evaluation is developed. Firstly, internal transport cost functions are given for road, rail and sea transport. Then, reference cost values are presented starting from literature analysis and

from a previous extensive work on European logistics providers and their costs (Ortolani, 2007). Finally, the innovative functions for internal costs evaluation are developed for both road and rail transport. The cost functions are then applied to two real industrial cases. The first case deals with an international fast food company which distributes products that need to be kept at three different levels of temperature according to their nature. The distribution network is fixed but the choice has to be made on which kind of vehicle to use. The result of the case is that multi-temperature vehicles represent a much more convenient alternative to mono-temperature trucks once all the costs (both internal and external) are considered. The second case investigates the redesign of a distribution network. In the case of a company which currently operates the collection of industrial liquid wastes using a 100% road network, the evaluation made considering internal and external costs highlights the convenience of using a mixed modes configuration (road and rail). As some assumptions are made in order to develop the cost functions, this chapter also includes a sensitivity analysis which is made in order to test these hypothesis and their validity.

Chapter 7, finally, presents the framework which I developed in order to properly estimate both operational and environmental costs generated by any road freight transport. The structure of the framework is explained in detail, starting from the values required in input, to the calculations made respectively for estimating internal and external costs, to the values in output. The framework is then applied to two industrial cases, related to the networks of two big Italian companies distributing all over Europe. In both cases the cost of a specific route is estimated using the framework: the calculated costs are consistent with the current transportation tariffs, slightly overestimating the prices currently paid to logistics providers, which in effect do not take into account any of the environmental costs. A sensitivity analysis is applied to the factors included in the framework and to their interactions: it shows that the factors having a major impact on the final cost are the volumetric saturation of the vehicle (which has a big influence on internal costs) and the kilometers covered in a urban environment in highly congested conditions, having a significant effect on both internal and external costs. Nevertheless, the most important result achieved with the developed framework is the confirmation of the impact of external costs on the total transportation costs. In effect, the percentage of the external share on total costs amounts on average to 18%. This confirms the need of estimating the external impacts as, once they are taken

into account in the evaluations, they become a strategical tool for environmental friendly network design and selection of transport modes.

Future developments of this work will consist in the expansion of the framework in order to deepen the analysis made on railway transport and to include in the cost calculation also maritime and air transport. These modes generate significant environmental impacts as well, even though literature on this theme is still scarce. Developing a framework able to capture such costs will provide a valuable tool in order to estimate correctly the overall costs of all the main transportation alternatives and to operate a conscious and adequate choice among modes, from both operational and environmental point of view.

In conclusion, this work has investigated in deep the problem of overall transport costs calculation, focusing on a theme, the external costs, which has not been analyzed in literature properly and which relevance is often underestimated. An extensive literature analysis has been conducted and a new analytical framework has been developed in order to calculate transport costs for any specific trip on a road distribution network. The application of the framework to real industrial cases and the results of a sensitivity analysis made on the model showed the relevance of the external costs amount on the overall transportation cost and highlighted the levers on which to act in order to reduce those costs. Future developments will widen the analysis in order to develop a comprehensive framework including alternative transport modes as well.



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