Evaluation of urban goods distribution initiatives towards mobility and sustainability: indicators, stakeholders and assessment tools

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“The reason and benefit of trade is that it allows the interchange between what have left to each one to get what is really needed.” Aristóteles (384 - 322 B. C.)

The origin of trade was based on a challenge to find a balance, considering the respective goods, distribution routes and customers. The trade, or at least the specific part of it which is focused on this work, continues to be based on a challenge to find a balance. Here, the balance is about cities and industry, quality of life and efficiency of services and whether it is possible to achieve both goals simultaneously.

1 Background

1.1 Topic overview

Urban goods distribution (UGD) takes place in areas with high density of buildings and population and a high demand for goods and services. Added to the current urbanization, important phenomena and transformations on the market like the internationalization and globalization of the economy, fast changes on markets and high pressure to reduce costs and to improve the type and level of service to customers contribute to a higher number of movements of goods and services to urban areas. Thus, urban goods distribution plays a relevant contribution to the sustainable development of cities. Urban goods distribution helps to support urban lifestyles, to serve and retain industrial and trading activities and contributes to the competitiveness of industry in the concerned region (Anderson *et al*, 2005).

Despite the relevant role urban goods distribution plays in cities, it also generates negative (economic, environmental and social) impacts on the economic power, accessibility, quality of life and on the attractiveness of those areas. The most common examples occur at the three dimensions of **sustainability**: air pollution (environmental sustainability), fatalities, noise disturbance, local traffic safety (social sustainability), journey unreliability and delivery delays (economic sustainability). Furthermore, goods traffic decreases the accessibility of passenger's transport in urban areas and the efficiency of the urban goods distribution process itself can be affected by congestion, affecting in this way also the **mobility** of the area.

Even being aware of the negative side of urban goods distribution, to some extent cities had tried to live with those problems. Each city tried to find and implement its own solution to the respective problem, obtaining initiatives that were usually less than optimal from a societal, environmental or an economic point of view. However, society is now becoming more demanding than it was in the past and cities are facing a difficult challenge, which resolution cannot delay anymore. Cities want to maintain and promote their **sustainability**, **mobility** and **quality of life**, while ensuring that urban goods distribution systems efficiently serve their needs. To win this challenge, cities mainly have to face the difficult task of **promoting urban goods distribution systems that are environmental friendly** and at the same time, efficient enough to satisfy, **both society and distribution companies**. Second, cities need to **overcome the lack of awareness and knowledge about urban goods distribution among governments and city planners**, which contributes for policy making mainly from the passenger transport perspective, without adequate consideration of goods movement actors and its complex characteristics.

The research conducted along this study aims to contribute to fill these gaps: a) it tries to evaluate initiatives that in specific contexts were considered ‘best practices’ in terms of its contribution to an increasing mobility and sustainability, b) it analyses the impacts on general motorised society and on suppliers simultaneously, by defining and measuring indicators, which will reflect their interest levels and c) it uses modelling tools to include freight specificities on the simulated scenarios providing a transparent and objective support for decision making.

1.2 Progress beyond the state of the art

Considering its significance and the problems associated with it, one would expect that urban freight transport and distribution would have been given a rather central role in European policy making. However, relatively little attention has been paid to urban goods distribution by researchers and policy makers until recently. Indeed, especially in the first half of the 1990s, “*in the documents that the Commission has published to* *support the making of a common European transport policy, issues of city logistics have in fact been only rarely mentioned*" (EC, 2006).

Conversely, during the last decade, EU has made some relevant steps and already promoted some initiatives to achieve sustainable targets.

Table 1.1 presents a list of research projects funded under EU program and sub-programs in the topic of urban freight transport and distribution, which constitute valuable sources of information.

Table 1.1. Research projects on urban freight transport and distribution

Project	AIM
BESTLOG	Collects and disseminates logistics best practice knowledge across Europe
BESTUFS	Establish and maintain an open European network between urban freight transport experts, user groups/associations, ongoing projects, interested cities, the relevant European Commission Directorates and representatives of national, regional and local transport administrations in order to identify, describe and disseminate best practices, success criteria and bottlenecks with respect to the movement of goods in urban areas
CITY FREIGHT	Provides guidance to a range of interested stakeholders on the best practices for analyzing their city freight problems as well as for designing and implementing integrated strategies to solve them.
COST 321	Studies innovative measures to improve environmental impacts of freight transport in urban areas
DIRECT	Analyses the aspects of transport-data sharing structures for better databases for traffic management within cities
eDRUL	Investigates and testes an innovative e-logistics platform and services to manage freight distribution in urban areas
EVD Post	Demonstrates the technical and economic viability of electric vehicles in the regular operations of postal services in Europe. Introduces electrical vehicles for a more sustainable postal service
FIDEUS	Provides a complementary set of vehicle solutions to support an innovative approach to the organization of urban freight transport, in line with political strategies to safeguard the livability of cities, while being compatible with efficient logistics. Contributes to the economic livelihood of business and retail activities located in the city in a practical way, with policies oriented towards more sustainable mobility
FREYA	Aims at facilitating the access of SME's to intermodal transport
FV-2000	Analysis and evaluation of several freight villages in Europe
GIFTS	Explores the use of telematics for the management of deliveries and the intensive use of automated and computerized methods for handling of freight. GIFTS provides applications for the operational as well as all the e-commerce functions and insurance of a door-to-door freight transport chain
IDIOMA	Shows the potential of optimisation of goods distribution in 5 urban areas within Europe
INFREDAT	Investigates the whole transport chain of intermodal transport, especially the requirements of data flows. Establishes a methodology for collecting intermodal freight transport data
LEAN	Aims to integrate LEAN LOGISTICS in urban multimodal transport management to reduce space demand and optimize use of transport mode
MEROPE	Regards the study and development of models and telematic tools for management and control of mobility and logistics in urban and metropolitan areas. The cities involved have different characteristics in relation to dimension, geographic position and socio-economic aspects.

MOSCA	Project has developed a set of tools for improving the efficiency of door-to-door transport of goods in urban areas. This set of tools offers services for shortest path finding, on-line vehicle routing planning and urban shop delivery planning.
NICHES	Innovative concepts for making urban transport more efficient, competitive and sustainable.
REFORM	Analyses and evaluates the effects of freight platforms regarding the urban traffic
SOFTICE	Identifies cost of freight transport within Europe with regard to harmonization in Europe and internalization of external cost
UTOPIA	Strategies for changing modal split (including transport means, organization and operation). The project aimed to provide project managers and policy-makers with the necessary information base, tools and guidelines to support the introduction of promising urban transport solutions based on cleaner vehicles

In addition to the above-mentioned examples of programs of the EU, some countries have also promoted along the last decade the development of projects that address the topic of urban goods distribution. The following are examples of national research programs across Europe. Many of these programs, however, deal primarily with public transport rather than freight and only individual projects within these programs focus directly on the area of urban freight transport and distribution:

- Logistics Austria Plus (Austria, 1999-2003)
- Mobility and Transport (Germany, ongoing)
- Optimized Transport Logistics for Recycling and Waste Management sub-program
- Flexible Transport Chain (Germany, 1997- 2001)
- Centre for Logistics and Freight Transport (Denmark, 2001-2005)
- Ministry of Transport and Communication's R&D Projects Supporting Transport Policy (Finland, ongoing): projects within the 'Goods Transport and Logistics', 'Transport of Dangerous Goods' and 'Environment and Vehicle Engineering' themes
- VALO Real-time Logistics in Networks (Finland, 2001-2004)
- VINNOVA SP8 Innovative Logistics and Freight Transport Systems (Sweden)
- Department for Transport (UK, ongoing), Freight Best Practice and Freight and Logistics Programmes. Examples of projects include 'Alternative Delivery Solutions – Nottingham Trial' and 'Urban Consolidation Centres' (Sustainable Distribution Research sub-programme)
- National Programme on Urban Goods Transport (France, ongoing); French Ministry of Transport, ADEME
- PIEK multi-annual programme into delivery noise (The Netherlands).

Together with these examples (resulting from the increasing concern on the sustainability and mobility of urban goods distribution in Europe), the dissertation will provide a more detailed state of the art through a compilation of 'best practices' and an exhaustive scientific literature review along chapter 3. Such set will support **the identification of more sustainable distribution initiatives and policies**.

1.3 Objectives and scientific contribution

Along this study it was intended to attain a general objective, assessing an hypothesis and fulfilling some recognised gaps on the research through scientific contributions to the topic.

As general objective, the thesis aims to evaluate the effects of alternative urban goods distribution initiatives, and to provide some reflections, considerations and ideas in the process of diagnosing urban goods distribution problems and designing the foundations of a general goods practice project and process approach. This objective supports the hypothesis of the study which puts into question whether the power of context on the study of urban goods distribution influences the effects of the implementation of the categorized 'best practices' towards mobility and sustainability and considering public and private stakeholders interests.

To attain this general objective, the thesis tries to fill relevant gaps in the literature, through the following scientific contributions:

First, there are no clear definitions of **mobility and sustainability** applied to urban freight transport and distribution. The thesis intends to present its own definition and interpretation of both concepts. These definitions of mobility and sustainability will be established to be the main targets to be achieved under a *public and private perspective* complemented with a specific *set of (quantitative) indicators*.

Second, there is not an established framework to make an evaluation towards mobility and sustainability on urban goods distribution. Each 'good practice' presents its own methodology of evaluation and respective outputs, making it impossible to take lessons out of it. The thesis intends to fill this gap, developing a **set of indicators**. The set will be established specifically to measure mobility and sustainability (on its 3 dimensions) of *urban goods distribution* and to consider *public and private stakeholders* perspectives.

Third, understanding why a given solution was a success/failure at a certain time, in a certain place is as important as knowing whether or not it was a success/failure. Nevertheless, there are no validated (scientific) contributions about pitfalls and success factors and which stakeholders should be involved to implement an initiative. The thesis also tries to fill this gap, suggesting a stakeholder-based analysis and evaluation. This approach tries to include public and private stakeholders in an attempt to identify pitfalls and success factors of each initiative.

Lastly, the challenge in urban goods distribution is often to find a sustainable collective optimum of drawbacks and benefits for all actors. If the effects could be estimated and the stakeholders would be aware of the benefits they could have with a specific measure, the negotiation process would be more transparent and could easily lead to an integrate strategy. Therefore, the thesis will try to suggest a tool of evaluation and of support to negotiation, in order to predict what can actually constitute a ‘best practice’: **microscopic traffic simulation**.

1.4 Scope and Delimitations

The scope of the research is the study and analysis of urban goods distribution initiatives and its interactions with the city, through the measurement of impacts on the quality of urban environment and on the efficiency of urban goods distribution processes (public and private interests).

The limited and sometimes fragmented information available on this topic means that some aspects cannot be addressed as comprehensively as others. These conditions forced to restrict the scope of the research, as it is explained in the following paragraphs.

The treatment given along the study to the relation urban goods distribution - sustainability – mobility does not intend to analyze in detail the mobility and sustainability concepts. The intention is rather to evaluate specific initiatives using indicators that can be a measure of **sustainability and mobility**. The coverage is meant to be comprehensive but not always excessively deep.

The cause-effect relation between urban goods distribution and the negative impacts generated on cities is not commonly accepted by the scientific community, in the sense that some authors point out the activity more as a victim of the specific context (Wild, 2002; Huschebeck, 2004) than as the source of the referred impacts. This raises some doubts if researchers should focus the attention on urban goods distribution in order to reduce its impacts or on a broad complex context that affects the urban goods distribution efficiency. Indeed, both perspectives have real arguments to support it. However, the study of the broad complex context that affects the urban goods distribution activity requires the consideration of multiple and complex phenomena's that are not aimed to achieve with this thesis. Thus, despite the awareness that other approaches are also valid, it was chosen to look at the problem considering **urban goods distribution as a source of impacts (both for private and public stakeholders)**. It is assumed that the way goods are delivered affects the efficiency of urban goods distribution and the attractiveness of urban areas, once it affects economic, environmental and social functions in the cities.

The geographical scope of this research is aimed at **urban areas**, which are densely populated areas with high concentration of residential, commercial and recreational activities. It is difficult to present a general and commonly accepted conceptual definition for 'urban area' adequate for the scope of this thesis. Thus, the formal definition will remain open and it will be considered 'urban area' an area with a large variety and density of activities.

The topic will be studied and developed from an innovative perspective. It will not be focused on logistics-chain or solely on technological developments, but in a point of view focused on the environmental, territorial and economic[1] impacts generated by urban goods distribution initiatives. The referred impacts are expected to be difficult to quantify and obtain due to the lack of data collection in urban goods distribution.

This research project focuses solely on **urban goods distribution,** covering the transport of goods to, from and within urban areas. It will only be analyzed goods, with a destination within the urban area, dealing with the delivery of consumer goods mainly

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[1] *The economic dimension often referred on this thesis is the micro level (level of the company or of a small group of society) and not the level of society (macro level).*

to supermarkets, bookstores, hotels, restaurants, cafés and offices, and other commercial retail stores.

It will only be considered **core goods**, which are the ones of primary importance and do not include secondary goods deliveries, waste collections, banking deliveries and collections, home deliveries, reverse logistics and service trips. In the case of a shop for instance, the core goods comprise all the goods the shop actually sells, but excludes those secondary goods such as plastic bags and paperwork, which are required by the shop but not sold on.

The focal point in this research is freight transport in urban areas. Passenger transport, land use issues, etc. are of importance in research about urban freight transport and distribution and therefore may occur as parameters; however, they are beyond the scope of this research.

Daily shopping activities and the resulting traffic generated by consumers is itself of greatest importance in urban distribution and mobility; nevertheless the study will be focused only on goods distribution in urban areas made by **companies**[2]. It will not be distinguished the logistic companies hired to make the delivery from the ones which integrate the logistic activity in the core business of the company.

Once road transport is the major mode in urban goods transport and railways, rivers and inland waterway have specific limitations for carrying goods inside urban limits, it is hard to switch goods from road to railway or boat for urban goods distribution. Besides these restrictions, transshipment costs are very high for short distances[3] (Van Wee, 2002; Beuthe and Kreutzberger, 2001) and demand for just-in-time deliveries is increasing significantly (OECD, 2003). Thus, attending to the referred limitations and to the geographical scope of the thesis, **intermodality** will not be focused in a detailed way in urban goods distribution.

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[2] *Delivery traffic to homes (generated or not by e-commerce) will not be focused on this research.*

[3] *Beuthe and Kreutzberger (2001) cite the example of Europe, where road-rail transport "is not competitive over distances shorter than 3500 km, or even 500 km, due to the existing tariffs, corridor characteristics and network organization."*

1.5 Structure and Methodology

The thesis is constituted by seven chapters.

Chapter 1 defines the problem, presents a brief progress beyond the state of the art, establishes the scope of the research and its objectives, and presents the research structure and methodology. The description of the thesis' structure reveals how the study will be carried out and allows a better understanding about the adopted methodology.

Chapter 2 makes explicit the interpretation and implications of three pillar concepts – urban goods distribution, sustainability and mobility – and two main perspectives – private (industry) and public (society) to the definition of more sustainable distribution initiatives. These concepts and objectives will constitute determinant guidelines for the structure of the study.

Chapter 3 presents a detailed state of the art and its aim is twofold. First, it offers a synoptic overview of the range of solutions available to decision-makers and other interested parties coping with urban freight transport and distribution problems. Second, it serves as input to the evaluation process (Chapter 4 and Chapter 6) and to support the search for concrete solutions to similar problems. The overview of the range of potential solutions is provided by an inventory of theoretical and already functioning initiatives whose impacts contribute to a better urban environment. The inventory includes a scientific literature review and a compilation of practical experiments, which have already proved to have positive impacts on urban areas. The detailed knowledge of theoretical and practical initiatives on urban goods distribution and the accurate description of those 'best practices' will allow to identify the adopted indicators and models (Chapter 4 and Chapter 5) and the measurement of the respective impacts in urban areas (Chapter 6).

Chapter 4 proposes a set of indicators which may serve as a framework for the assessment of goods distribution initiatives performance and for the analysis and comparisons of policy scenarios/strategies to mitigate negative impacts originated from goods transport and distribution activities. The set of indicators includes both stakeholders' main interests and mobility and sustainability criteria, taking into consideration the essential qualitative and quantitative principles which based their selection. The result of the described methodology leads to a final compilation of indicators to be adopted on the micro simulation exercise described in Chapter 6.

Chapter 5 has a determinant role on the structure of the dissertation and on its intrinsic objectives. It introduces microsimulation as a modeling technique and adopting the concepts of mobility, sustainability and urban goods distribution (defined in chapter 2), allows to evaluate the measures presented on chapter 3, making use of the evaluation criteria identified on chapter 4. Results from the application of microsimulation exercise are later presented on chapter 6.

Chapter 6 is mainly divided in 2 parts. The first part presents the background of the case study: it describes the area from a macro geographical level to a micro level in terms of population, employment, daily movements and mobility. Such characterization helps to define the case study area. After establishing the case study geographical boundaries, the network base conditions are presented and it is defined the modeling framework, making it explicit the methodology to be used along the chapter. The second part describes the simulation of scenarios and evaluates several initiatives, implemented in an individual way:
(1) alternative fuels with a penetration rate of 10% and 20%
(2) collaborative systems
(3) cooperative distribution systems
(4) enforcement;
(5) pricing policies (road pricing)
(6) regulation of access
(7) reserved-capacity strategies (shared usage of a bus lane by freight vehicles),

The effects are measured privileging both public and private objective. The assessment follows two distinct approaches, based on geographical coverage and on stakeholders' impacts. The first one distinguishes the impacts of the initiative at street level, unit level and on the overall system (city). The second one distinguishes the respective impacts by stakeholder group: suppliers on LGV's, suppliers on HGV's, citizens and users, public transport and administrators.

The evaluation (based on microsimulation) is complemented with empirical knowledge in order to validate each initiative as a 'best practice' for the specific area of implementation. In the few cases an alternative is validated as 'best practice' towards the improvement of mobility and sustainability, a further detailed evaluation is carried out. A summarized quantification of the operational financial impacts complements the general evaluation based on the indicators defined in Chapter 4. The thinking behind each of these scenarios, together with the assumptions used in the modeling are discussed along the chapter.

Chapter 7 presents the final conclusions. The theoretical and empirical contributions are presented and recommendations for further research outlined.

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2 Fundamental Concepts

2.1 Introduction

For a long time, transport and goods distribution generated conflicts with the city structure. With the increase and complexity of consumption needs, physical supply flows to the city have increased and consequently, have intensified its impacts on urban environment. Therefore, it is now expected, or even demanded, from logistics activities, including transport and goods distribution, the achievement of a 'negotiated balance' with the Environment, Economy and Society[4] (Figure 2.1).

These worries about the impacts of urban goods distribution on the cities sustainable development have been "reflected" in the way research has being carried out on this topic.

At the Environmental perspective, researchers have been trying to find solutions that might contribute to an improvement of the urban environment quality: lower environmental impacts, less noise and less congestion. At the Economic level, research tries to find solutions to optimize the transport of goods to the city, to avoid congestion, to minimize the number of trips to the city and to maximize profits. Lastly, at the Society level, it is intended to maximize the efficiency of the all system, mitigating the negative impacts associated with urban goods distribution activity and thus, to promote mobility and sustainability within the system (Melo, 2003).

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[4] *Recently some authors (Janic, 2006; Spangenberg, 2002) identify an additional fourth level: the institutional one, which on this thesis will be considered as a transversal level of the other three.*

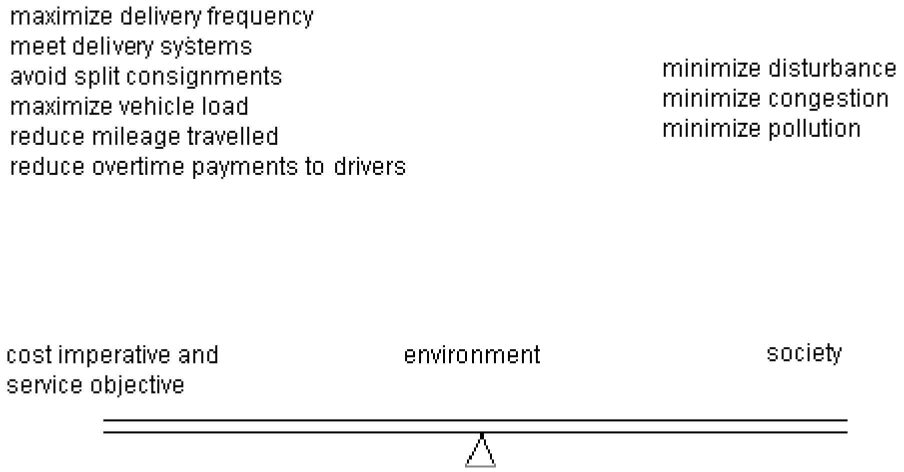

Figure 2.1. Dimensions of urban goods distribution

When put together, the 3 dimensions of urban goods distribution (Environment, Economy and Society) suggest an environmentally friendly and efficient distribution system. One system which integrates the main objectives of society and companies, achieving a balance on their different perspectives. As this target (somewhat similar to 'green logistics') is explored, its implementation seem to be more difficult than it is expected on first encounter.

Table 2.1 illustrates the three high level aims, complementary to the ones presented on Figure 2.1, of a sustainable distribution strategy.

Table 2.1. High level aims

Source: adapted from Steele (2006)

Economy	Environment	Society
Support city's growth in population and economic activity Improve the efficiency of Freight distribution and servicing within the city Balance the needs of Freight and servicing with those of transport users and demands for city resources	Improve air quality and contribute to climate change by reducing emissions of local air pollutants and CO2 caused by Freight and servicing Improve the quality of life in the city by minimizing the impact of noise and vibrations caused by Freight and servicing	Improve health and safety in the city by reducing the number of deaths and injuries associated with Freight and servicing Improve the quality of life in the city by reducing the negative impacts of Freight and servicing on communities

The balance between the dimensions of urban goods distribution and the high level aims of a more sustainable distribution strategy is not easily achieved. To find possible paths to accomplish it a) three pillar concepts are defined - urban goods distribution, sustainability and mobility and b) two main objectives are highlighted – private (industry) and public (society) ones. These concepts and objectives constitute a determinant support for the research carried out along the thesis.

Chapter 2 makes explicit the interpretation and implications of the visions the three concepts sub-assume. The three concepts are by no means unambiguous; there is not one uniform approach and not one general application of the three concepts and it is doubtful whether one would - or could - ever exist. The definition of 'urban goods distribution', 'mobility' and 'sustainability' is highly dependent on the specific context, and can serve different users with different priorities and concerns. The following sections present the interpretation the three concepts assumed on this study.

2.2 Urban Goods Distribution

The analysis of the concept '*urban goods distribution*' requires a previous definition and association to the concepts of '*supply chain*' and '*logistics*'.

According to the Supply Chain Council, "***supply chain*** *encompasses every effort involved in producing and delivering a final product or service, from the supplier's supplier to the customer's customer*". The reason for the existence of supply chains is that there are very few companies that can produce end products for end-customers from raw materials on their own, without the assistance of other organizations. The company that produces the raw material is often not the same company that sells the end products to the end-customer. In order to provide end products to the end-customers, a network of actors is involved in activities (as purchasing, transforming and distribution) to produce products and/or services (GSCG, 2007). The series of companies (actors) that interact for this producing and delivering is what is called supply chain. Actors are connected through the flow of products, the flow of information and the flow of money (Figure 2.2).

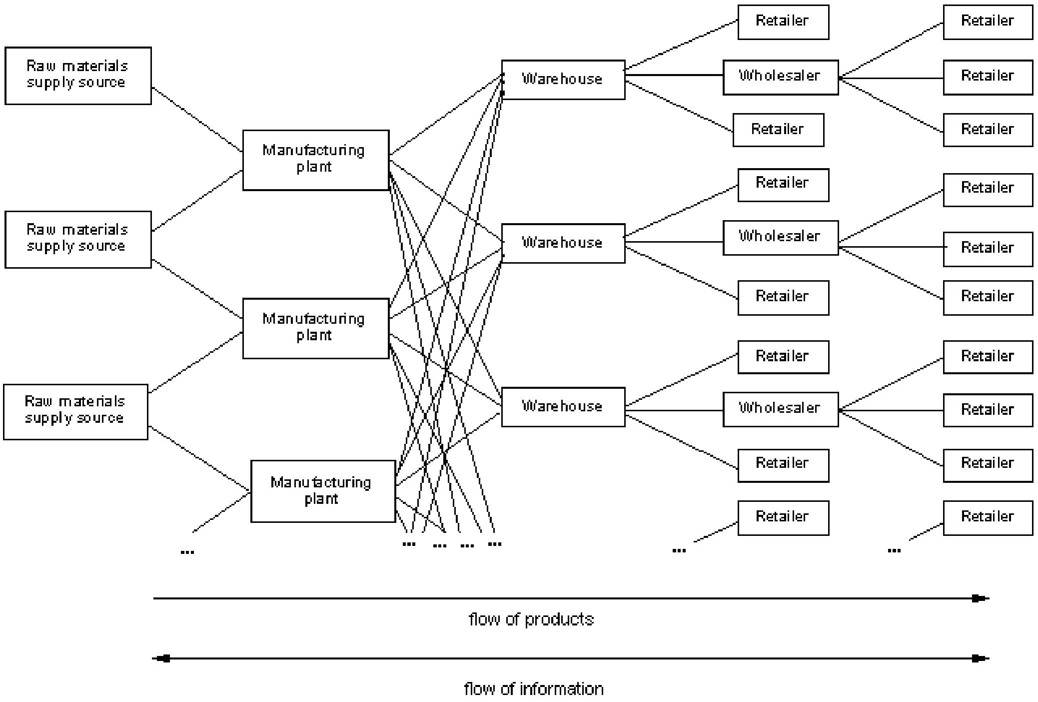

Figure 2.2. Supply chain scheme

Source: adapted from GSCG (2007)

Supply chain is the mechanism, which guarantees that products or services go from an origin point to a destination, passing through various stages, including transformations, storage and transportation.

Logistics is a transversal function that exists in all the structures, sometimes in a more obvious way than others and works like the "*integrated system that relates the needed processes, activities and logistic resources to materialize the supply chain*" (Guedes, 2004a). This means that logistics is what assures that products pass all the stages from figure 2.2 in an effective way and arrive according with the required conditions. The Council of Logistics Management (2004) presents the concept as "*the process of the supply chain of planning, implementing and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and all the related information from the origin point until the consumption point, considering the service requirements of customers*". It is a less visible function that assures a good functioning of the supply chain. Brewer *et al.* (2001) defined it saying that *"logistics contributes to the creation of time, place and even form utility through the management of processes* *that enable companies to get the right goods to the right place at the right time in the right condition at the right cost".*

Logistics is the function which assures "*right materials, right quantity, right quality, right place, right time, right method, right impression, right cost*" (Rosini and Preti, 2006).

When logistics activities take place in urban areas they show unique characteristics making them different from the general logistics activities. For this reason, goods distribution in urban areas is usually labeled in a specific way as *"city logistics", "last mile"* or *"**urban goods distribution**"*. Distribution refers to the last step taken to move and store a product from the supplier stage to a customer stage in the supply chain (Chopra, 2003). It differs from general logistics in the sense that it lays more importance on consolidation, distribution and transportation of goods to the city centres. It concentrates mainly on goods transport, although some authors (Muñuzuri *et al*., 2005; Allen *et al*., 2000) suggest the concept should also include service vehicles (inspections, installations, technical service, and emergencies) and other commercial uses (sales representatives, company cars).

Taniguchi *et al.* (2001) define this activity as "*the process of totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, traffic congestion and energy consumption within the framework of a market economy*". This definition of the concept, as many others, assume that the distribution activity is closely related and even dependent of transports, and highlights the need to balance private companies aims and society concerns.

Urban Goods Distribution moves goods to the final customer, using a transport system and creating social, environmental and economic/financial impacts. It is defined on the present dissertation as the process which ensures that the resources needed in urban areas are positioned in the right places, at the right times, in the quantity and quality required and at a certain cost, not neglecting the main stakeholders involved and the criteria to be achieved: sustainability and mobility.

2.3 Mobility

"…mobility is really getting somewhere to do something" (Beverly Ward[5])

According with Himanen *et al.* (2005b) people use the transport system to satisfy their needs and mobility is "*a derived need which surfaces when basic human needs and related activities cannot be satisfied in one place*". Kronbak and Rehfeld (1999) present a similar interpretation, saying that mobility is created by the need of individuals to take part in opportunities (or activities) located in different places. The individual's possibility of traveling is provided by a transport system, and thus from a transport planning point of view, mobility measures how well the transport system is fulfilling its purpose, providing the individual with the possibility to participate in spatially based activities. Thus, mobility **occurs to fulfill specific plans and projects, through a physical and/or virtual movement** and is influenced by several elements like life styles, spatial characteristics and accessibility (Meurs and Haaijer, 2001).

In various studies, mobility takes on different definitions according to the purpose of the study and implies other components such as temporal and individual ones. On this study, it is focused the attention on the purpose of mobility[6] rather than on its intrinsic characteristics and mobility is associated with the "*ease of movement*" as defined by Levine and Garb (2002). Kronbak and Relief (1999) also relate mobility with spatial movement, stating that mobility denotes the "*ease with which an individual can move away from a location, using a particular transport system*". A similar definition of mobility is presented by Dimitriou (2006) as "*an ability of an individual to move within, and interact with, the environment, usually involving the utilization of public and/or private transportation*".

Vandenbulcke *et al.* (2007) relates the importance of the easy of movement with a better quality of life. All the ingredients are generally available only if there is adequate means of moving people, goods and ideas. Thus, higher mobility means an increased quality of life for the individual (greater freedom to choose activities and greater amount of time to dedicate to them). On this sense, mobility plays a key role for the development and depends essentially on the means allowing to move.

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[5] *Ward, B. (1976) Home of man, W.W: Norton&Company, New York, p144.*

[6] *Some authors distinguish the "motorized" mobility from the "non-motorized" one (Schafer and Victor, 2000). On this thesis, it will mainly be focused the "motorized" mobility, which will be referred to as 'mobility'.*

Despite the close relation between ‘mobility’ and ‘movement’ society should not aim to achieve increasing movements, but ‘easy’ movements. If the concepts ‘mobility’ and ‘movement’ are used interchangeably, as sometimes they are in an inadequate way, that would imply that as long as vehicles would be on the move, society would have greater levels of mobility, which is not necessarily true. The truth is that this principle is a myth in so far as freeing-up one stakeholder movement *can* often have negative impacts on others or other parts of the transport system, and/or indeed on the environment in which the improved mobility is offered (Dimitriou, 2006). This reveals that one of the consequences of mobility may be immobility (Albertsen and Diken, 2001). Increasing levels of mobility (above a certain level) can also contribute to urban sprawl, air pollution, traffic noise, accidents and declining city centers (Greene and Wegener, 1997). Bellow a certain level, the increase of mobility can increase the quality of urban environment and have potential positive impacts on local economy, through the decrease of congestion, related pollution and delays on deliveries. Along this study, and particularly on chapters 4 and 6, it is assumed the increase of mobility occurs within this level range in which it leads to positive impacts on the system.

The definitions mentioned above, as most of publications on mobility, are generally applied for passengers. Indeed, little has been written and is known about mobility for freight transport compared to passenger transport and thus, much less studies focus on freight transport mobility. Such a shortcoming is due to the restricted availability of data concerning freight transport but attenuate by the fact that mobility concepts and indicators used for freight transport are relatively similar to the ones applied for passenger transport.

Adapting the definitions previously presented to passenger transport, to the particular topic of urban goods distribution, it can be assumed that **‘mobility’ is the ease of movement, dependent of an (efficient) transport system and of a diversity of (sustainable) options to get to a final destination, where the consumption needs are met at moderate costs to transporters and to society and as timely to the predicted as possible (reliability).**

2.4 Sustainability

The term '*sustainability'* came to be used world-wide following the publication of the Brundtland report provided by the World Commission on Environment and Development (WCED, 1987), that defined **'sustainable development'** as "*development that integrates the economic, social, and environmental objectives of society, in order to maximize human well-being in the present without compromising the ability of future generations to meet their needs*".

The popularity of the term has made it a buzzword of uncertain meaning. The concept of **sustainability** is nebulous and has multiple and contestable meanings (Ryan and Throgmorton, 2003). The ambiguity of the concept is referred by Davis (1996) to whom 'sustainability' "*to date, has meant all things to all people*". It is one of the most ambiguous concepts but also one of the most used one in different fields, under diverse perspectives and with various purposes. Considerations on sustainability mainly depend on the perceptions, preferences and objectives of the particular actors involved. And hence in the past years new complementary concepts have emerged from the sustainable concept, such as **sustainable transport**.

The definition of sustainable transport faces the challenge of translating the meaning of the vague 'sustainable development' and 'sustainability' definitions into the transport sector. It is clear that a first barrier to an unambiguous definition of sustainable transport would be the lack of clear definitions of sustainable development and sustainability in general.

Black (1996; 2000) and Richardson (2005) by modifying the WCED's definition could derive a definition of sustainable transport as the "*ability to meet current transport needs without jeopardizing the ability of future generations to meet their transport needs*''. Mészáros (2000) cites the approach of the Centre for Sustainable Transport, which tries to be more detailed than the previous one and states that sustainable transport allows "*basic access needs of individuals and societies to be met safely and in a manner consistent with human ecosystem's health and with equity within and between generations"…"it is affordable, operates efficiently, offers choice of transport modes and supports a vibrant economy, limits emissions and waste within the planet's ability to absorb them, minimises consumption of non-renewable resources, reuses and recycles its components and minimises the use of land and production of noise."*

This is a more detailed definition but still it is an ambiguous way to define 'sustainable transport' that, as many others from other authors, has "*limited meaning other than as guide-posts*" (Root *et al.*, 2000).

Although no common accepted definition of sustainability, sustainable development or sustainable transport is available (Beatley, 1995; Black, 2000; Janic, 2006), it is generally accepted that the definition of those concepts implies a frequent reference to the "triple bottom line" of economic, environmental and social equity sustainability (Richardson, 2005; Steg and Gifford, 2005). Dimitriou (2006) refers to this balance when citing a clear definition[7] that explain that "*at its core, the concept of sustainable development is about reconciling 'development' (which implies the use of resources and the generation of wastes) with the 'environment' (which implies finite use of many resources) at local, regional and global scales*". Himanen *et al.* (2005a) use this "balance" on the definition of "sustainable transport" as "*a transport system that in itself is structurally viable in an economic, environmental, and social sense and does not impede the achievement of overall sustainability of a society*". This means that sustainable transport is a concept that refers to an acceptable level of social costs associated with the physical movement of people and goods (Verhoef *et al.*, 2001). These social costs are related to a decay of environmental quality (e.g., CO2 emission affecting the global environment, or noise annoyance affecting local quality of life), fatality rates as a consequence of accidents in the transport sector, or congestion causing a burden to the economy at large. The same issues are mentioned by Janic (2006) when defining sustainable transport as "*one in which fuel consumption, vehicle emissions, safety, congestion, and social and economic access are of such levels that they can be sustained into the indefinite future without causing great or irreparable harm to future generation of people throughout the world*".

The definitions mentioned above, as most of publications on sustainable transport, are generally applied for passengers. Indeed, much less studies focus on freight transport and distribution sustainability and there is no consensus about the implications of the concept for freight transport in urban areas. Urban freight transport and distribution involve many actors and local stakeholders with many different interests and for balancing these interests there has to be a commonly-held concept of what the characteristics of a sustainable urban freight transport system are.

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[7] *Hardoy, J.E., Miltin, D. and D. Satterthwaite (2001) Environmental Problems in an Urbanizing World, Earthscan, London, pp337.*

Taking into consideration the above definitions and focusing on the particular case of the urban goods distribution topic, the translation of the aims of the WCED's definition would present the sustainability concept through the following question: how can a certain piece of freight be transported with the most efficient and environmentally friend mode, on the shortest way and without loss of time, from its origin to its destination at the urban area causing minimal costs, using a minimum of land and a minimum of follow-up pollution? (*adapted from* Dimitriou, 2006). The answer to this question can be a sustainable urban freight transport and distribution, which would consider the three dimensions of sustainability.

The quantification of the three dimensions through modeling would allow to operationalize these concepts. Such operationalization can be the basis for setting up quantitative targets on particular impacts, refining the scope of sustainability and building up systems for monitoring strategies and policies.

2.5 Mobility and sustainability of transports and distribution

Road transport is the main mode used for freight transport and distribution[8]. Road mode has a high degree of flexibility, adjusting rapidly to time, place and quantity requirements of client demands (Whitelegg, 1994). Thus, it is the more adequate mode to deal with the increasing demand for delivery small loads with a high frequency to cities and to deal with the pressure of reliability and punctuality on suppliers.

Despite the considerable role that road transport plays supplying cities, with its presence throughout the production chain, this mode is also the source of many harmful impacts on the urban quality of life.

The following sub-sections present some attempts to quantify the negative impacts of road transport and in particular its externalities and external costs.

Externalities are the difference between the full social costs (private and external) and what the individual actually pays by practicing an action (in transport, usually, the user only pays the private ones). This means that externalities represent a form of market

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[8] *Road transport represents more than 94% of the freight sector's total share.*

failure because true costs are not taken into account when production and consumption decisions are made.

Schreyer *et al*. (2004) estimate that in the year 2000, the externalities from transport (*excluding congestion*, with high climate change shadow prices) accounted for 650 billion Euros in EU-15 plus Norway and Switzerland, making up 7.3% of total GDP. Freight transport was responsible for one third of these external costs.

External costs usually include accidents (fatalities, injuries and property damages), emissions (air pollution and greenhouse gases), noise, climate change and unrecovered costs associated with the provision, operation and maintenance of public facilities (Forkenbrock, 1999).

Maibach (2000) quantified the total external costs of transport (*excluding congestion*) by transport means and cost category. Results show that road transport is responsible for 92% of total external costs, followed by air transport causing 6% of total external costs, railways (2%) and waterways (0.5%). The total costs for HDV (heavy duty vehicles) amount to 72 euros/1000 tonkm, which is 3.8 times higher than the cost for railways. Table 2.2 illustrates these results in more detail.

Table 2.2. Marginal costs by cost category and means of transport (the ranges reflect different vehicles categories (petrol, diesel, electricity) and traffic situations (urban-interurban)

Source: Maibach (2000)

Marginal Costs (average) [Euro per 1000 Pkm/Tkm]	Road					Rail		Aviation		Waterborne
	Car	MC	Bus	LDV	HDV	Pass	Freight	Pass	Freight	Freight
Accidents 1)	11-54 (36)	79-360 (250)	1-5 (3.1)	44-163 (100)	2.3-11 (6.8)	0-1 (0.9)	0 (0)	0-1 (0.6)	0 (0)	0 (0)
Noise	0.2-2.1 (5.7)	0.6-53 (17)	0.1-7.5 (1.3)	5.3-496 (36)	0.6-52 (5.1)	0.2-23 (3.9)	0.1-1.6 (3.5)	2.3-17 (3.6)	17-87 (19)	0 (0)
Air Pollution 2)	5-17 (17)	14 (7.9)	4-25 (20)	28-118 (131)	14-50 (32)	2-24 (4.9)	1-6.8 (4)	0.8-2 (1.6)	0.8 (2.6)	4.5 (9.7)
Climate Change	12-25 (16)	9.6 (14)	5.5-11 (8.9)	125-134 (134)	15-18 (15)	4.2-8.9 (5.3)	4.2-5.3 (4.7)	36-42 (35)	117 (154)	4.7 (4.2)
Nature & Landscape	0-1.8 (2.5)	0-1.8 (2)	0-1.3 (0.8)	0-23 (23)	0-8.9 (2.2)	0-0.8 (0.7)	0-0.3 (0.5)	0-2.9 (1.7)	0-8.5 (8.5)	0-0.5 (0.5)
Urban Effects	10.7-11.7 (1.5)	6.7-7.4 (1.1)	3-3.2 (0.5)	75-83 (12)	8-9 (1.3)	0 (0.9)	0	0	0	0
Upstream Process	3.3-6.7 (8.6)	2.7-5.4 (6)	2.8-6.5 (4.3)	40-72 (69)	4.2-8.8 (8.7)	1.1-9.8 (3.8)	0.4-3.4 (5)	4.1-4.6 (5)	18-23 (21)	0.6-1.4 (2.6)

1) Average of countries considered

2) Values for specific traffic situations in Germany, adjusted to European average

The values in brackets denote average values.

The discrepancy of values on the valuation of external costs of pollution (like the one illustrated in Table 2.2) comes from the ambiguity of the task (Henry and STRATEC, 2003).

Results presented along section 2.5 should be carefully interpreted, once the valuation varies according to methodologies and assumptions, which effects are included or not and local circumstances.

In spite of several uncertainties, some relations remain stable and show the level of specific external costs: a) passenger transport accounts for two thirds and freight for one third of the external costs, (Liechti, 2004), b) within passenger transportation, railways are still the means of transport with the lowest level of external costs and c) for freight transport, rail and waterborne transport are about equal.

2.5.1 Congestion

Congestion is one of the most ambiguous components of external costs to be quantified and also the largest externality within many urban areas (European Commission, 2006). An attempt to quantify it in the EU predicted a value of about 1% of the Gross Domestic Product of the European Union by 2010. This impressive value corresponds to 80 billion Euro and 14% of the external costs (Blauwens *et al.*, 2006). Kreutzberger *et al.* (2003) state the value of congestion on the external costs of road mode is of 23%, equivalent to 5.5 euro/1000 tonkm. Another study, implemented in Brussels, established a much higher proportion on freight traffic of the congestion costs: 86% of the external costs generated by trucks in Brussels were referred to congestion (Mayeres *et al.,* 1996).

This discrepancy of values mainly derives from the methodology and assumptions adopted in each study. The common outcome of the studies is the recognition of the significance of congestion on the total external cost and on the acknowledgment of the non-sustainability of transports.

2.5.2 Air Pollution

Transport pollutes the environment on three geographical levels: global, regional and local scales. The effects at *global level* may affect global warming and usually refer to greenhouse gases such as CO2 emissions. The effects at *regional level* can transcend the immediate area where the transport is undertaken and mostly refer to 'acid rain' gas emissions (such as sulfur and nitrogen oxides) and oil spills. The *local level* effects affect the quality of life creating toxic impacts and include problems like noise, visual intrusion and local air pollution.

Table 2.3 relates those main effects of transport emissions on the environment with the respective geographical level.

Table 2.3. Main effects of transport emissions on different geographical levels

Source: Adapted from Henry and STRATEC (2003); Mészaros (2000)

	Global	Regional	Local
Methane (CH4)	X		
Nitrous Oxides (N2O)	Stratospheric ozone depletion		
Carbon Dioxide (CO2)	Global warming	Global warming	-
Nitrogen Oxides (NOx)	Stratospheric ozone depletion	Acidification/climate changes	Toxic impacts
Volatile organic compounds (VOCs)	X	Acidification/climate changes	Toxic impacts
Carbon Monoxide (CO)			Toxic impacts
SO2	X	Acidification/climate changes	
Ozone		Acidification/climate changes	
SPMs			Toxic impacts

X – *Main geographical contribution*

While not technically air pollution, **greenhouse gas emissions** (carbon dioxide, methane and nitrous oxides) constitute a threat to society by contributing to global climate change. At the global level, some greenhouse gases occur naturally in the atmosphere, while others result from human activities. Naturally occurring greenhouse gases include water vapor, carbon dioxide, methane, nitrous oxide and ozone (Table 2.3). However, certain human activities (like transport) also add to these naturally occurring gases: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfurhexafluoride (SF6).

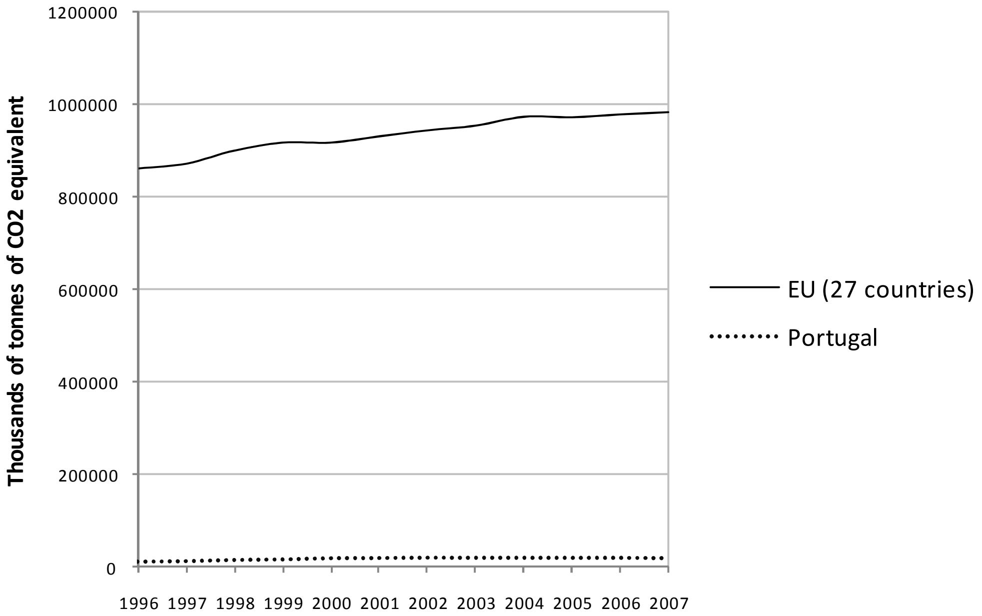

Figure 2.3. Greenhouse gas emissions from transport activities (EU27) and Portugal
Source: EUROSTAT (2009)

Figure 2.3 represents the aggregate emissions of Kyoto basket of 3 greenhouses gases (carbon dioxide, methane, and nitrous oxide) weighted by their global warming potential individual gases translated into CO2 equivalent (EUROSTAT, 2009). The figure shows that greenhouse gas emissions from transport activities within the 27 members of European Union has been increasing since 1996, by 14% at an annual rate of 1.4%. Within the same period, greenhouse emissions from transport activities in Portugal increased 38% at an annual rate of about 4% (EUROSTAT, 2009).

Carbon dioxide (CO2) is by far the most prominent greenhouse gas released by human activity, accounting for about 85% of total emissions weighted by global warming potential (Forkenbrock, 1999). CO2 is released to the atmosphere when solid waste, fossil fuels (oil, natural gas and coal) and wood are burned. It is considered dangerous because it interferes with oxygen transfer in the bloodstream (Meyer and Miller, 2001).

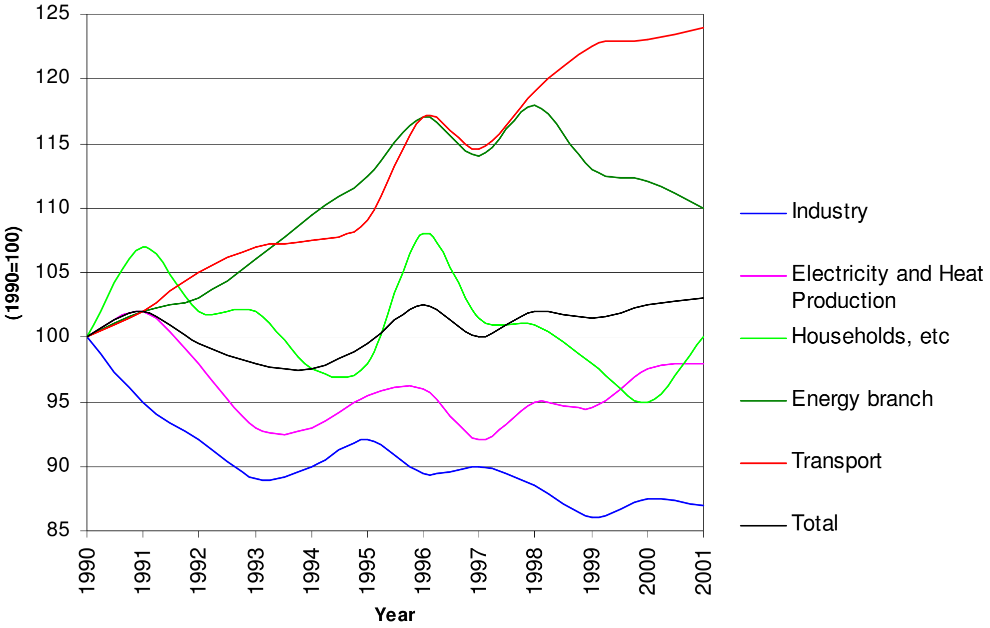

Figure 2.4. Carbon dioxide emissions in the EU-15

Source: Himanen et al. (2004)

From the human activities illustrated in Figure 2.4, transport is the one which registers the greatest increase on CO2 emissions in the EU-15. From all the modes of transport, the road mode is the one which most contributes to CO2 emissions increase (EUROSTAT, 2005). The figure also shows CO2 emissions generated by transport increased along the last years, which significantly contributed to global warming (Henry and STRATEC, 2003).

2.5.3 Energy Consumption

Besides its dominance on the production of CO2 emissions, road transport also has remarkably higher levels of **energy consumption** than the ones registered on other means of transport (Figure 2.5).

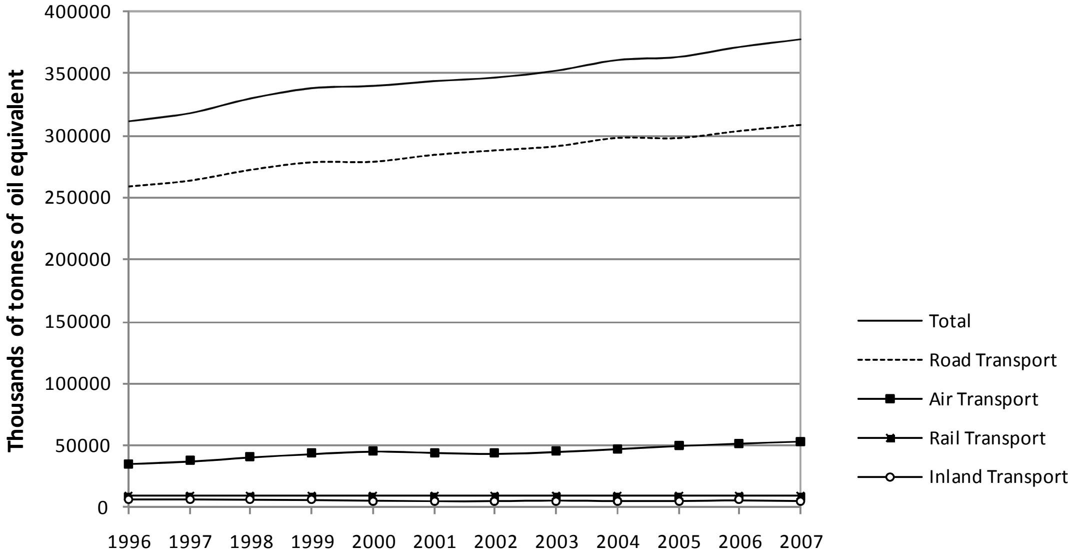

Figure 2.5. Energy Consumption by Transport (EU27)

Source: EUROSTAT (2009)

Figure 2.5 reveals the energy consumption levels from road transport are the main contributors to the total energy consumed by the transport sector, representing 82% of the total. This fact is particularly relevant on the study of Urban Goods Distribution, which mainly uses road transport, the mode of transport that consumes more energy and that according with Verny (2005) generates higher pressure on the environment.

2.5.4 Noise

Despite goods traffic represents a smaller share than passenger's traffic on total urban traffic, its impacts in terms of pollution and noise are very significant in terms of negative consequences generated by local traffic on urban environment (Whitelegg, 1994; Hesse, 1995).

The production of noise is one of the most apparent physical impacts of a transportation facility's operation. There are diverse potential effects of noise on health, in domain such as annoyance, speech interference, concentration on tasks, mental health, stress or sleep disturbance (Henry and STRATEC, 2003). In case of urban transportation, however, noise levels are usually not high enough to actually cause physical harm. The main noise problems are caused by exhaust, engines, tires, doors and body rattle of freight vehicles and freight equipment. According to Whitelegg (1994) at a speed of 50km/h a lorry can produce as much noise as 23 cars and states that some studies show that road traffic is also responsible for the greater part of noise pollution. Henry and STRATEC (2003) tried to measure those effects in monetary terms and quantified the average[9] noise costs of trucks to EU17 of 6.7 EUR/1000 tKm, while car, bus and railways have values of 5.7, 1.3 and 3.9 EUR/1000 pKm.

2.5.5 Accidents

Besides the impacts on environment and energy consumption, road transport also represents a black spot on sustainability in what concerns to fatalities.

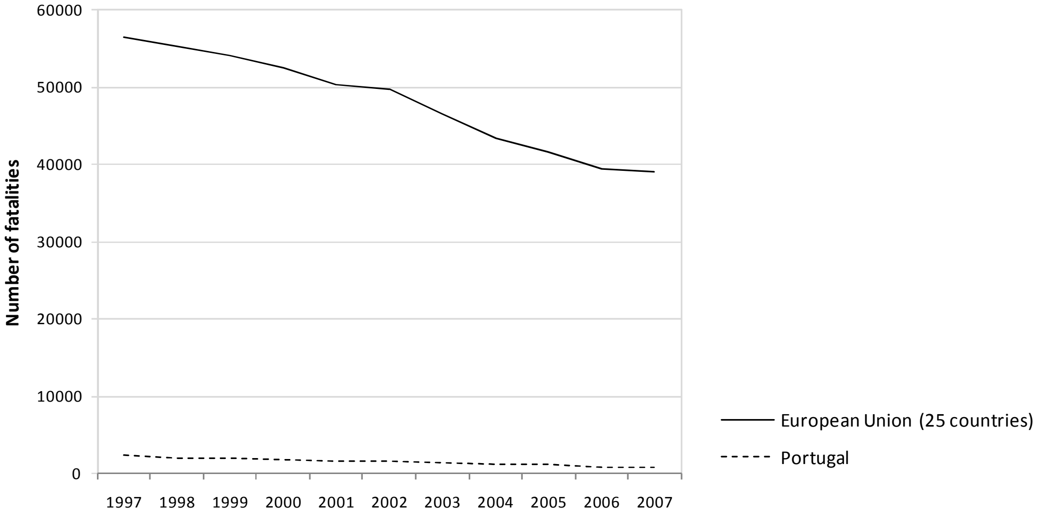

Figure 2.6. People killed in road accidents (EU25)
Source: EUROSTAT (2009)

Figure 2.6 illustrates the number of fatalities caused by road accidents. Although this indicator seems to be decreasing in the last years, it still has remarkably high values that confirm that the transport activity is not sustainable. On this negative picture, it is

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[9] *These values are always dependent on traffic conditions and type of roads.*

important to quote that when road accidents involve trucks, they tend to be more serious in terms of damages and personal injury than those involving passenger cars, which reveals the particular non-sustainability of goods transport activity (Nam and Lee, 2003). These accidents often include shedding of goods and therefore, the social loss is larger since it takes more time to deal with the accidents, leading to long traffic jams (OECD, 2003).

The level of detail of European statistics (CARE database) is insufficient to determine how many accidents and fatalities involving urban freight transport take place. For non-European countries like Japan, the accident rate (number of fatal or injury accidents per million vehicle kilometers) for freight vehicles is 0.96 per 1 million in urban areas and 0.47 per 1 million in non-urban areas. In Australia, for all fatalities resulting from a crash on Australian roads, one in five crashes involves a truck.

2.5.6 Consumption of Land

Road transport is by far the largest consumer of land for transport. The road network (motorways, state, provincial and municipal roads) occupies 93% of the total area of land used for transport in the EU-15 and 85% in the new Member States and Accession Countries. Rail adds to this only 4% of land taken by transport in the EU-15 and 10% in the new Member States (EEA 2004).

Figure 2.7 illustrates the total land take by road transport infrastructure as a percentage of the total area of the respective country.

On the total surface area of the country, road transport has a share varying from 0.5% to values close to 4%. From the countries included on the analysis, Portugal is one with lowest shares represented on the figure, with a value lower than 1%.

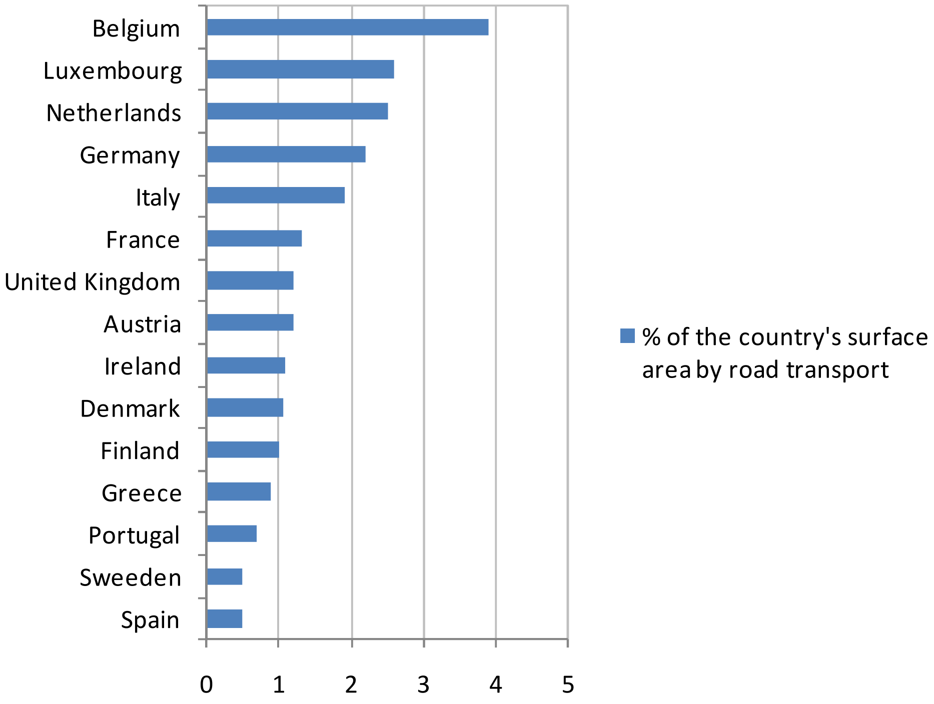

Figure 2.7. Consumption of land by road transport infrastructure (%)

Source: European Environment Agency (2009)

Within urban areas, these indicators are even more remarkable: the consumption of land for road infrastructure is of 25% of the total urban area in Europe and 30% in the United States. An analysis to establish a connection between the land use consumption and the respective traffic, brings surprising results. A research carried out in the Paris region showed that private car, which accounts for 33% of total trips, consumes 94% of road space/hour, while the bus with 19% of total trips consumes only 2,3% (Henry and STRATEC, 2003).

3 State of the Art: Literature Review and Compilation of Good Practices

3.1 Introduction

The aim of this chapter is twofold. First, it offers a synoptic overview of the range of solutions available to decision-makers and other interested parties coping with urban freight transport and distribution problems. Second it serves as input to the evaluation process (Chapter 4 and Chapter 6) and to support the search for concrete solutions to similar problems.

The overview of the range of potential solutions will be provided by an inventory of theoretical and already functioning initiatives whose impacts contribute to a better urban environment. The inventory includes a scientific literature review and a compilation of practical experiments. Theoretical and practical initiatives presented on the inventory were validated, respectively, through theoretical simulations, published in research projects reports, academic journals, public sector documents and conceptual articles, or through empirical studies, trials and practical experiments that have been referred to in the literature. Both types of solutions, whether it has a theoretical or practical validation, constitute potential good practices to improve sustainability and mobility of urban goods distribution activity. Therefore, both will be described as good practices on chapter 3 and evaluated within the case study on chapter 6.

The identification of the positive and negative impacts of the initiatives (in quantitative and qualitative terms) on economic factors, traffic volumes, the environment (emissions, noise), safety, transport infrastructure and land use will provide the input to the evaluation. Each initiative will be presented with considerations about the suitability to tackle the problems experienced in goods distribution, which will support the selection task.

Much of the interest of the inventory lies, first, in the scope of the initiatives (analyzed throughout the research), and second, in the nuances displayed in the specific remarks and considerations addressed to each domain. This scope, diversity and nuances make it particularly challenging to provide cross-case conclusions. However, along the chapter it is possible to observe almost as a general rule that **the involvement of stakeholders is determinant for the success on the implementation of an initiative**.

3.2 Methodology

Good practices presented on this chapter try to achieve the sustainability and mobility goals and to fulfill the interests (sometimes conflicting) of all stakeholders and actors involved or affected by urban goods distribution. **Good practices can be projects, initiatives or activities which directly change goods transport and distribution or which will not directly change it but will provide tools to influence and set up decisions. Good practices are planned or implemented by private sector, by public sector or in public private agreements.**

The **scientific articles and empirical initiatives** presented on this chapter as good practices describe theoretical and practical measures that belong mainly (but not exclusively) to **one of the following domains:**

- Infrastructural and urban space management measures (section 3.3)
- Technological and operational measures (section 3.4)
- Legislative and organizational measures (section 3.5)

These domains, grouped according to the focus of their application, might include diverse initiatives associated with impacts on different levels in order to achieve broader positive results on mobility and sustainability. Table 3.1 summarizes the initiatives and respective domains focused on this work. It is recognized that more initiatives could be included on the list, but there is the conviction the most relevant ones were selected.

Table 3.1. Synopsis of Initiatives

Domain	**Operational Initiatives**
Infrastructural and Urban Space Management Measures	▫ Rail underground distribution systems ▫ (Un) loading spaces ▫ Urban distribution centers
Technological and operational measures	▫ *Intelligent transport systems* ▫ Vehicle routing and scheduling ▫ Collaborative systems ▫ Alternative fuels
Legislative and organizational measures	▫ Pricing Policies ▫ Regulation of access ▫ Reserved-capacity strategies ▫ Licenses ▫ Cooperative distribution systems

Most of the initiatives described on chapter 3 cover more than one domain. The three domains are **inter-dependent** and have specific approaches focused on **intrinsic targets**. All the initiatives have environmental, economic or/and social goals (sustainable goals). The goals can belong to more than one domain and one domain can achieve more than one goal, making this interdependency reciprocal. The goals will be assigned to the main domain for purposes of evaluation. The criterion to assign an initiative, under a sustainable perspective, on a certain domain is that it mainly tries to achieve the respective main goals. Therefore, issues, domains and relations should be understood as a simplification of a complex reality on the study of urban goods distribution under a perspective focused on environmental **sustainability and mobility**.

Moreover, the domains help to see the initiatives from the different stakeholders' perspectives. The consideration of the diverse stakeholders and respective interests and opinions in each of those three domains is essential for the success of any measure to attain environmental, economical or social goals.

There are some clear correlations between initiatives and stakeholders: logistic operations initiatives are mostly of interest to companies (economic goals), whereas infrastructure, land use, policy and regulative initiatives concerned more to the authorities at national, regional and local level (environmental and social goals).
Along this chapter, it will be highlighted the importance and identification of stakeholders in each initiative and domain.

3.3 Infrastructural and urban space management measures

This domain includes initiatives that provide infrastructures to improve the efficiency of urban goods distribution process or use the urban space in a more effective way to reduce its impacts on other city functions. Measures included on domain 3.3 are mainly promoted by public stakeholders considering private stakeholders needs and public good:

- Rail underground distribution system
- (Un) loading Spaces
- Urban Distribution Centers

3.3.1 Rail underground distribution systems

The increasing use of cars, the limited availability of road capacity and a growing antagonism to more urban road building, coupled with the increased demand for goods, means that some major cities are exploring the feasibility of alternatives to road transport, such as the use of underground systems to make distribution.

An underground goods transport distributes a certain type of goods, consolidated and transported through underground systems, under passing heavily congested roads and sensitive areas (Binsbergen and Bovy, 2000). The reasons to support this initiative are that underground infrastructure allows multiple space use and thus leads to space savings at the surface level. It also offers some advantages like the operation in a system protected against climatic influences, not being disturbed by other traffic and protecting the surroundings from negative influences (as noise and pollution). In opposition to these advantages, the negative side-effects of these systems are the need for vertical transport to overcome height differences between the tunnel and the surface, the high investment costs in underground infrastructures and the demand for automated vehicles (Binsbergen and Bovy, 2000).

Koshi *et al.* (1992) made a theoretical application of an underground goods transport system working complementarily with electric vans distribution from depots in the central area of Tokyo (Japan). Results of the simulation revealed that building an underground goods transport system would greatly improve the environment, reduce driving labor force and energy: it would increase travel speed in Tokyo Ward Area by approximately 24%, NOx emissions would predictably fall 24% and energy consumption by about 20%. Ooishi and Taniguchi (1999) complementarily studied the economic feasibility of the underground goods transport system in Tokyo and concluded that this project would have an internal rate of return of 10% if the infrastructure would be constructed by the public sector[10]. Despite these theoretical benefits, the project was not put into practice.

Binsbergen and Bovy (2000) tried to compare, through a theoretical application, this initiative with alternative distribution models in the city of Delft (Holland). Results of the comparison are summarized in Table 3.2 and show that in underground networks a significantly higher average speed can be achieved compared with surface operations, due to the absence of intermediate stops (traffic lights, giving way, etc.).

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[10] *This value might have been influenced by the methodology used on its calculation: once the investment is public, it is assumed the costs are null. Such approach, although often adopted, is not accurate or reasonable to analyze the economic viability of a project.*

Table 3.2. Distribution models and average speeds at links

Source: Binsbergen and Bovy (2000)

	Through urban roads			Other urban roads		
	Maximum speed (km/h)	**Stopping distance (m)**	**Average speed (km/h)**	**Maximum speed (km/h)**	**Stopping distance (m)**	**Average speed (km/h)**
Direct Distribution	50	250	27	30	200	20
Round Trip	50	250	27	30	200	20
UDC + direct distribution	50	330	30	30	250	21
UDC + round trips	50	330	30	30	250	21
UUT + underground direct	40	1000	35	30	500	25

UDC - Urban distribution centre

UUT - Underground urban transport system

The study also concluded that local air pollution can be controlled or significantly reduced because emissions produced underground can only escape the underground infrastructure via specially designed conduits. Calculations also showed that operational costs of rail underground distribution systems would be comparable or lower than the costs of other urban distribution schemes, mainly because of the fact that in underground networks cheap automated systems would be used.

Table 3.3 summarizes the rail underground systems review.

Table 3.3. Rail underground distribution systems review

Author	Method/Location	Measured Indicators and Results		Main stakeholders Considered
		Positive	Negative	
Koshi *et al.* (1992)	Tokyo (Japan) Theoretical	Travel speed; traffic congestion; labor force; NOx emissions; energy consumption		Public administrators and citizens
Oishi and Taniguchi (1999)	Tokyo (Japan) Theoretical	Internal rate of return		Private industry Public administrators and citizens
Binsbergen and Bovy (2000)	Delft (Holland) Theoretical	Speed; Air Pollution; Operational Costs		Private (suppliers) Public administrators and citizens

The measured indicators identified along the review, as well as the main stakeholders involved on the implementation of the measure, will help to define both a selection of indicators and the stakeholders interests, respectively, on chapter 4. For this reason, every initiative and domain review are summarized in the end of the respective section and subchapter, respectively. Tables 3.3, 3.4, 3.6, 3.8, 3.9, 3.10, 3.14, 3.17, 3.18, 3.19 and 3.20 illustrate the review of the respective initiatives. The 'method' indicates how the evaluation and validation was carried out (practical implementation or theoretical evaluation). The 'location' refers to the area of implementation, in case it is a practical experiment. If it is a theoretical evaluation, the location refers to the area used as case study. The distinction of 'positive' and 'negative' refers to the results (evaluated towards criteria of increasing mobility and sustainability). For instance, the indicator 'air pollution' has a positive result if the assessment reveals a decrease of air pollution with the implementation of the initiative (vide Table 3.3). In this case the indicator 'air pollution' will be on the column of 'positive' results. The 'main stakeholders considered' include the ones mentioned on the article, project or experiment.

3.3.2 (Un) loading spaces

Cities try to ensure the existence of a relevant and adequate number of loading and unloading zones, through regulation of the use of road infrastructure. These regulations are quite different between countries, cities and even within the city. Just as an example, in Madrid (Spain), there must be one (un) loading space for each 500 m^2 of sales surface area, in Paris (France) the requirement is one loading space for each 250 m^2 (LT and BCI, 2002) and in Porto, the loading/unloading zones should be created inside the building "*with a dimension adequate to the function and type of commercial activity*", obligatory to a surface area larger than 2500 m^2 (art 62º, PDM do Porto, 2005).

The diversity of rules can be explained with the fact that different countries and cities have different needs and also different ways of replying to those needs. What seems to be a common fact is that the success of these measures strongly depends of an effective enforcement and of the location of the (un) loading zones. Suppliers want to park as close to the customers as possible and they will only use the designated areas under two conditions: first, if they are forced to do it (**enforcement**) and second, if the designated area fulfills their **requirements** in terms of price, layout and location.

Results from a practical survey carried out in Porto confirmed both of these facts and respective consequences. By one hand, there's not an effective enforcement and by the other suppliers usually need to open the back doors of the vans and the unloading zones layout is not adequate for their operation. The survey revealed that in a central area (Camões Street) with available unloading spaces for goods vehicles, 97% of the suppliers chose to park illegally (double lane, pavement, bus lane) instead of using the available and reserved zone (Melo, 2003).

These impressive values are only possible to accept and understand with the knowledge of the background in which they occur. In the particular example mentioned above, the explanation for these results relies mainly in cultural and enforcement issues. Suppliers park illegally to deliver goods because due to the lack of enforcement, it is not probable to have someone at the street to fine them. Moreover, in cases when there is in fact a police man or an inspector, the most common attitude would be of total flexibility with the supplier. The same permissive position is also taken by drivers, shopkeepers and pedestrians who are also flexible with suppliers' behavior. Such acceptance of transgressions, which is clearly more obvious in some cities than others, explains the remarkable values presented above.

Table 3.4 summarizes the (un) loading zones review.

Table 3.4. (Un) Loading zones review

Author	**Method/Location**	**Measured Indicators and Results**		**Main stakeholders Considered**
		Positive	**Negative**	
Melo (2003)	Quantitative survey Porto (Portugal)		% of suppliers illegally parked	Private stakeholders (suppliers)

3.3.3 Urban distribution centers

Along this work, it is adopted the definition of urban distribution centers (UDC) provided by Muñuzuri *et al.* (2005): "*a small freight transport center located inside the urban area. It is usually based on only one mode of transport (road transport), and is intended to improve load factors in delivery vehicles, since the city terminal can be accessed by larger trucks, and the goods are then transferred to smaller vans for their final delivery, which have to cover smaller distances.*" It is this focus on **distribution efficiency** and its **city orientation** that differentiates the UDC from other logistic terminals. For this reason, UDCs are sometimes also referred to as city terminals.

Urban distribution centers (UDC) can help to reduce traffic congestion and environmental problems. Inserting a physical 'break' in the logistic processes of goods distribution to urban areas by introducing an urban distribution centre introduces an extra intermediary (who makes the final delivery) but at the same time opens the potential for optimizing intra-city transport techniques independently from transport techniques outside the city limits (Binsbergen and Bovy, 2000).

Table 3.5 shows a more detailed reading about the advantages and disadvantages of consolidation.

Table 3.5. Advantages and disadvantages of consolidation

Source: Huschebeck and Allen (2005)

Advantages	Disadvantages
- environmental and social benefits (more efficient and less intrusive transport operations) - better planning and implementation of logistics operation - better inventory control, product availability and customer service - can facilitate a switch from push to pull logistics through better control and visibility of the supply chain - potential to link in with wider policy and regulatory initiatives - theoretical cost benefits from contracting out "last mile" - public relations benefits for participants - potential to allow better use of resources at delivery locations - specific transport advantages - opportunity for carrying out value-added activities	- potentially high set up costs (and sometimes high operating costs) - much urban freight is already consolidated at the intra-company level or by parcels carriers, so limited benefits (or even negative consequences) for trying to channel these flows through a consolidation centre. - difficult for a single centre to be able to handle the wide range of goods moving in and out of an urban area, for example due to different handling and storage requirements - most studies report an increase in delivery costs due to an additional stage in supply chain which imposes a cost (and often a time) penalty - a single consolidation centre for an urban area is unlikely to be attractive for many suppliers' flows due to the degree of diversion required from normal route (and may therefore negate transport savings for onward distribution) - lack of enforcement of regulations for vehicles not included in the consolidation scheme - organizational and contractual problems often limit effectiveness - potential to create monopolistic situations, thus eliminating competition and perhaps leading to legal issues - loss of the direct interface between suppliers and customers

Despite the positive results that are usually pointed out to UDC, it became clear that in some European cities, urban distribution centers are running and are sustainable while in others it doesn't seem to be feasible (Huschebeck, 2003; Browne *et al.,* 2005). Instead of reducing congestion, in some cases UDC can even generate more freight vehicle movements, depending of local conditions (LT Consultants and Buck Consultants International, 2002). One negative (theoretical) example is the one presented by Browne and Allen (1998), who modeled the effects of an UDC in the reduction of the negative impacts of London's road freight transport and compared with the situation in 1991. Results showed an increase on trips by 7%, on vehicle-kilometers by 15% and on fuel use by 9%.

Also van Duin (1997) evaluated UDC and concluded that urban distribution centers usually only handle goods which are not fresh, not dirty, not unpleasant to handle, not voluminous and not valuable. These logistics criteria cause a reduction of the potential market share, which is reflected in low supply and low demand. Another reason pointed out by the author for the modest market share using the city distribution center is the logistic structure. The possible logistic structures are direct delivery one-to-one, one-to-many, many-to-one deliveries and many-to-many deliveries. The first two structures create well-organized transports with a full truck load and thus stakeholders involved do not change their distribution structure to an UDC. The last two structures are the only candidate distribution structures to switch over to the city distribution concept.

One practical example of a (public) urban distribution centre successful implemented was carried out in Monaco. The terminal was owned and operated by the government, who contracted out the operation of freight distribution to a single carrier (a regional transport company). This sub-contractor was given a monopoly over the municipal depot and added to this was a partial monopoly on the delivery of goods. All trucks over a GVWR[11] of 8 tons were banned from the city of Monte Carlo. If they were to deliver goods to clients there, they had to go to the local public distribution centre and unload first. The municipal service then took the final distribution in charge, with specific vehicles. The costs of the service were shared between the municipality, which gave financial aid and free warehouse space to the carrier; by the carrier that provided driving and handling staff as well as the vehicles; and finally by the retailers who supposedly paid for the amount of goods they received through the service (Egger and Ruesch, 2002). This system revealed to be helpful in the reduction of the required number of trucks used for deliveries (Taniguchi and Heijden, 2000).

Table 3.6 summarizes the urban distribution centers review. Due to the lack of information on quantified impacts of unsuccessful UDC, only good examples of *practical* implementation were presented.

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[11] *Gross Vehicle Weight Rating: It is how much weight a vehicle is designed to carry. The GVWR includes the net weight of the vehicle, plus the weight of passengers, fuel, cargo and any additional accessories. The GVWR is a safety standard used to prevent overloading.*

Table 3.6. Urban Distribution Centers review

Author	**Method/Location**	**Measured Indicators and results**		**Main stakeholders Considered**
		Positive	**Negative**	
Van Duin (1997)	Theoretical Netherlands		Deliveries/day	Private stakeholders (suppliers)
Browne and Allen (1998)	Theoretical London (England)		Trips Vehicle kilometers Fuel use	Private stakeholders (suppliers)
Egger and Ruesch (2002)	Practical Monaco	Number of trucks/delivery		Public Stakeholders Private stakeholders
Browne *et al.* (2005)	Theoretical/Practical	Number of vehicle trips Number of vehicle kilometers Number of vehicles Travel time Goods delivered per delivery point Vehicle load factor Parking time and frequency Fuel consumed Vehicle emissions Operating costs		Public Stakeholders Private stakeholders

It must be noted that other criteria rather than the financial point of view should be considered. For instance, small and medium-sized companies cannot individually construct such integrated logistics terminals due to the huge investment required (Yamada, 2003). To overcome such obstacles, public stakeholders keep promoting UDC, even when financing analysis reveal they are not profitable. On that sense, (public) distribution centers can be seen as an initiative financed by public stakeholders, who try to improve mobility and sustainability in urban areas and simultaneously, to help private stakeholders to be more efficient. Following this line, private distribution centers are an initiative promoted by private stakeholders mainly in their own interest (and minimizing issues like sustainability).

3.3.4 Considerations and Remarks

The analysis of infrastructural and urban space management measures, summarized in Table 3.7, includes 3 initiatives: rail underground distribution systems, (un) loading spaces and urban distribution centers.

Table 3.7. Infrastructural and Urban Space Management Measures

Initiative	Measured Indicators and Results		Stakeholders	Synthesis
	Positive	Negative		
Rail Underground Distribution Systems	Travel speed; traffic congestion; labor force; NOx emissions; energy consumption, Income rate, Speed; Air Pollution; Operational Costs		PU, C, PR	1
(Un) loading spaces		% of suppliers illegally parked	PR	2
Urban Distribution Centers	Trips Vehicle kilometers Fuel use Deliveries/day Number of trucks/delivery Number of vehicles Travel time Goods delivered per delivery point Vehicle load factor Parking time and frequency Vehicle emissions Operating costs		PR	**X**

PU – Public Stakeholders including Administrators; C – Citizens
PR – Private Stakeholders including suppliers
1 – Limited implementation and operational conditions
2 – Success highly dependent on enforcement
X – To be evaluated on the case study in a complimentary way with other measures

The following considerations and remarks summarize what can be learnt from the previous description, highlight the determinant factors to be considered on the implementation of each initiative and support the selection process for chapter 6.

First, despite the positive theoretical benefits of **rail underground goods distribution**, this initiative still doesn't have practical experiments to confirm the expected results from theory. It is a *costly initiative* mainly supported by *public stakeholders*, whose success strongly depends of specific local requirements that are not easy to fulfill in European cities. The most demanding criteria are: the *previous existence* of an acceptable underground network and the *interest of private stakeholders* in being part of such a system. The interest of private stakeholders depends more in operational conditions rather than in eventual public funding. One important operational condition difficult to overcome is the fact the use of underground distribution systems is more restrictive in terms of delivery places, once it only stops in specific points. This means that these stops must be coincident with the main commercial areas and it is needed to have significant amounts of physical flows to be delivered by this system in order to guarantee its feasibility. In other words, ***underground distribution systems can be considered in over dense urban areas when there's an existent underground network acceptable by public and private stakeholders***. Due to its limited implementation and to the fact that the area of study (Porto) doesn't fulfill the previous conditions, this initiative will not be evaluated within the case study.

Second, despite the fact that the discussion in many cities is already how to manage the parking, once it is not possible to provide more **(un) loading spaces** or to better use the existing ones[12], in some others the issue is still about how to convince suppliers to park legally. The provision of (un) loading spaces is an initiative with proven benefits to mobility and urban sustainability, which is promoted by public stakeholders but whose success strongly depends of the local conditions of implementation. The critical issues are, as it was already mentioned, the *enforcement* and the *operational conditions* offered by those spaces. The two points could seem to be at the first sight only dependent on public stakeholders will to control their own regulations and to provide appropriate conditions for private stakeholders to follow their rules. However, there's

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[12] *In Lyon (France) it is being carried an experiment called RAPIDO that manages the short time parking with the aim of obtain more available spaces for delivery operations.*

much more to say about it. Cultural issues are also on the basis of suppliers (and police) behavior, which justifies the very high number of suppliers parking illegally (in countries like Portugal) even with available legal places.

With a common will, both from public and private stakeholders, (un) loading spaces should always be considered in urban areas with a relevant density of commercial activities. Ideally, it is also suggested a more specific regulation of unloading spaces based on the historical data of local distribution patterns, particularly in the Portuguese context. Instead of providing (un)loading zones merely based on the area of the commercial establishment, it should also be considered the type of commercial branch and the distribution pattern of the local.

The provision of (un) loading spaces will not be simulated and evaluated in chapter 6.

Lastly, the third initiative analyzed on the domain 3.3 was the implementation of **urban distribution centers**. Although the idea of consolidation centers sounds very appealing, particularly the target of increasing the efficiency of urban delivery by consolidating multi-company delivery, it has proved difficult to meet in the past.

Besides, despite one of the key reasons for considering the implementation of a consolidation centre is the potential to reduce transport impacts within the area of operation, there have been relatively few attempts to quantify the actual transport impacts. Several studies have claimed that vehicle trips and/or vehicle kilometers have been reduced by 30 to 80% for those flows that switch to using a consolidation centre. As a result of generally low uptake, though, the wider reductions in freight movements within the study areas seems to be 1% or less and some schemes report no measurable change in overall transport activity (Huschebeck and Allen, 2005).

These values are not impressive enough to announce urban distribution centers as a good practice to be implemented in a generalized way. Therefore, it is suggested to a) set up a study that would identify financial costs/benefits for private and public stakeholders; b) in case the results of the study support it, make UDC trials to analyze how they are funded, run and to measure the results and c) involve the interested parts in the planning process of a UDC, in case the previous steps lead to the conclusion it is appropriate and feasible to build the UDC.

This last step is determinant for the success of the initiative. Publicly-organized urban distribution centers do not have a good track record in terms of implementation and operation. For UDCs to be attractive to companies and to be effectively set-up, they should be led and operated by one or several key commercial stakeholders that have identified the potential advantages of being involved. The standard objection to UDCs is that they will lead to higher costs in the delivery operation. It is therefore important to discuss the wider implications of such schemes with the road transport business and retailers and to demonstrate that, by using such centers, costs in other parts of their operation could be reduced. Such reductions could be achieved through less time being spent on (expensive) town deliveries, shorter journey times and increased vehicle utilization, and the possibility of night-time deliveries (UDCs could be open when their customers are closed). Additionally, public funding needs to be made available to pay for the research work and pilot studies for any form of UDC that is not related to a major new property or commercial development. Without this funding such UDC research and trials are unlikely to proceed (Huschebeck and Allen, 2005).

Along the literature review, it was found that UDC do not present encouraging results by themselves, but when they are used in a complimentary way to other measures (like tax and pricing schemes) they can indeed be good practices. Therefore, the implementation of an UDC (in a complimentary way with other measures) was considered to be evaluated on the case study (Chapter 6).

3.4 Technological and operational measures

The domain technological and operational measures includes initiatives of operational management, like adopting systems to improve the efficiency of the distribution process or organizing the transport activity in a more effective way to reduce its impacts on other city functions. Measures included on domain 3.4 are mainly promoted by private stakeholders and are not easy to influence by public stakeholders. These initiatives are mainly adopted when market rules demand it or when suppliers consider to have benefits with its implementation:

- Intelligent transport systems
- Vehicle routing and scheduling
- Collaborative distribution systems
- Alternative Fuels

In spite of the limited influence of public stakeholders on these decisions, it was considered to refer and describe initiatives included on the cited domain in order to give a broader overview of the existent good practices on urban goods distribution.

There are also other best industry practices that try to promote efficiency and simultaneously to make a step in the direction of a more sustainable development, like the ‘Eco-Driving’ projects, in which companies give a salary bonus to the drivers who drive more efficiently (lower fuel consumption) and in which got reductions up to 20% by effective management of fuel consumption (IRU, 2004). However, once those practices do not involve public stakeholders (despite they bring advantage to all society), it were not analyzed in detail along this study.

3.4.1 Intelligent Transport Systems

Intelligent transport systems (ITS) is a broad term used to refer to many different applications on the transports field. ITS can be seen as one condition to integrate diverse variables in order to achieve a more efficient transport and it is based on three features: information, communication and integration. It involves the application of advanced information and communication-based technology in order to reduce the costs of transport. On the particular field of freight transport, the most common applications are on traffic management, fleet management, terminal management, traffic information, electronic access control, and dynamic and adaptive routing and planning (Abel and Ruesch, 2003b).

There are numerous potential benefits for freight operators when advanced information technology is implemented, namely, reduced manual data entry, increased transaction speed and accuracy, lower communication costs and simplified procedures (Thompson, 2003). Besides the referred advantages to the private sector in the planning and organization of operations, ITS can also be beneficial to manage and improve services provided by public stakeholders. Results from COST321 Urban Goods Transport indicate that the usage of ITS can lead to a reduction of vehicle mileage of 10% due to better loading capacity and to reductions in fuel consumption and pollutant emissions due to the improvement in the efficiency of transport. Additionally, in general ITS also lead to improvements in internal efficiency in terms of kilometers traveled, which reduce the environmental impacts and number of crashes (Jorna and van Drunen, 2000).

The benefits obtained by private and public stakeholders from ITS derive from different purposes. Generally, it can be said that ITS mainly promoted from the public side are applied to improve the traffic situation within the cities, e.g. by access control. Privately operated ITS management systems are mainly applied to optimize logistics and distribution processes, hence contributing to a cost optimization of the supply chain (Huschebeck, 2004). But independently of who the promoter is, the success of ITS applications implemented by public stakeholders is influenced by how well it covers operators' interests (Abel and Ruesch, 2003b).

Despite ITS represent a powerful tool on the improvement of the efficiency of transports, it will not be analyzed in detail on this thesis. First, it is not easy to make a detailed differentiation using ITS in urban freight transport, because most of the applications are covering the full transport chain which normally oversteps the border of city areas (Abel and Ruesch, 2003b) and the geographical scope of this work is mainly the urban area. Second, it is an initiative that can be considered as a support to the implementation of an experiment. Along this work, it is aimed to analyze the effects of initiatives such as road pricing rather than accessory measures chosen by stakeholders to put them into practice. However, once it is an important operational tool to support the initiative, it was considered adequate to make a short reference to ITS.

3.4.2 Vehicle Routing and Scheduling

Vehicle routing and scheduling (VRS) is an example of initiative dependent of the application of ITS, also worth it to be analyzed. It is a process that given a fleet of vehicles and a list of customers, their locations, the size of loads and the restrictions associated with the transport operations, designs routes that minimize the total costs of delivery (Eilon, 1995). The order in which customers are visited is determinant for the transport costs, the level of service and the truck trips patterns.

Through mathematical simulation, Taniguchi and Heijden (2000) estimated the effects of advanced routing and scheduling systems penetration at 0, 50 and 100%. Figure 3.1 illustrates those effects.

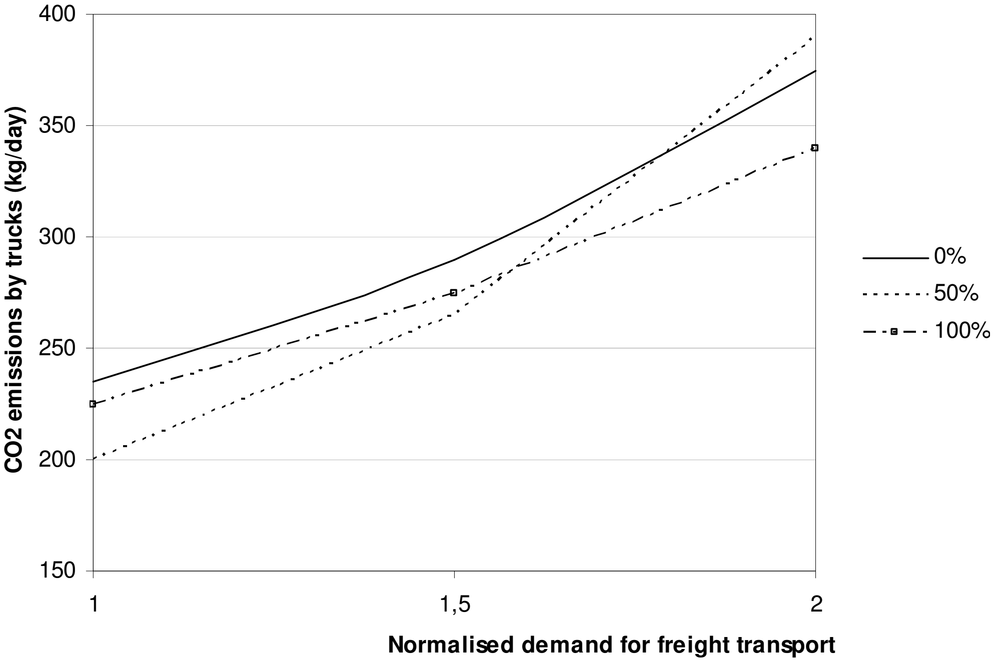

Figure 3.1. Effects of penetration rate of advanced routing and scheduling system on change in CO_2 emissions with increasing demand for freight transport

Source: Taniguchi and Heijden (2000)

Results show that introducing advanced routing and scheduling systems helps to reduce CO_2 emissions when the demand for freight transport increases. The normalized CO_2 emissions would be reduced by 8.3% when the penetration rate rose from 0% to 100%, when the demand level would double.

Practical experiments also confirm the benefits of vehicle routing but there are few examples of quantified impacts.

A practical experiment of vehicle routing was carried out in UK by Transco company. Transco National Logistics' distribution was optimized using a pre-determined delivery schedules. After the implementation of optimized vehicle routing, the annual environmental benefits (based on current trends) were of 38640 kilometers saved, 8000 liters of fuel not consumed, 360 journeys avoided, 21 tons of carbon dioxide saved, reduction of other polluting emissions and financial savings of 47000 Euros per year (TransportEnergy BestPractice, 2003).

Another successful experience of vehicle routing and scheduling presented by a Japanese milk-producing company using satellite-based communication also presented positive results. The detailed historical record of the pickup/delivery trucks operations was stored, including times of starting/arriving times at the storehouse, the waiting times, traveling speeds and routes traveled. The company analyzed these statistics and changed their routes and schedules in order to increase the efficiency of their vehicle fleet. After introducing a satellite-based information system for 1 year, the company reduced the number of pickup/delivery trucks by 13.5% (from 37 to 32 vehicles) and increased their average load factor by 10% (from 60 to 70%), (Taniguchi and Heijden, 2000). These are good examples of good practice using ITS that are beneficial both for private company in terms of cost reduction and society for alleviating congestion and improving the environment.

Table 3.8 summarizes the routing and scheduling review.

Table 3.8. Routing and Scheduling review

Author	**Method/Location**	**Measured Indicators and Results**		**Main stakeholders Considered**
		Positive	**Negative**	
Taniguchi and Heijden (2000)	Mathematical simulation	CO_2 emissions		Private (suppliers)
Taniguchi and Heijden (2000)	Milk producing company (Japan)	Number of pickup/delivery trucks, average load factors		Private (suppliers)
TransportEnergyBestPractices (2003)	TRANSCO company (UK)	Trip length, fuel consumption, journeys avoided, financial savings, CO_2 emissions		Private (suppliers)

3.4.3 Collaborative systems

The basic idea of collaborative systems is that a group of outlet owners, shippers and transport companies (suppliers) cooperate and organize their own goods distribution, with the aim of ensuring a fast and effective delivery. These systems can be promoted by shops belonging to the same business segment and by shops that sell products with similar physical and marketing characteristics, located within close proximity of each other's (Melo and Costa, 2007). Figure 3.2 illustrates the concept of collaborative systems.

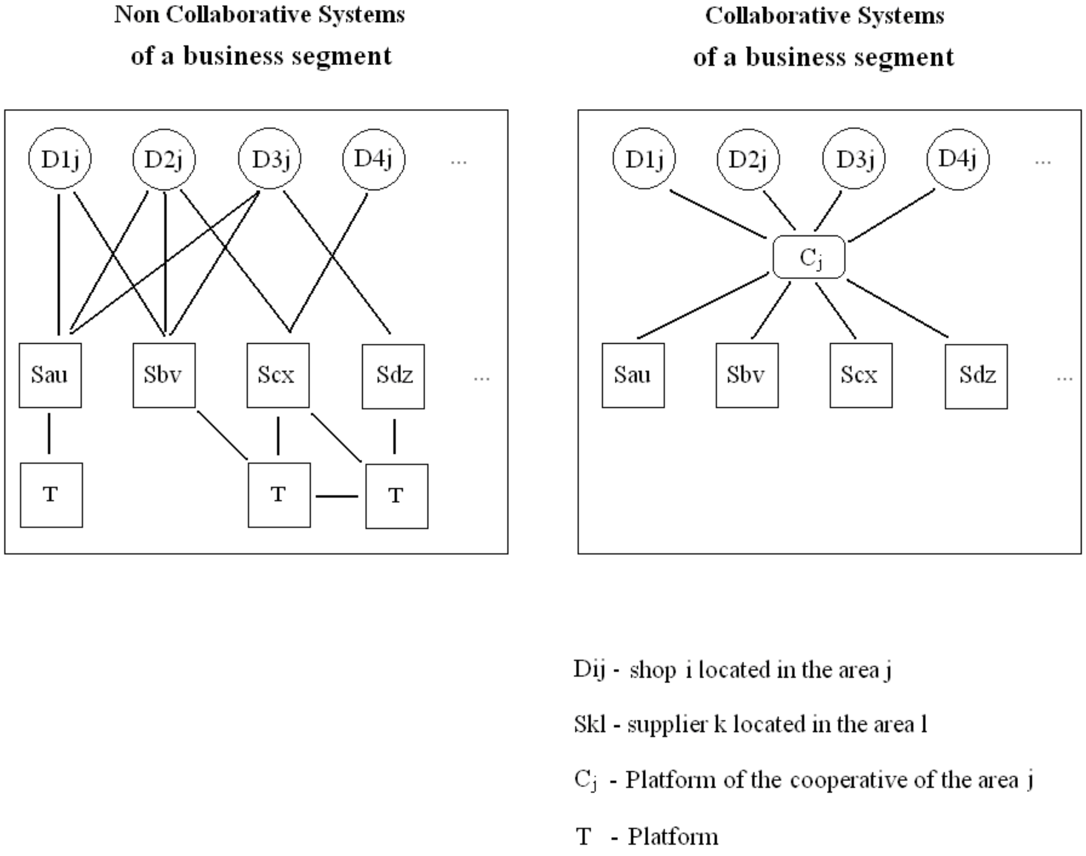

Figure 3.2. Scheme of Collaborative and Non Collaborative Systems

Source: Melo and Costa (2007)

Collaborative systems can be implemented within a certain area, where similar types of goods with similar packaging are delivered, through a specific distribution channel. The implementation of collaborative systems involves setting up partnerships between the receivers, since the final step of urban distribution is the delivery process. Through the implementation of partnerships between receivers, it is possible to establish local or regional cooperatives, which receive all the orders from their associates and ensure their fast and effective supply. Cooperatives are responsible for the transport and distribution of products and sometimes also for the negotiation with suppliers. The cooperative ensures the distribution of certain products to the respective area and, thus, its operation is similar to a local or regional depot serving all destinations in a specific area. The main difference is that each cooperative manages physical and informational flows of its own business segment located on the respective local or regional area. By guarantying the maximization of load factors of its vehicles, the cooperative generates a smaller number of trips to urban areas and thus causes fewer impacts than a traditional distribution where all suppliers go to the city whenever they are called (Melo, 2003). The existence of a cooperative is not a restriction to receivers as regards the ordering process, since they can also buy secondary products (which do not represent the core business of the shop) directly from suppliers. Services provided by suppliers under collaborative systems are characterized by a low contact service and thus have a higher level of production efficiency (Chase, 1978). Once the physical presence of the supplier increases the variation in the service delivery process (Verma, 2001), collaborative systems having a low contact service, also have a higher level of production efficiency. These systems imply a high degree of customization, guarantying that each receiver (shopkeeper) gets a similar service adapted to his specific needs. Thus, each receiver is known to the organization and all transactions are individually recorded and attributed. With a formal relationship, it is easier to predict the receivers' demands in terms of transport and supply services and consequently, to improve the receivers' satisfaction and increase the quality of service.

Collaborative systems can, under specific conditions of implementation, be successful in reducing the impacts of urban goods distribution on traffic congestion and environment. A successful implementation of collaborative systems requires as base conditions: a) a joint effort from public and private stakeholders, b) the existence of specific local characteristics like the location of stores with similar products within the same area and c) the existence of a depot to manage the flows of the respective cooperative. These requirements are not easy to be achieved (particularly without expensive costs) and this can be one of the main reasons why collaborative systems do not have a wider implementation.

In Porto, these requirements seem to be fulfilled and a practical experiment is now being carried out by the 'Associação dos Comerciantes do Porto' (ACP). In 2007, ACP had 3500 associated commercial establishments grouped in 12 activity branches located in the city. ACP is an association that represents the interests of its associates and provides them some important support to its functioning. This organization is promoting a practical experiment, enabling the necessary vehicles to make deliveries and promoting an agreement with some hotels located in the inner centre to organize their distribution system. Under the coordination of ACP, 12 hotels established an agreement with the main traditional street market (Mercado do Bolhão) to daily receive fresh products (bread, dairy products, vegetables and fruits). The experiment is still ongoing and for now it has a positive feedback from the involved partners.

The second example is from Sweden. In Upsala, the 4th biggest city in Sweden, during a trial experiment, 97 transport companies delivered goods to a shopping area under a collaborative system. About 43% of the delivered goods were food and about 69% were delivered before 11 a.m. The trial demonstration was carried out for a period of one year (until May 2001) and resulted in a reduction by 40% of the number of delivery trips and in general, the retailers were satisfied (Gebresenbet and Ljungberg, 2002).

Portuguese pharmacies collaborate and organize their own goods distribution systems cooperating through regional cooperatives. The respective regional cooperative assures the delivery of any medicine, after the order have been made by the pharmacy. Once the system is strongly supported by the use of information systems, there's a low contact service and thus, the delivery operation is very effective.

Table 3.9 summarizes the collaborative systems review.

Table 3.9. Collaborative systems review

Author	**Method/Location**	**Measured Indicators and Results**		**Main stakeholders Considered**
		Positive	**Negative**	
Gebresenbet and Ljungberg (2002).	Practical Upsala (Sweden)	Number of deliveries Satisfaction of retailers		Public Stakeholders (citizens) Private Stakeholders (suppliers, retailers)

3.4.4 Alternative fuels

Other initiatives from technological and operational measures could have been selected, but it was considered (based on research) the alternative fuels as one of the most promising initiatives on this domain.

Alternative fuels are a good example of new technologies related with vehicles, which can be helpful in the reduction of the dependence on petroleum-derived fossil fuels used for transport. In the particular case of goods transport, the use of alternative fuels, like biofuel, compressed natural gas CNG, fuel cells, can bring relevant environmental benefits, but it is still needed to develop these fuels fully to guarantee that they are well accepted by consumers (Martin *et al.*, 1995). The lack of use of alternatives is partly caused by two different forces: a) without vehicles able to drive on alternative fuels it is too expensive to create the necessary fuel infrastructure and b) the fuel infrastructure is regarded as one important pre-requisite to enhance investment in this technology (Huschebeck, 2002).

A good example of alternative fuel is the **Compressed Natural Gas** (CNG), which can be an environmentally "clean" alternative to gasoline, diesel and propane. Its use has been recently increasing, promoted by the high fossil-fuel prices and by the increasing environmental concerns. The broader use of CNG is now extended to the light-duty passenger vehicles and pickup trucks, medium-duty delivery trucks and school buses. According to an IVECO survey, 29% of the Northern Europe transport companies use low emission vehicles (CNG, LPG or electric propulsion) within their fleet and 30% of the European companies consider trying low emission vehicles (Huschebeck, 2002). This proliferation is not, however, a sign of universal acceptance by society yet. There are still issues of appearance[13] and operation, that must be improved. However, it is already a good start.

A practical experiment of CNG was made in UK by Transco's National Logistics, a company that stores and delivers engineering materials and meters for National Grid Transco's gas supply business. The company delivers every year about 177 million of Euros worth of goods to 14 warehouses and over 200 customer locations in UK. In order to reduce the impact of Transco's distribution operation, the company introduced CNG vehicles. Monitoring the performance of the CNG vehicles revealed that they are 10% per mile cheaper (fuel costs) than their diesel counterparts. The experiment that Transco made with six vehicles represents a fuel cost saving of about 37000 Euros per year. In terms of annual environmental benefits, 42 tons of carbon dioxide emissions can be avoided, there's a reduction of 98% in particulate emissions and of 86% in nitrogen oxide emissions (TransportEnergy BestPractice, 2003).

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[13] *Since it is a compressed gas, rather than a liquid like gasoline, CNG takes up more space for each gallon of gas equivalent, which makes it difficult to design smaller vehicles that look and operate like people and suppliers are used to.*

Another example of the use of alternative fuel with increasing share of market is the hybrid electric vehicles.

The use of **(hybrid) electric** vehicles already has some examples in Europe, despite its advantages in terms of environment in the city are not universally[14] accepted yet. Hybrid vehicles are equipped with an internal combustion engine and an electric motor, enabling them to drive in the electric mode for short distances, particularly in city centers, and use a higher payload in long ones.

A project funded by the European Commission, ELCIDIS, tested the use of (hybrid) electric vehicles in 6 European cities, with the purpose to check the viability of (hybrid) electric vehicles for urban distribution, preferably in combination with the use of an UDC. Considering that more than 80% of current road goods transport in European conurbations are on distances bellow 80km (Abel and Ruesch, 2003b), the restriction of usage of hybrid vehicles for urban or urban-regional transport is not determinant. The project ELCIDIS (Electric City Delivery System) succeeded in verifying the merits of these vehicles and "*provided indisputable proof that there are no predominately objections to the use of hybrid and electric vehicles in urban distribution, neither from company managers nor from drivers, nor from local authorities*" (ELCIDIS, 2002).

In La Rochelle (France), a city of 135000 inhabitants, it was set up an urban distribution platform near the city centre, from which (hybrid) electric powered commercial vehicles delivered and collected parcels. After one year and a half of operation, the results obtained with this ELCIDIS experiment were highly encouraging. The time saved per day and per lorry was estimated at 3 hours, working conditions of drivers had improved, there was a substantial reduction in noise and a noticeable decrease in delivery-related traffic congestion (ELCIDIS, 2002).

In Stavanger (Norway), a city of 100000 inhabitants, it were introduced seven (hybrid) electric vehicles for urban distribution. It were evaluated the impacts of such solution and results were quite impressive: running costs for vehicles with combustion engines are five times more costly than electric powered vehicles. This ELCIDIS' experiment revealed that the savings in fuel costs alone would pay for the extra initial vehicle cost in slightly more than two years or four years depending on vehicle type. If on these

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[14] *The method of producing electricity has an effect on the total environmental impacts of electric vehicles (LT and BCI, 2002).*

calculations it would also be considered the maintenance costs, the returning would happen in 1,5 years to 3 years.

The third example of alternative fuel presented on this work is the use of **electric vehicles**. An electric vehicle, or EV, is a vehicle with one or more electric motors for propulsion. Electric motors are mechanically very simple, and release almost no air pollutants at the place where they are operated. Electric motors often achieve 90% energy conversion efficiency over the full range of speeds and power output and can be accurately controlled. Typically, electric vehicles have proven already to have less vibration and noise pollution than a vehicle powered by an internal combustion engine, whether it is at rest or in motion. For these reasons and for the experiments which have been carried out worldwide, the use of electric vehicles (as an alternative fuel) is considered a good practice for goods distribution.

Taniguchi *et al.* (2003a) described a practical experiment in Osaka City (West of Japan). The experiment relates an organization that provides 28 electric vans (EV) at 8 public parking places with the full charge of electricity to be used cooperatively by 79 voluntary companies and public corporations that belong to various business areas. The users could return electric vans to any of these parking places after using for business. About 73% of users recognized that the electric vans had better or same capability as conventional vehicles (Taniguchi *et al.*, 2003a).

Some practical experiments are also already been put into practice. The city of Paris is currently considering changing its access and parking rules for transport operators, promoting clean delivery vehicles instead of small delivery vehicles. Euro III, electric and Compressed Natural Gas (CNG) vehicles would be offered larger delivery hours than the other lorries and very old lorries are intended to be banned from the city streets (Baybars and Dablanc, 2004).

In London, to specified vehicles which run on cleaner fuels, there is 100% discount given to access to the Central London Congestion Area in order to reduce pollution and improve air quality. The eligible vehicles are powered by liquefied petroleum gas (LPG, CNG, electric and hybrid, biofuels and fuel cells (Baybars and Dablanc, 2004).

Table 3.10 summarizes the alternative fuels review.

Table 3.10. Alternative fuels review

Author	Method/Location	Measured Indicators and Results		Main stakeholders Considered
		Positive	Negative	
ELCIDIS (2002)	Practical Europe (several cities)	Time saved per day Working conditions of drivers Noise Congestion		Private stakeholders
Taniguchi *et al.* (2003 a)	Practical Osaka city	Capability		Private stakeholders Users of the system (suppliers)
Transport Energy Best Practice (2003)	Practical UK	Fuel costs CO2 emissions Particulate emissions NOx emissions		Private stakeholders Public stakeholders (citizens, society)

3.4.5 Considerations and Remarks

The analysis of technological and operational measures, summarized in Table 3.11, includes three initiatives: vehicle routing and scheduling, collaborative distribution systems and alternative fuels.

Table 3.11. Operational and Technological Measures

Initiative	Measured Indicators and Results		Stakeholders	Synthesis
	Positive	Negative		
Vehicle routing and scheduling	CO_2 emissions Trip length, fuel consumption, journeys avoided, financial savings, Number of pickup/delivery trucks, average load factors		PR	1
Gebresenbet and Ljungberg (2002).	Number of deliveries Satisfaction of retailers		PR, PU	**X**
Alternative fuels	Fuel costs, CO2 emissions, Particulate emissions, NOx emissions, Time saved per day, Working conditions of drivers, Noise, Congestion, Capability		PU, C, PR	2

PU – Public Stakeholders including Administrators; C – Citizens
PR – Private Stakeholders including suppliers
1 – Implementation dependent on private stakeholders will
2 – Implementation highly dependent on public incentives
X – To be evaluated on the case study

The following considerations and remarks summarize what can be learnt from the previous description, highlight the determinant factors to be considered on the implementation of each initiative and support the selection process for chapter 6.

First, **vehicle routing and scheduling** is an initiative with proven benefits, particularly for private stakeholders (suppliers). However, due to the intrinsic characteristics of the measure, vehicle routing and scheduling will not be evaluated on the case study.

Second, **collaborative systems** can, under specific conditions of implementation, be successful in reducing the impacts of urban goods distribution on traffic congestion and environment. A successful implementation of collaborative systems requires as base conditions: a) a joint effort from public and private stakeholders, b) the existence of specific local characteristics like the location of stores with similar products within the same area and c) the existence of a depot to manage the flows of the respective cooperative. These requirements are not easy to be achieved (particularly without expensive costs) and this can be one of the main reasons why collaborative systems do not have a wider implementation.

Third, it seems to be clear that the obstacles of **alternative fuels** remain on the following: **The technology is now available to do whatever we want in the supply chain…the problem is that either it is not mature enough to be used or we are not mature enough to use it.** And this is the key issue here. Technical solutions exist, but there is potentially a limit to what technology can do. For sure, technology by itself cannot first, assure its marketability and second, force consumers to accept it. Alternative fuels in urban goods distribution are not utopian, but some substantial barriers have to be taken before they can be applied generally. One of the barriers is the vehicles investment costs, which are higher than the internal combustion engines vehicles. Authorities must introduce beneficial incentives to promote clean vehicles utilization. If transport companies receive advantages in exchange for the use of these vehicles, their support and involvement should be granted. Due to the lack of adapted data, the impact of alternative fuels will also not be evaluated on the case study.

Lastly, a short general note. The diversity and scope of initiatives on the technological and operational domain promoted by private stakeholders goes much further than the ones described on this inventory. But considering the scope and objectives of the thesis, it were valued the ones which implementation strongly involve both private and public stakeholders.

3.5 Legislative and organizational measures

This domain includes initiatives that try to influence demand through the establishment of rules, restrictions, regulations and incentives. Measures included on domain 3.5 – Legislative and organizational measures are mainly promoted by public stakeholders considering private stakeholders needs and public good:

- Pricing policies
    - Road pricing
    - Fuel taxes
- Regulation of access
    - Vehicle characteristics
    - Weight/size regulations
    - Control of load factors
    - Time windows
- Reserved-capacity strategies
    - Dedicated exclusive lanes
    - Shared usage of a bus lane
- Licenses
- Cooperative systems

Along chapter 3, there will be more good practices analyzed on the domain legislative and organizational measures than in the other domains (already described). This dominance mainly happens due to the following points:

a) first, public stakeholders can easily implement initiatives and most of them without significant costs. For instance, the establishment of a regulation is usually done without relevant (public) costs with the purpose of the public good, and private stakeholders are expected to adapt themselves to the regulation. On this sense, it is easier that an initiative from domain 3.5 – Legislative and organizational measures is implemented and consequently, it might be a fruitful domain to be included in any strategy to improve urban goods distribution impacts on urban environment.

b) second, domain 3.4 – Technological and operational measures is strongly dependent on private stakeholders, whose decision relies on market rules. Even if private stakeholders put in practice many initiatives on the respective domain, they are not expected to publish and spread the positive results of their measures. Therefore, there is not so much information on good practices from domain 3.4 (Technological and operational measures) as from domains 3.3 (Infrastructural and urban space management measures) or 3.5 (Legislative and organizational measures) to be described as good practices.

3.5.1 Pricing Policies

Despite being aware of the externalities issue associated with freight traffic (particularly on the road mode) public authorities do not have a large variety of instruments to directly intervene in goods transport. The most effective instruments would be within the domain of the logistical management of production and distribution but decisions in that field are made by shippers and transport companies. Public authorities may only indirectly affect such decisions, predominantly through infrastructure and fiscal policies. Towards these two options, fiscal policies like regulation of freight transport through taxation are becoming more common (Runhaar and Heijden, 2005). Despite an increasing acceptance, there are still some issues to be solved and which resolution is essential for the success of pricing policies. Issues like the methods used to quantify the costs, the costs measured, the followed approach, the use of the fees charged, and the choice of strategies to be financed are some examples of problematic points of acceptance of such pricing policies. These problems can, however, be minimized through the quantification in advance of the overall results that are expected to be achieved with the initiative. In some cases this quantification can reveal that the expected results are not significant enough to justify the implementation of the initiative. That was what happened when Runhaar and Heijden (2005) tried to evaluate (through in-depth-interviews to logistic managers) the impacts of intervening on direct transport costs. A 10-year time span was examined and the results of the study revealed that taxation would have a modest impact on production and distribution. Increases in generalized transport costs would notably be compensated within the domain of transport operations and by adapting the scheduling of product flows.

An in depth analysis of pricing policies should consider the whole system of pricing measures applied to transport users of all modes in a certain area including fuel and vehicle taxes, public transport subsidies, transport related income tax deductions, road pricing, parking fees, etc. (Egger and Ruesch, 2003). However, this would lead to an analysis of the whole fiscal system which cannot be done in the context of the thesis. Therefore, the thesis only deals with road pricing and fuel taxes, being fully aware that they represent just one element of an entire pricing system.

Road Pricing

Road pricing is an example of a transport pricing policy, which aims to influence the demand by manipulating transport costs. Road pricing is a (direct) charging fee for the use of road, based on the "user pays principle" and that tries to charge external costs, influence demand or to attain a fair charge of infrastructure cost (Wild, 2002). When compared with regulatory and prohibitive measures, road pricing has the advantage of being more flexible. Instead of only allowing/prohibiting, it assures the payment for the ones who benefit is higher than the charged price.

A simulation of the impacts of road pricing through the use of a meta-model (EXPEDITE), concluded that with an increase of lorry costs, it would occur a small reduction of external costs (emissions, noise, road damage) and in time costs and an increase on driving costs and on the total costs (Jong *et al.*, 2004). Those results are illustrated in Table 3.12.

Table 3.12. Main evaluation results for the policies for freight transport in Europe (2020 Reference Scenario)

Source: adapted from Jong et al. (2004)

Policy	Scenario	Total (MECU95)	Driving (MECU95)	Time (MECU95)	External (MECU95)
Congestion and road pricing	1. Variable lorry costs +25%	11.6	17.7	-0.8	-0.9
	2. Variable lorry costs +40%	18.4	28.0	-1.3	-1.4
Fuel price increase	1. Lorry fuel cost +10%	2.8	5.1	-1.8	-2.5
	2. Lorry fuel cost +25%	6.1	11.4	-4.5	-6.2

The study also showed that road pricing seems to have a high effectiveness on modal shift from road to other modes, represents a big cost increase for user, requires low investment and implies government revenues (Table 3.13).

Table 3.13. Overall Assessment of the policies for freight transport

Source: adapted from Jong et al. (2004)

	Effectiveness (modal shift from road to other modes)	**Change in internal and external transport cost**	**Required investment and operation and maintenance cost**
Congestion and road pricing	High	Big user cost increase	Low investment and government revenues
Fuel price increase	High	Big user cost increase	Low investment and government revenues

Other theoretical study analyzed the effects of the implementation of a road pricing system to the first ring of Porto Metropolitan Area (Pimentel *et al.*, 2008). It was modeled a single cordon fare with a fee of 2.5 Euros for private cars and of 3.5 Euros for heavy duty vehicles. Figure 3.3 illustrates the impacts of road pricing for private transport, public transport and freight transport in Porto. Results showed improvements both in environmental and mobility terms. CO_2 emissions and fuel consumption would be reduced by 8% and travel times and delay times would decrease more than 14%. Other pollutant emissions would also have reductions for all the traffic types inside the delimited road pricing area (CO: 8%, PM: 7%, VOC's: 9%).

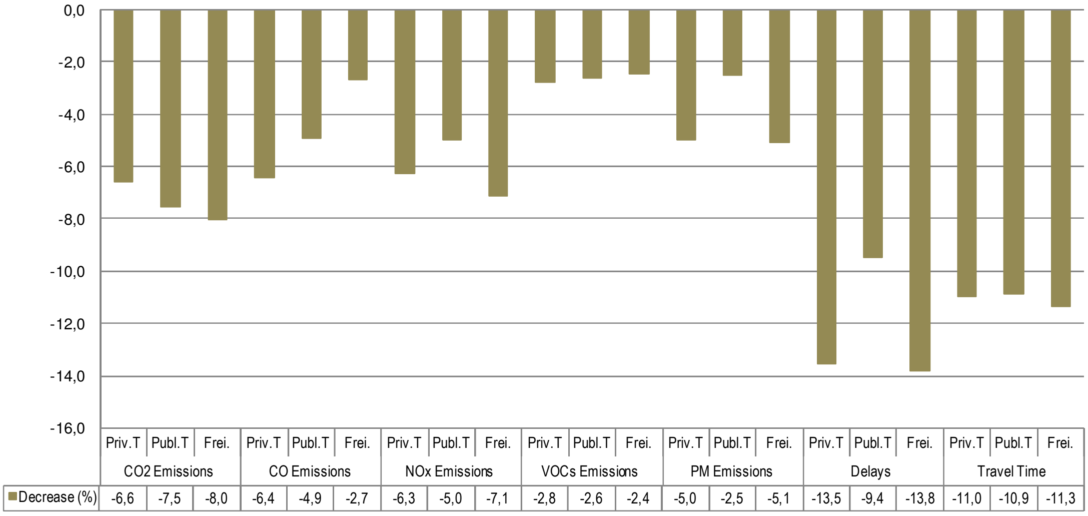

Figure 3.3. Effects of the implementation of a road pricing system in Porto

Source: Pimentel et al. (2008)

Practical experiences of road pricing seem to confirm the theoretical results, although the following examples do not present a quantification of the impacts for *freight transport* in particular. In London, it was implemented a “central London congestion charging scheme” in February 2003, with a daily fee of 5£ (8 EUR) for each vehicle driving within the central charging area in weekdays. Two years later, measured reductions in congestion within the charging zone have remained at an average of 30% since the introduction of the scheme. It was achieved a reduction in traffic volumes of 18% compared with the pre-charging situation (in case of vans and lorries the reduction was of 13%) and estimated reductions of 12% in emissions of NOx and PM10 and of 19% of CO_2 from road traffic within the charging zone. Observed excess delays during charging hours remain typically between 1.4 and 1.8 minutes per kilometer (average of 1.6 minutes per kilometer), against the pre-charging reference value of 2.3 minutes per kilometer (Egger and Ruesch, 2002; TfL, 2005). Money collected on this scheme has been spent largely on improved bus services within London.

Singapore (4425720 inhabitants over an area of 693 km²) set up a charging area in 1998: the ERP (Electronic Road Pricing) system. The charging area is divided into central business districts, where scheme applies from 7.30am to 7.00pm, and expressways/outer ring roads, where scheme applies from 7.30am to 9.30am. It applies different charges for different roads at different times, which are automatically deducted from CashCard as vehicle passes under gantries (TfL, 2005). The benefits of this scheme was an immediate reduction of 24700 cars during peak and rise of traffic speed by 22%, a total reduction of traffic in zone during charging period by 13% from 270000 to 235100, a reduction of the number of solo drivers and a shift of vehicle trips from peak to non-peak periods.

In Rome (Italy) it was implemented the Limited Traffic Zone (LTZ), which covers about 5 Km^2 and restricts the access to the historical centre (cordon pricing). The system started in August 2001 and had aimed a **reduction of congestion and modal shift from private towards public transport.** The access to the LTZ was restricted on weekdays from 6:30-18:00 and on Saturdays from 14:00-18:00. Goods vehicles could get an annual access permit, paying the equivalent of a 12 month public transport pass (340 EUR). Results showed a decrease by 15% on the total flow of incoming traffic (Egger and Ruesch, 2002).

Fuel Taxes

Pricing transport's externalities is an option to achieve an efficient use of resources through economic instruments. As many environmental externalities are in some way or other related to fuel use, **fuel taxes** are often considered to be an attractive economic instrument with which externalities can be internalized. The principle is that as fuel becomes more expensive, drivers will attempt to reduce energy consumption per tone-km transported using larger trucks, fuller trucks (reduction of empties), changing drivers' behavior and using more fuel-efficient trucks.

Like on the previous example with road pricing there is no consensual opinion about the use of fuel taxes on the overall traffic. It seems to exist, however, some consensus about the reduced impact of these measures on urban goods distribution. According to Koopman (1995) fuel taxes "have practically no effect as they only reduce *overall* mobility to a certain extent, while what is needed is a reduction at *certain places and points* in time". In freight transport they are not likely to lead to a significant substitution in the direction of other modes and will, in the short run, have only very modest effects on transport demand. In the longer run, freight fuel consumption might be reduced further, on one side, by more fuel efficient trucks coming on the market, and on the other side, by somewhat reduced transport demand, following adjustments in production, inventory and transport patterns (Koopman, 1995).

Results from a theoretical study seem to confirm this statement. Jong *et al.* (2004) simulated the impacts of a fuel price increase policy and concluded that with a lorry fuel cost increase, it would occur a minor decrease in external costs and time costs and an increase on driving times (Table 3.12). The study also showed that fuel price policies seem to have a high effectiveness on modal shift from road to other modes, represents a big cost increase for user, requires low investment and implies government revenues (Table 3.13).

Table 3.14 summarizes the pricing policies review described on the thesis.

Table 3.14. Pricing policies review

Author	**Method/Location**	**Measured Indicators and Results**		**Main stakeholders Considered**
		Positive	**Negative**	
Jong *et al.* (2004)	Simulation Europe	External costs Driving costs Time costs		Public and Private Stakeholders
TfL (2005)	Practical London / Singapore	Congestion Traffic volume NOx, PM and CO2 emissions Delays		Public and Private Stakeholders
Runhaar and Heijden (2005)	In-depth-Interviews Netherlands		Transport costs	Private Stakeholders
Pimentel *et al.* (2008)	Simulation Porto Metropolitan Area	CO2 emissions Fuel consumption Travel times Delay times CO,PM,VOC's emissions		Private transport, Public transport and Freight transport

3.5.2 Regulation of Access

Currently, one very common strategy to manage, or at least to influence, goods traffic in cities is to set different kind of regulations on access of goods vehicles (especially to city centers, pedestrian street areas and old towns). The purpose of regulations is to reduce negative effects in the city area caused by the interaction of goods vehicles with the inhabitants in the city and others users of the infrastructure (Ruesch and Glücker, 2001). So, regulations of access manage to constrain goods traffic to areas or periods less sensitive to its impacts. These regulations, which are widespread in Europe, usually try to constrain goods traffic based on:

- Vehicle characteristics (particularly to vehicle emissions, weights and sizes);
- Delivery time windows;
- Control of load factor;
- Access control and enforcement control (e.g. video surveillance).

The regulations vary among different municipalities and are usually a combination of the above-mentioned categories. An example of the variability of access regulations is shown in Table 3.15.

Table 3.15. Example of variability of access regulations in Netherlands

Source: OECD Working Group on Urban Freight Transport (2003)

Vehicle Classes	Vehicle Characteritics	City access regulation
1	Weight: 3,5-7 tonnes lenght: max 7 meters Wheelbase: <4,5 meters Width: max 2,3 meters Height: max 3,2 meters Environment: Euro II, LPG, electric, gas, etc Loading requirements: none	Always, pedestrain areas have time frame restrictions – preferably between 6:00 a.m.-12.00 a.m.
2	Weight: 7,5-18 tonnes lenght: max 10 meters Wheelbase: <5,5 meters Width: max 2,55/2,6 meters Height: max 3,6 meters Environment: Euro II or more, LPG, electric, gas, etc Loading requirements: >80%	Often, but pedestrian areas have time frame restrictions – preferably between 6:00 a.m. – 12 a.m.
3	Weight: 18-40 tonnes Types: various lenght: 11-18,75 meters Wheelbase: various Environment: Euro II or more, LPG, electric, gas, etc Loading requirements: >80%	Frequently, but only with special permission for the pedestrian areas and inner cities
4	Weight: 40 tonnes Types: various Environment: Euro II or more Loading requirements: none	Sometimes, but only with special permission for the pedestrian areas and the inner cities

Experience shows that the lack of enforcement can make a policy less effective, which has lead to the development of several tools in the last years. Examples are the use of electronic identification, automatic (video-) cameras, and roadblocks (such as rising pyramids or rising steps), (Visser *et al.*, 1999).

Regulation of Access according with vehicle emissions

The regulation of access according with vehicle's characteristics may be dependent on length, capacity, age, emissions. The vehicles meeting defined criteria are granted either exclusive access to the restricted area or wider time windows.

One example of regulation of access based on vehicle's characteristics is the establishment of Low Emission Zones (LEZ). Browne *et al.* (2004b) cite a practical experiment of the implementation of LEZ based on weight and load factor regulations, which were carried out in the central area of Stockholm (Sweden) in 1996. The access to the city centre was forbidden to lorries heavier than 3.5 ton from 10 p.m. to 6 a.m., to vehicles longer than 12 meters, to motor traffic (with exception to taxis) from 11 a.m. to 6 a.m. and to heavy diesel powered vehicles older than 8 years. The measure led to a reduction of emissions: particles: 15 to 20%, hydrocarbons, 5 to 10% and NOx: 1 to 8%, (Ruesch and Glücker, 2001).

London also implemented the LEZ (low emission zones) since February 2008 to improve air quality in London. Road transport was the biggest source of Particulate Matter (PM_{10}) and oxides of Nitrogen (NO_X) of the city and LEZ was an effective way to achieve reductions of the most harmful generated emissions.

Regulation of the access based on vehicle weight/size regulations

The most usual regulation of access in Europe is to ban lorries above a certain dimension/weight from operating within the city, which has enhanced the use (and number) of small delivery vehicles. Existing regulations on truck size and weight within city centers are currently reviewed for making them simpler and closer to the professional needs of carriers and suppliers (Huschebeck, 2001). As other access regulations, the ones based on vehicle weight can vary within the same city as from city to city and from country to country.

The weight restrictions, as most of the regulations, can lead to benefits in terms of urban space management (public interest) but can also lead to some changes on private companies, that should be taken into account when considering the implementation of this kind of initiative. As a main negative change, regulation based on weight can encourage the use of light goods vehicles (Browne *et al.*, 2004a). With the increase in operating restrictions on HGVs[15] in urban areas, companies' vehicle selection policies are forced to change and eventually to prefer (lighter) vehicles which are not affected by those restrictions. This is a common example of a solution that suppliers use to avoid regulations. The use of LGV's[16] is difficult to control and enforce and thus, allows industry to ignore the regulations that are put in place on the logistics decision making process. In these cases, as a result of the ban, total lorry trips, total energy used in freight transport and total road freight pollutant emissions can even increase (Browne and Allen, 1998). That was what happened, from 1997 to 1999, after the adoption of weight limitations: the city of Amsterdam experienced a 43% increase in the number of deliveries by vehicles lighter than 7.5 tones and 9% decrease in vehicles heavier than 7.5 tones (LT and BCI, 2002).

This Dutch example is not an exception; in fact, the predilection for vans seems to be a current tendency. Vans are easier to operate in inner cities, allowing the distributor to overcome the limitations of urban infrastructure (narrow roads) as the city access regulations and thus multi-drop distributors are now replacing trucks by vans. Besides these factors, the choice for lighter vehicles is also promoted due to the driving license requirements, drivers' hour legislation, operator licenses, speed limits and on operating restrictions. All those facts together seem to promote the use of LGV's, which is not necessarily advantageous for all the interests as it is shown in the following examples.

Anderson *et al.* (2005) examined the effects of weight regulations in Basingstoke, Birmingham and Norwich. Authors simulated the restriction of access of vehicles over 7,5 tones to the inner area between 10:00 and 16:00 and concluded that the companies would be affected differently by this policy measures. Companies operating light goods vehicles would not be affected, while companies operating heavy goods vehicles with a

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[15] *HGV (heavy goods vehicle) is the generic term for goods motor vehicles (like lorries, trucks) weighting more than 3.5 tonnes.*

[16] *LGV (light good vehicle) is the generic term for goods motor vehicles (like vans, pickups) with a maximum allowed mass of over 3.5 tonnes.*

gross weight of 12 tons or more would have to make significant changes to their distribution patterns in order to comply. These changes would result in increases in total vehicle operating costs of as much as 30% for some companies depending on the weight restriction. The environmental impact of the vehicle rounds performed by those companies worst affected by the weight restriction scenarios would increase significantly as a result of the increase on total distance traveled (calculated to double for one company if a 7.5 tones gross vehicle weight limit was introduced), which would lead to increases in total fuel consumption and pollutant emissions. The increase in the total time taken to complete the same quantity of collection and delivery work would require an increase in total time taken (which is expected to rise by as much as 50% in the case of one company) and would also lead to negative impacts (see Table 3.16).

Table 3.16. Results of weight restriction in urban areas

Source: Anderson et al. (2005)

	Basingstoke	Birmingham	Norwich
Total number of rounds	Was 20 Now 27	Was 57 Now 75	Was 43 Now 59
Number of round affected	4/20	10/57	8/43
Total time taken	+13%	+6%	+4%
Orig. driving time as % of total	Was 54% Now 58%	Was 46% Now 49%	Was 43% Now 44%
Orig. stationary time as % of total	Was 46% Now 44%	Was 54% Now 51%	Was 57% Now 56%
Total distance travelled	+23%	+14%	+7%
Total vehicle operating costs	+11%	+4%	n/c
Total CO emissions	+12%	+6%	+3%
Total CO2 emissions	+7%	+4%	n/c
Total NOx emissions	+8%	+4%	n/c
Total PM emissions	+32%	+14%	+8%

No vehicles over 7.5 tones (gvw) allowed in inner areas between 10:00 and 16:00. The results suggest that the weight restriction scenarios in some differences in the three urban areas in terms of (i) the proportion of vehicle rounds affected by each scenario, (ii) the proportional increase in vehicle rounds that would be necessary to carry out the same amount of collection and delivery work, and (iii) the effect of each scenario on the total distribution costs, time taken, distance travelled and pollutant emission levels. The scenario regarding 7,5 tones vehicles in inner areas would affect approximately the same proportion of vehicles rounds in all three urban areas (approximately 20%).

Browne and Allen (1998) modeled the effects of banning heavy lorries in the reduction of the negative impacts of London's road freight transport and compared it with the situation in 1991. Results showed an increase of the number of trips by 9%, of the vehicle kilometers by 20%, of the fuel usage by 16% and of the CO_2 emissions by 21%[17]. The authors also concluded that banning heavy lorries combined with improving load consolidation, would decrease the number of trips by 9%, the fuel consumption by 3% and the vehicle-km would remain unchanged.

Regulation of the access based on the control of load factors

The control of load factors assumes that higher load factors produce lower environmental impacts as it is also illustrated by Taniguchi and Heijden (2000) in the figure 3.4.

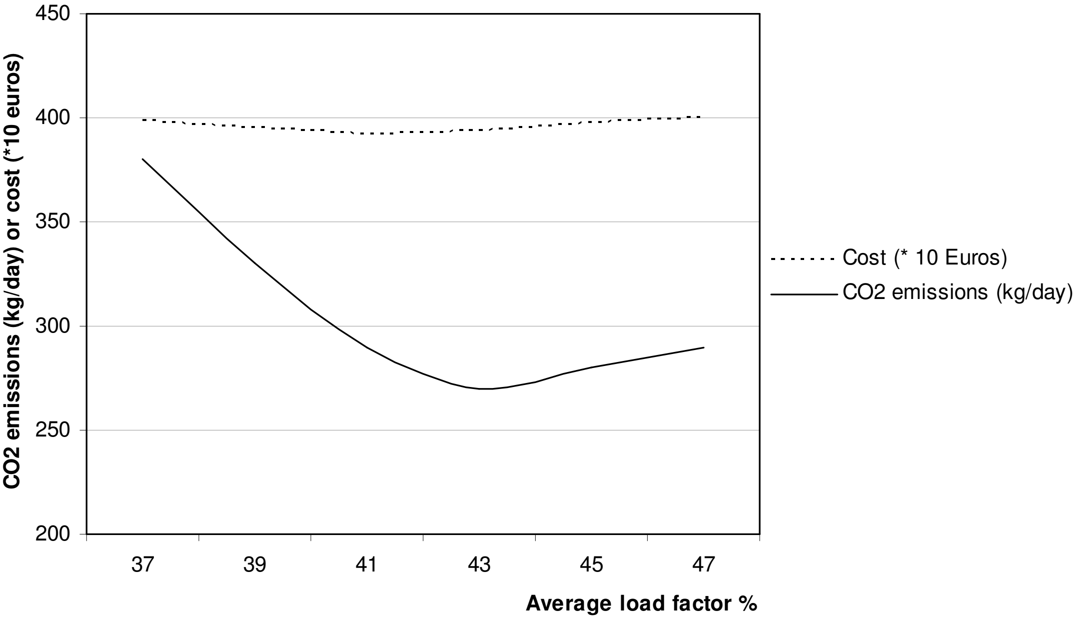

Figure 3.4. Changes in CO_2 emissions and cost with average load factor of pickup/delivery trucks

Source: Taniguchi and Heijden (2000)

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[17] *The removal of heavy lorries from London would bring environmental benefits in terms of reduction in noise and vibration levels and less visual intrusion.*

The figure indicates that, in order to obtain the maximum benefit of the initiative, an appropriate level of controlling the load factor in urban freight transport must be defined. In the particular case of the illustration, the optimal load factor for minimizing both CO_2 emissions and cost is of 43.9%.

The load factor is an important criterion because it is an indicator of the efficient use of vehicles (Visser *et al.*, 1999). The OECD working group on urban goods transport (OECD, 2003) estimated that around 30% of vehicles carry loads 25% below capacity and 50% loads of more than 50% below capacity. These values can even be more surprising in some areas. In a case study carried out in Porto (Portugal), the survey revealed that 75% of the freight vehicles carried goods 50% below capacity (Melo *et al.*, 2006). In Copenhagen, 85% of the freight vehicles carried goods bellow 60% of the capacity (Ruesch and Glücker, 2001). These statistic values help to explain the fact that private cars are now being used for urban goods transport in most of the cities, although their share is not significant yet. In studies carried out in Porto the private car share was valued around 1% of the total freight traffic (Melo *et al.*, 2006).

To increase the use of capacity in the lorries and vans entering the city centre in 1998, Copenhagen introduced a certificate system for freight vehicles within the central city areas. Only vehicles with a certificate (green sticker) were allowed to use public loading/unloading terminals in the inner city. In Copenhagen, this certificate could only be issued to vehicles satisfying the following conditions: (1) load factor > 60 %; and (2) vehicle < 8 years old. Companies owning vehicles were required to produce a report on the load factors of their vehicles every month and to maintain certification, a company must have an average load factor during the previous month > 60%. 80 companies (300 vehicles) participated voluntarily on this scheme for one year and a half until February 2000. 86% of the participants revealed that would like to have an obligatory arrangement. The obligatory project would lead to a reduction of the number of lorries and trucks entering the city center by 30% and to a reduction of emissions (particles: 25%, NO_2 : 5%, NOx: 10%), (Ruesch and Glücker, 2001).

Besides this practical experiment, there are theoretical simulations that seem to confirm the benefits of controlling the load factor of trucks. Taniguchi and Heijden (2000) simulated the impacts of load factor regulations, as shown in Figure 3.5.

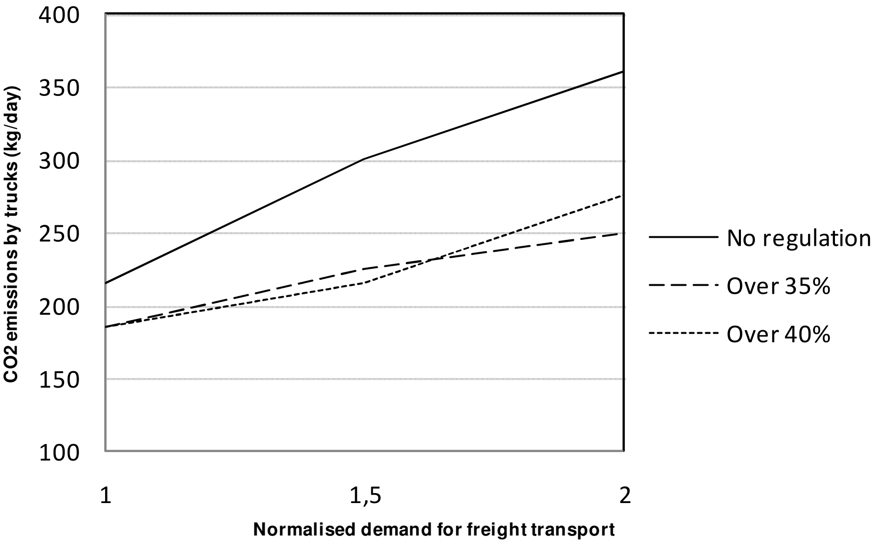

Figure 3.5. Effects of controlling load factor on change in CO $_2$ emissions by trucks with increasing demand for freight transport

Source: Taniguchi and Heijden (2000)

The effects of controlling load factors on CO $_2$ emissions produced by pickup/delivery trucks with increasing demand for freight transport highlight a clear reduction of CO $_2$ emissions by restricting the average load factor to be above a certain level. CO $_2$ emissions increased by up to 1.7 times when the demand doubled the base case without regulation, but enhanced only 1.4 times when the average load factor was > 35%. The normalized CO $_2$ emissions with the regulation of load factor were reduced by 18.2% from that without the regulation, when the demand was doubled.

Therefore, controlling the average load factor of pickup/delivery trucks is an effective measure to depress the increasing CO $_2$ emissions associated with the increase of demand for freight transport (Taniguchi and Heijden, 2000). It is however important to keep in mind that operators will not implement it by themselves unless they will be forced to do it, once the scenario of increasing load factors is "***contrary to industry trends towards lower load factors and just in time deliveries, which are likely to increase emissions***" (Marquez *et al.*, 2004).

Regulation of Access based on Time Windows

The regulation of access based on time is a measure imposed by public authorities, who force suppliers to make their deliveries to a specific area in limited and less sensitive periods. The idea is to define periods in which the distribution activity causes fewer disturbances in the city and on other users of the road infrastructure (Melo *et al.*, 2006). It is expected that less interaction with other users, through the separation of different types of traffic, leads to less congestion and to an improvement in safety and environment (Ruesch and Glücker, 2001). On the suppliers' side, the regulation of the access based on time can contribute to some changes in the way their trips into the city are organized. In principle (and depending on the characteristics of the distribution activity) suppliers will opt to increase the load factors of their vehicles, which will lead to less trips into the city and consequently, to less congestion. The environmental and commercial benefits of regulations based on time is however dependent of the local conditions of the place. Each case is different and the regulation must be established according with the specific tool conditions: cultural habits, opening schedule of the stores and local pattern of distribution. The reason why this initiative is widespread in Europe and with such positive acceptance is strongly related with the fact that it is easy to adopt it and change it depending on the observed conditions.

The results in many cities are inspiring, but not always the effects of this kind of regulation are positive. Huschebeck (2003) cites a study carried out by PTV for a real business case with a commercial trip planning application. Results showed that without time restrictions 559 orders of the case study could be delivered within 20 trips resulting in a total of 2840 km. Imposing a delivery time window of 1 hour would result in 114 trips and 9605 km driven. Once the reliability of delivering goods is one of the major concerns of freight carriers, strict time windows have led to smaller loads of goods being transported more frequently and consequently led to more trips to the city, which contradicts the first intentions of these policies (Taniguchi, 2003). These results reveal that restrictions based on time may cause unexpected problems to distribution companies. If time windows vary a lot from city to city, it may also be difficult to plan multi-stop deliveries in an efficient way (as it concerns both the total costs and the distance traveled). Time restrictions can lead to distribution activities being compressed into a shorter period at the start or end of the working day (Anderson *et al.*, 2005) and consequently to even require more trucks to fulfill the requirements.

Off Peak Deliveries

The off peak deliveries are a particular example of regulation of access based on time windows. Daytime commercial vehicle deliveries can significantly contribute to traffic congestion because of the lack of suitable parking for commercial vehicles, which forces on street double parking and increase the price of goods and of doing business. Consequently, increasing the amount of off-peak deliveries, by reducing truck traffic during the peak hours, may reduce pollution and congestion (Holguin-Veras *et al.*, 2005).

The Freight Transport Association carried out a survey among its members and concluded that the goods vehicle traffic could raise just 2,8% between 2000 and 2010 (instead of the expected 6%) if it were possible to remove the entire out of hours restrictions on HGV (Browne *et al.*, 2007). A practical example of night delivery in Holland confirms these benefits. TNT Innight operates night deliveries distributing into locker boxes and operators assessed up to 20% savings in transport costs (Huschebeck, 2004).

Holguin-Veras *et al.* (2005) tried to better understand the impacts that off peak deliveries might have in New York, taking into consideration private sector stakeholders' will namely: receivers, shippers, third party logistic providers (3PLs), trucking companies, and warehouses. Authors concluded that receivers were the key to initiating off-peak deliveries because they were the ones that control delivery times – delivery companies accommodate to their needs. The majority of the problems with off-peak deliveries affect receivers, once it forces them to have staff on hand to accept deliveries. In addition to increased employee costs, receivers can also have additional heating, lighting, security and insurance costs. Commercial businesses are not prepared for a 24 hour economy. Without receivers willing to do off-peak deliveries, shippers and carriers cannot implement off-peak deliveries on their own.

Besides the private stakeholders' obstacles, it is important to be aware that off-peak deliveries cannot be adopted everywhere and to every supply chain[18] and other perspectives must be taken into account. Residents are easily annoyed by noise generated by vehicles and cargo handling during night-time. Therefore some cities have

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[18] *Some supply chains specifically require for a night delivery while other supply chains do presently not ask for the possibility of night delivery (Huschebeck, 2004).*

strict restrictions concerning night operations, and others may ban these in the whole city area (LT and BCI, 2002). In London, there's a night-time ban on deliveries to many stores. The ban is imposed by local authorities, through the planning act or noise abatement orders, with aim of protecting the amenity of local residents. The community might accept a relaxation of the ban in exchange for improved delivery methods, which would include the use of quiet vehicles and delivery techniques (Baybars and Dablanc, 2004).

Table 3.17 summarizes the regulation of access review.

Table 3.17. Regulation of access review

Author	**Method/Location**	**Measured Indicators and Results**		**Main stakeholders Considered**
		Positive	**Negative**	
Browne and Allen (1998)	Simulation London		number of trips vehicle/km fuel use and CO2 emissions	Public and Private stakeholders
Taniguchi and Heijden (2000)	Simulation	CO2 emissions		Private stakeholders
Ruesch and Glücker (2001)	Practical Copenhagen	Number of lorries Emissions	% load factors	Private stakeholders
LT&BCI (2002)	Practical Amsterdam		Increase in LGV	Public and Private stakeholders
Huschebeck (2003)	Practical		Trips Km driven	Public and Private Stakeholders
Huschebeck (2004)	Practical Netherlands	Transport costs		Private stakeholders
Baybars and Dablanc (2004)	Practical London	Journey time reliability Movements per day		Public and Private Stakeholders
Browne *et al.* (2004b)	Practical Stockholm	Emissions		Public and Private stakeholders
Anderson *et al* (2005)	Simulation Basingstoke Birmingham Norwich		Vehicle operating costs, environmental impacts, fuel consumption, pollutant emissions	Private stakeholders
Holguin-Veras *et al.* (2005)	Survey New York	-	-	Private Stakeholders

3.5.3 Reserved – capacity strategies

Several studies have explored ways to improve urban congestion limiting truck travel by restricting lanes, routes, or time of day. These strategies are based on the perceptions that large trucks (1) restrict motorists' vision because of their size, (2) threaten safety because of slow braking capabilities, and (3) delay motorists because of slow accelerations and an inability to maintain speed on upgrades (Nam and Lee, 2003). However, given that *large trucks* typically make up less than 5% of the average daily traffic in urban areas (BST Associates, 1991), perhaps a disproportionate amount of effort is being spent on restricting large truck travel.

Reserved-capacity strategies are measures that contradict those efforts, going against the usual limitation/restriction of freight vehicles movements or accessibility. It include solutions like exclusive dedicated lanes for trucks and more moderate approaches in which trucks and buses share a common dedicated lane. Under the assumption that trucks operations are more efficient when trucks are separated (physically or by time of day) from general traffic, reserved-capacity strategies can have positive benefits for trucking industry and society. The main potential benefits besides a better efficiency of trucks operations are the improvement of safety, the reduction of incident impacts, the increase on capacity of the infrastructure, decrease on fuel consumption and better air quality (Nam and Lee, 2003).

Dedicated exclusive lanes

The exclusive dedicated lanes for trucks are measures that can be operated continuously throughout the day or only during peak congested periods (allowing the lane to be opened to general traffic at other times of the day). Despite the potential benefits of dedicated lanes for freight traffic, only in few cases it is justified to have them in urban areas. Only in situations that the designated routes prove to lead to less congestion and to overall positive or acceptable results, this initiative can be put into place. Additionally, the privilege of a dedicated lane may be perceived in a negative way by other road users, unless the implementation of the measure leads to significant benefits to other users. Issues of reduced operational flexibility of use of the road may also arise.

Nam and Lee (2003) evaluated the impacts of reserved-capacity strategies for trucks in the Seattle region (USA). Results estimated nearly 10 million dollars in annual travel savings for the trucking industry, a saving of about 2.5 minutes per average truck trip and almost 30 million dollars in annual travel time savings for single occupancy vehicles.

An example of doubtful success was the use of dedicated routes implemented in Bremen. The main purpose was to minimize time and distance of trips for trucks and residents. Separating different types of traffic and advertising the new measures lead to significant improvements on urban environment quality, through the decrease of truck volume on minor roads by 11% and on residential areas by 40%, but it also lead to an increase of 1.5% in the number of trucks in highways (Ruesch and Glücker, 2001).
Considering the restrictive application of exclusive dedicated lanes, another initiative with a broader implementation is suggested: the (shared) usage of bus lanes by freight traffic.

Shared usage of a bus lane

A more moderate approach of the reserved-capacity strategies would be to provide a shared lane in which vehicles of different types of traffic could share a common lane and yet be separated from general traffic. Private trucking firms could support the development of a cooperative dedicated lane by paying a per-use toll, as suggested by Nam and Lee (2003).
A bus/truck lane is a lane reserved for large trucks and buses only. Trucks and buses share many of the same characteristics, which makes the idea of allowing trucks to utilize the lane feasible. The usage of bus lanes for freight traffic under specific conditions can help to reduce congestion and to improve safety on urban roads, through the decrease of the interaction of freight vehicles with other users. The idea is that bus lanes occupy a considerable area of road infrastructure and are not used all the time, giving the opportunity to be used by other type of traffic. The separation of types of traffic leads to less physical interaction of freight vehicles with other users, which leads to less congestion, more safety and to a better quality of urban environment.
Despite the theoretical potential of such initiative to a better use of urban infrastructure and to the reduction of the disturbance caused by goods vehicles, some requirements must be considered. Once the aim is to improve freight traffic through the exploitation of the rest of the capacity of the bus lane that is not being used, it must be an obligatory

condition that buses wouldn't be significantly affected by congestion and delays on the lanes. For freight traffic, it is preferable that bus lanes serve industry and/or shopping areas and offer several options to access or leave the bus lane. The separation of movement types which supports the implementation of this initiative must bring advantages for all the road users.
Being a quite recent initiative and only feasible under specific conditions, there are not many examples to be cited.

London (England) and Amsterdam (Netherlands) are considering the allowance of freight vehicles on the bus lanes. In London a study has been carried out to analyze, based on bus and lorry flows and general traffic flows, the possibility of the allowance of lorries above 7,5 tones in bus lanes (Baybars and Dablanc, 2004). Amsterdam is also considering the accommodation of delivery zones on protected bus lanes in non peak hours (LT and BCI, 2002).

The evaluation of the effects of one shared lane (public transport and freight traffic) through the reduction of one lane from private transport on the first ring of Porto Metropolitan Area (Portugal) was carried out by Pimentel *et al.* (2008). With this solution private transport would have an increase in fuel consumption of about 14%. Public transport wouldn't feel significantly the effects of the initiative, once there are only few lanes moving along the first ring and freight transport would have decreases of about 24% in fuel consumption. Delays and travel times would follow this tendency: private transport would have increases resulting from the reduction of one lane of circulation and freight traffic would have improvements of about 6% (not only for the ring but for the entire metropolitan road network). In the long term the effects on public transport would be expected to be more positive through potential transfers from private transport to public one.

Table 3.18 summarizes the reserved-capacity strategies review.

Table 3.18. Reserved-capacity strategies review

Author	Method/Location	Measured Indicators and Results		Main stakeholders Considered
		Positive	Negative	
Nam and Lee (2003)	Simulation Seattle region (USA)	Travel costs, travel times, delay times, truck volume		Private stakeholders
Pimentel *et al.* (2008)	Simulation Porto Metropolitan Area	Fuel consumption CO2 emissions Delay Times Travel Times		Public Stakeholders (public transport) Private Stakeholders (freight transport, private transport)

Although there are many factors to consider, one key concern is whether suppliers could take advantage of reductions in travel time and travel time variance that would result from the implementation of reserved-capacity strategies. This is a difficult question to answer and not even the trucking industry itself can answer. It is a recommendation of this study that the idea of reserved-capacity strategies for trucks continues to be presented to suppliers, to the public, and to other impacted agencies for discussion and consideration.

Due to its characteristics, namely its innovative side, the involvement of different stakeholders, the need to harmonize traffic management decisions with urban space and use management and its potential benefits, the usage of a bus lane for freight traffic in non peak hours was selected to be evaluated as a case study in the thesis. In chapter 6 it will be presented a theoretical evaluation of the impacts of the usage of a bus lane for freight traffic in an area located in Porto (Portugal).

3.5.4 Licenses

The introduction of licenses can be used to influence and control access, only allowing operators with licenses or licensed vehicles to access to a street, city or to a parking zone. The criteria that allows the vehicle to access varies from city to city and it depends of the aim of the regulation itself.

Following a national program of energy reduction in cities, many Dutch cities have set up systems of urban freight distribution licenses. Strict operating regulations were imposed on the licenses in exchange for an extended usage of street space and longer delivery hours. Applicant carriers had to respect a list of criteria such as good level of truck loading, minimum number of shipments and the use of electric vehicles (Egger and Ruesch, 2002).

In Copenhagen, it was carried out a voluntary scheme, where vehicles would only get the license to access to preferred loading and unloading zones if their capacity use would be at least 60%. For one year and a half, almost all of the 80 companies were able to achieve the required 60% use of capacity (Huschebeck, 2001) and about 20% of the companies had to change their daily planning of goods during the experiment. The increase of the average load factor lead to less vehicles entering the city and consequently to less congestion, noise and pollution. It also contributed to reduce the operational costs of the suppliers once it forced them to change their planning in order to maximize the load factor of their trucks.

Table 3.19 summarizes the licenses review.

Table 3.19. Licenses review

Author	Method/Location	Measured Indicators and Results		Main stakeholders Considered
		Positive	Negative	
Huschebeck (2001)	Practical Copenhagen	Load factor congestion, noise, pollution, operational costs, travel times, delay times, truck volume		Private stakeholders

3.5.5 Cooperative Distribution Systems CDS

Cooperative Delivery Systems are usually adopted in areas with severe traffic congestion and intensive economic activities (Takahashi *et al.*, 2004) and allow a reduced number of trucks to be used for collecting or delivering the same amount of goods (Taniguchi and Heijden, 2000).

Cooperative Delivery System (CDS) can decrease traffic volume and improve environment in urban areas, through a reduction in the number of trucks and on the total travel times of trucks (Taniguchi *et al.*, 2003 b). Besides these public benefits, CDS can also lead to private benefits: many carriers enjoy both a cost reduction and the provision of better services to customers.

These benefits were already shown by some authors through mathematical simulation.

Taniguchi *et al.* (2003b) described a simulation modeling of cooperative systems between some carriers combined with vehicle routing and scheduling that estimated that the total costs of carriers would be reduced by 19%, a rate largely attributable to the reduction of the distance traveled. In addition, freight carriers not included on CDS would enjoy a reduction in total costs of 6.1% due to less road congestion as a result of cooperation.

Taniguchi and Heijden (2000) analyzed the effects of cooperative systems on CO_2 emissions, within a small road network using dynamic traffic simulation. The cooperation was based in carrying goods by common pickup/delivery trucks. Results from the simulation are illustrated in Figure 3.6 and revealed that the CO_2 emissions produced by all freight carriers would be reduced for the normalized demand for freight transport of 1.0 and 2.0 by cooperative freight transport. It was also shown that total costs were reduced by 23-29% after implementing a cooperative freight transport system for the three demand levels.

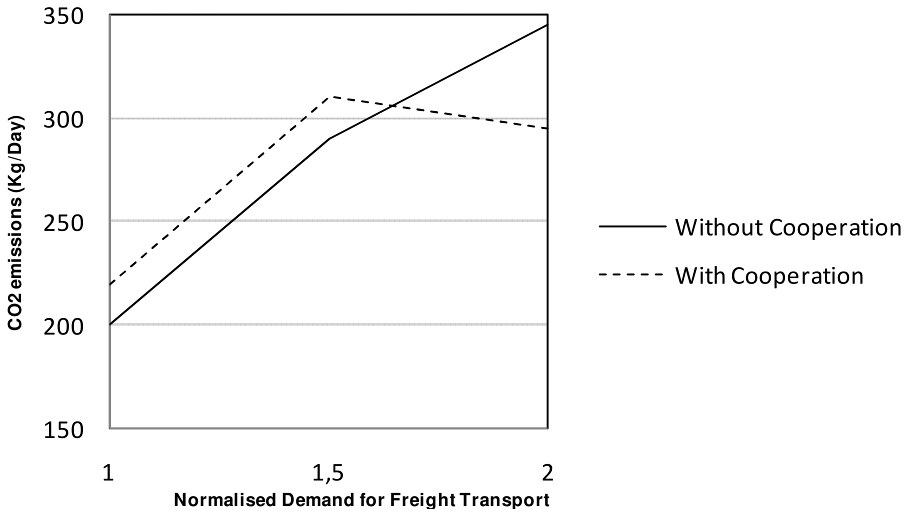

Figure 3.6. Effects of cooperative freight transport systems on change in CO_2 emissions with increasing demand for freight transport

Source: Taniguchi e Heidjen (2000)

Ieda *et al*. (1992) quoted by Egger and Ruesch (2002) estimated the benefits of CDS for Tenjin. Results showed a decrease of number of trucks in the served area by 65%, decrease of total distance traveled (km/day) by 28%, decrease of total distance traveled within Tenjin district (km/day) by 87%, decrease of total frequency of parking (times/day) by 72% and decrease of total parking time (hour/day) by 17%. Nemoto (1997) additionally estimated a decrease in total NOx emissions of 0.4% and a decrease in total fuel consumption of 0.3% in Tenjin, after the introduction of the UDC.

Another outstanding case of cooperative delivery system was described by Taniguchi *et al.* (1995). Authors carried out a survey in the Kyoto-Osaka-Kobe area of Japan and found that 57 companies of the 445 that reply to the questionnaire were involved in some kind of cooperative freight transport systems. 72% of the companies recognized that these systems lead to a reduction of costs (attributed to the reduction of the number of trucks and to the increase in load factors). 56% recognized an improvement of reliability on pickup/delivery time.

Practical experiments confirm the theoretical benefits presented above of cooperative distribution systems.

IRU (2004) describes a practical experiment (ECOLOGUS) carried out in Évora (Portugal). The ECOLOGUS – Ecoefficient Distribution in Évora is a system which operates in a specified area, with biodiesel vehicles from a central warehouse located outside the city centre where deliveries are grouped. Results of this experiment were quite positive for the environment: decrease on the number of trips per day and vehicle by 35%, a reduction on emissions by 35% (if the system uses diesel fuel) and zero emissions if the fleet uses bio-diesel (IRU, 2004).

Köhler and Straub (1997) also describes a survey of competitive freight carriers cooperating in delivering goods to the inner city of Kassel, Germany (200 000 inhabitants) starting in 1994. At a terminal near the city center, goods were grouped according to their type, quantity, time and location and trucks were loaded in an optimal way. A neutral freight carrier collected goods from 10 freight carriers and delivered them to 350 retailers in the inner city. With co-operation, carriers achieved a traffic reduction of about 60% and the number of trucks driving into the city per day was reduced from 15 to 2 or 3 trucks. The kilometers towards inner city were reduced by 40% and the average lorry frequency per retailer decrease 13% (Browne *et al.,* 2005). Through model calculations, it was shown that the loading volume for deliveries to the city center of Kassel improved from 40% without co-operation up to 80-90% with co-operation (Köhler, 2004). After introducing this system the total time traveled by trucks was reduced and queues of trucks for waiting to deliver goods on streets was also reduced.

Table 3.20 summarizes the cooperative systems review.

Table 3.20. Cooperative Distribution System review

Author	Method/Location	Measured Indicators and Results		Main stakeholders Considered
		Positive	Negative	
Ieda *et al*. (1992)	Theoretical Tenjin	Number of trucks Distance traveled Frequency of parking Total parking time		Private stakeholders
Taniguchi *et al.* (1995)	Theoretical Kyoto-Osaka-Kobe	Reduction of costs Reliability		Private stakeholders (suppliers)
Köhler (1997; 2004)	Practical Kassel, Germany	Traffic Number of trucks Total time traveled		Public stakeholders (citizens) Private stakeholders (suppliers)
Taniguchi and Heijden (2000)	Theoretical	CO2 emissions Total operational costs		Private stakeholders (suppliers)
Taniguchi *et al.* (2003b)	Theoretical	Total costs of carriers Distance travelled		Private stakeholders (suppliers)
IRU (2004)	Practical Évora, Portugal	Number of trips per day Emissions		Public stakeholders (citizens) Private stakeholders (suppliers)

3.5.6 Considerations and Remarks

The analysis of legislative and operational measures, summarized in Table 3.21, included 4 measures: pricing policies, regulation of access, reserved-capacity strategies, licenses and cooperative delivery systems.

Table 3.21. Legislative and Organizational Measures

Initiative	**Measured Indicators and Results**		**Stakeholders**	**Synthesis**
	Positive	**Negatives**		
Pricing Policies	External costs, Driving costs, Time costs, Congestion, Traffic volume, Delays, CO2 emissions, NOx, PM, CO, VOC's emissions Fuel consumption Travel times	Transport costs	PU, C, PR	2
Regulation of access	Emissions CO2 emissions Journey time reliability Movements per day	Increase in LGV number of trips, vehicle/km , CO2 emissions, Vehicle operating costs, environmental impacts, fuel consumption, pollutant emissions % load factors, Trips Km driven	PU, C, PR	**X**
Reserved-capacity Strategies	Travel costs, travel times, delay times, truck volume		PR	**X**
Licenses	Load factor, congestion, noise, pollution, operational costs		PR, PU	2
Cooperative Distribution Systems	CO2 emissions Total operational costs, Number of trucks, Distance traveled, Frequency of parking, Total parking time, Traffic, Total time traveled, Number of trips per day, Emissions		PU, C, PR	**X**

PU – Public Stakeholders including Administrators; C – Citizens
PR – Private Stakeholders including suppliers
2 – Implementation highly dependent on public incentives
X – To be evaluated on the case study

The following considerations and remarks summarize what can be learnt from the previous description, highlight the determinant factors to be considered on the implementation of each initiative and support the selection process for chapter 6.

First, although regulation in transport demand through taxation has become increasingly popular, it seems to be clear that the effectiveness of the manipulation of transport costs in reducing the negative effects of freight transport depends of the instrument and of the conditions of implementation. **Pricing policies** still face some relevant implementation barriers: there is not enough transparency given about the share of concrete motivations and the use of the revenue (small retailers in the city for instance). Additionally, companies have costs with the implementation of such schemes, namely in access equipment, accounting processes, renewal of plans, etc and do not have part of the revenue. Other issue is that the level of applied charges in road pricing is more a result of political negotiations or public acceptance rather than economic costs calculations. In an accurate way, prices should reflect true costs (internal plus external ones) and be a function of supply and demand, but practical experiments already revealed fees would have to be rather high than they are to have considerable demand effects. This is even more complex when it is applied to urban goods distribution: in order to create a net benefit for freight transport operators, the charged fee needs to be high enough to make private car usage decrease and low enough for transport operators not to offset the benefits it creates for them. Under those conditions, urban freight transport could indeed be one of the beneficiaries of urban road pricing, because road pricing would expectably reduce road usage by private cars, reducing congestion and increasing the efficiency of the remaining high value commercial trips.

Secondly, with the recent increase of fuel costs to levels which were not predictable to be achieved, **fuel taxes** initiative revealed to be inappropriate to influence freight transport flows in an effective way. A good practical example is the stroke from suppliers in June 2008, which strongly affected Portugal, Spain, Italy and other European countries. In few days, the Portuguese government gave in and reduced the toll roads during the night and changes on fuel taxation in 2009. It is not realistic anymore, after have experienced this process to suggest an increase in fuel taxes in Portugal to influence demand.

Thirdly, despite the positive benefits that **access regulations** can have on the quality of urban environment, there's the belief that whatever are the regulations put in place to organize the traffic of delivery vehicles, goods will reach the final receiver in the place and time which resulted from logistics decision making process (Dablanc, 2006). Only with tight and strictly enforced legal regulations it is possible to influence those decisions. Operators will only follow regulations established by public stakeholders if they are forced to do it or if they get benefits from it. Such facts highlight two crucial situations to be considered on the implementation of regulation: a) carefully analyze if the expected benefits are relevant enough to compensate the labor and equipment costs required to implement and control the initiate as well as the operational costs imposed to suppliers, b) as much as possible, to consider the private stakeholders interests to assure no counter intuitive effects will happen.

Lastly, despite **cooperative distribution systems** (CDS) can reduce transport costs as well as environmental impacts, the number of carriers that are willing to join this system usually only represent a very small part of freight traffic (Köhler, 2004). Thus, the benefits achieved with this system in the overall traffic might not be significant by itself. The study recommends, based in literature (Nemoto, 1997), the implementation of CDS as a complimentary measure with other initiatives in order to improve its profitability. In chapter 6, CDS will be evaluated together with the implementation of an UDC.

3.6 Findings from the inventory

It has been particularly difficult while undertaking this research the fact the documentary records of all the initiatives are, in the main, quite **inadequate** for the purpose of tracking the start, progress, results and current status of the initiatives. As a result, some of the dates used should be considered as indicative rather than absolute. Added to this difficulty, a large number of initiatives **have stop being reported** following the research or testing phase which suggests the initial enthusiasm associated with the launch of many of the schemes soon fade away. However, it does seem reasonable to assume that those experiments that proved to be successful and worth extending are the ones that have received the greatest attention from both the scientific and industry stakeholders, whereas those that are no longer mentioned have been terminated. A summary of the existing information on innovative ways of delivering goods, under the perspective chosen on this dissertation, is presented through the previous literature review and compilation of good practices, illustrated in Table 3.22 and Figure 3.7.

It is recognized that more initiatives could be included on the list, but there is the conviction the most relevant ones in terms of contribution to an increasing mobility and sustainability were selected.

Table 3.22 reveals that scientific publications, which mainly used simulation tools to evaluate initiatives, are usually focused in a specified city or area to where they evaluate the impacts of the respective solution.

All the analyzed examples included on table 3.22 are recent and were published by a reduced number of authors. This might be due to the fact that the concern about the impacts of urban goods distribution is recent, which also explains that about 70% of the initiatives described on this chapter were evaluated or put into practice in the last 5 years (Figure 3.7). Also the fact that theoretical publications appeared first and are still in a larger number than practical ones seem to confirm the **earlier stage of research** on this topic, although it might also happen because **practical experiments are not monitorized** and thus, the dissemination of **practical results** is not widely promoted yet. One exception to the lack of practical data is given by BESTUFS European Network and recently by SUGAR, who publish reports describing good practices, identifying the conditions of implementation and the results obtained. These reports were used on this thesis and allowed to reduce the issue of the limited available results of (validated) practical experiments in Urban Goods Distribution. The analysis of Table 3.22 also shows that the first publications present measures from domains ‘Infrastructural and Urban Space Management’ and ‘Technological and Operational’. Publications on ‘Legislative and Organizational’ measures only appear this decade and are now in larger number than the ones from other domains.

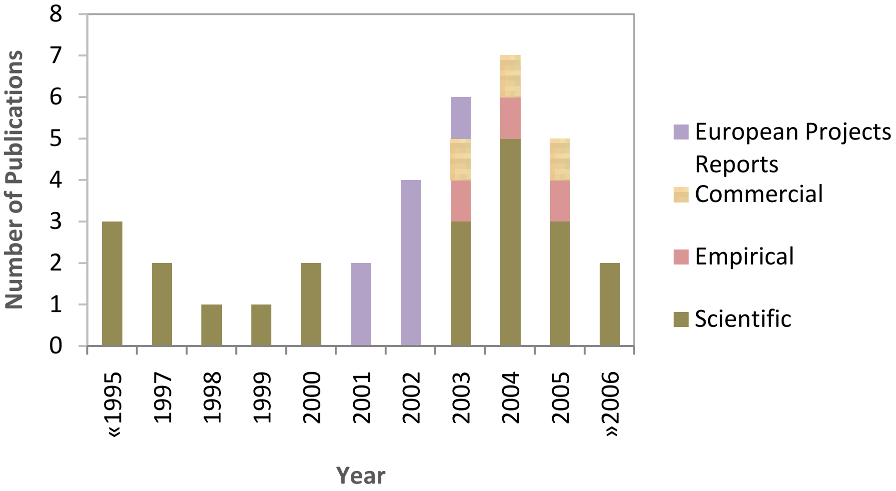

Figure 3.7. Overview descriptive statistic of the inventory

All publications have the common concern of reducing environmental impacts and congestion associated with the transport and distribution of goods in urban areas. This is to say, all of them have the concern to improve the quality of urban environment.

The previous work allow at this point to: a) identify initiatives considered 'good practices' on UGD, b) have a better knowledge of possible indicators adopted on the assessment of those initiatives, c) understand which stakeholders were involved in the respective implementation. This information, added to the remarks highlighted on each domain on chapter 3, **will now support the establishment of a set of indicators** in chapter 4.

Table 3.22. Literature Review and Compilation of Good Practices

Infrastructural and Urban Space Management measures

Initiative	Author (s)	Description	Results	Remarks
(Rail) Underground Distribution Systems	Koshi *et al.* (1992)	Koshi *et al.* (1992) estimated the impacts of urban goods distribution working complementarily with electric vans distribution from depots in Tokyo Ward Area (Japan)	The environment, driving labor force and energy would be improved. Reduction of NOx by 24%, CO_2 emissions by 20%, energy consumption by 18% and increase on average travel speed by 24%.	Underground Distribution Systems can be considered in over dense areas when there's an existent underground network acceptable by public and private stakeholders. Stakeholders to be considered: PU, PR, C
	Oishi and Taniguchi (1999)	Oishi and Taniguchi (1999) studied the economic feasibility of automated underground transport in Tokyo	If the infrastructure would be constructed by the public sector, the project would have an internal income rate of 10%. Project expected to be economically viable.	
	Binsbergen and Bovy (2000)	Binsbergen and Bovy (2000) compared underground distribution with other alternative distribution models in Delft (Holland), using simulation	Allow multiple space use. Leads to space savings at the surface level. Significantly reduce local air pollution and improve average travel speed. Underground goods distribution can function from a logistic point of view, be economically viable and will, under strict conditions, benefit the environment.	

Infrastructural and Urban Space Management measures (cont.)

Initiative	Author (s)	Description	Results	Remarks
(Un) Loading Spaces	Melo (2003)	Characterized the delivery pattern of a central area in Porto (Portugal)	97% of suppliers opted to park illegally even when reserved zones were available.	The success of these measures strongly depends of an effective enforcement and of the location of the (un) loading zones. Suppliers want to park as close to the customers as possible and they will only use the designated areas under two conditions: first, if they are forced to do it (enforcement) and second, if the designated area fulfills their requirements in terms of price, layout and location. Stakeholders to be considered: PU, PR
Urban Distribution Centers	Van Duin (1997)	Evaluated the effects of UDC	UDC have logistics criterions and structure which reduce the potential market share.	The author suggests to a) set up a study that would identify financial costs/benefits for private and public stakeholders; b) in case the results of the study support it, make UDC trials to analyze how they are funded, run and to measure the results and c) involve the interested parts in the planning process of a UDC, in case the previous steps lead to the conclusion it is appropriate and feasible to build the UDC. For UDCs to be attractive to companies and to be successfully set-up, they should be led and operated by one or several key commercial players that have identified the potential benefits of being involved. Similarly, public funding needs to be made available to pay for the research work and pilot studies for any form of UDC that is not related to a major new property or commercial development. Without this funding such UDC research and trials are unlikely to proceed. Stakeholders to be considered: PU, PR
	Browne and Allen (1998)	Modeled the effects of urban distribution centre to examine its potential in the reduction of the negative impacts of London's road freight transport in comparison with the situation in 1991	Increases on trips by 7%, on vehicle km by 15% and on fuel use by 9%. If several terminals (instead of one) were constructed at different entry points to the city, trip lengths would be reduced and this would reduce the total vehicle-kilometers performed, the fuel consumed and the carbon dioxide and other pollutants emitted.	
	Egger and Ruesch (2002)	Effects of a public distribution centre in Monaco	The system revealed to be helpful in the reduction of the required number of trucks used for deliveries.	
	Egger and Ruesch (2002); Ambrosini and Routhier (2004)	Effects of a public distribution centre complemented with cooperative distribution in Kassel (Germany)	Public benefits from fewer trips, less vehicles and less emissions. Loading of vehicles has multiplied by 1.5 in weight. Mileage traveled has decreased by 45%. Transport operators have an image of being innovative and responsible.	

Technological and operational measures

Initiative	Author (s)	Description	Results	Remarks
Vehicle Routing and Scheduling	Taniguchi and Heijden (2000)	Simulated the effects of advanced routing and scheduling system	Introducing advanced routing and scheduling systems helps reduce CO2 emissions when the demand for freight transport increases. The normalized CO2 emissions reduced by 8.3% when the penetration rate rose to 100% from 0%, when the demand level was doubled.	Vehicle routing and scheduling is an initiative with proven benefits, particularly for private stakeholders (suppliers). Stakeholders to be considered: PU, PR
	Taniguchi and Heijden (2000)	Measured the impacts of the use of routing and scheduling in a Japanese milk-producing company.	The company reduced the number of pickup/delivery trucks by 13.5% (from 37 to 32 vehicles) and increased their average load factor by 10% (from 60 to 70%).	
	Transport Energy Best Practice (2003)	Practical experiment of vehicle routing carried out in UK by Transco company	After the implementation of optimized vehicle routing, the annual environmental benefits (based on current trends) were of 38640 quilometers saved, 8000 liters of fuel not consumed, 360 journeys avoided, 21 tons of carbon dioxide saved, reduction of other polluting emissions and financial savings of 47000 Euros per annum.	

Technological and operational measures (cont.)

Initiative	Author (s)	Description	Results	Remarks
Collaborative Systems	Gebresenbet and Ljungberg (2002)	Practical Upsala (Sweden)	During a trial experiment 97 transport companies delivered goods to a shopping area under a collaborative system. About 43% of the delivered goods were also food and about 69% were delivered before 11 a.m. The trial demonstration was carried out for a period of one year (until May 2001) and resulted in a reduction by 40% of the number of deliveries and in general the retailers were satisfied.	Collaborative systems can, under specific conditions of implementation, be successful in reducing the impacts of urban goods distribution on traffic congestion and environment. A successful implementation of collaborative systems requires as base conditions: a) a joint effort from public and private stakeholders, b) the existence of specific local characteristics like the location of stores with similar products within the same area and c) the existence of a depot to manage the flows of the respective cooperative. These requirements are not easy to be achieved and this can be one of the main reasons why collaborative systems do not have a wider implementation.
Alternative fuels	ELCIDIS (2002)	Tested the use of (hybrid) electric vehicles in 6 European cities to prove their viability for urban distribution	Results are highly encouraging, but electric vehicles still have to overcome some barriers, namely the vehicles investment costs.	Alternative fuels in urban goods distribution are not utopian, but some substantial barriers have to be taken before they can be applied generally. One of the barriers is the vehicles investment costs, which are higher than the internal combustion engines vehicles. Authorities must introduce beneficial incentives to promote clean vehicles utilization. If transport companies receive advantages in exchange for the use of these vehicles, their support and involvement should be granted. Stakeholders to be considered: PU, PR, C
	Transport Energy Best Practice (2003)	Describes an experiment carried out in UK by Transco company using alternative fuel vehicles (CNG)	Monitoring the performance of the CNG vehicles revealed that they are 10% per mile cheaper (fuel costs) than their diesel counterparts. The experiment made with six vehicles represents a fuel cost saving of about 37000 Euros per year. In terms of annual environmental benefits, 42 tons of carbon dioxide emissions can be avoided, there's a reduction of 98% in particulate emissions and of 86% in nitrogen oxide emissions, besides the fact that CNG vehicles are quieter.	
	Taniguchi *et al.* (2003a)	Tested the use of electric vehicles in Osaka at 8 public parking places	73% of users recognized that the electric vans have better or same capability of conventional vehicles.	

Legislative and organizational measures

Initiative	Author (s)	Description	Results	Remarks
Road Pricing	Egger and Ruesch (2002)	Describe the effects of the Central London Congestion Charging Scheme	Two years later, measured reductions in congestion within the charging zone have remained at an average of 30 %. In 2005, it was achieved a reduction in traffic volumes of 18% compared with the pre-charging situation and estimated reductions of 12 % in emissions of NOx and PM10 from road traffic within the charging zone. Observed excess delays during charging hours remain typically between 1.4 and 1.8 minutes per kilometer (average of 1.6 minutes per kilometer), against the pre-charging reference value of 2.3 minutes per kilometer.	Pricing policies still face relevant implementation barriers: there is not enough transparency given about the share of concrete motivations and the use of the revenue. Additionally, companies have costs with the implementation of such schemes and do not have part of the revenue. Other issue often referred is that the level of applied charges in road pricing is more a result of political negotiations or public acceptance rather than economic costs calculations. Stakeholders to be considered: PU, PR, C
	Egger and Ruesch (2002)	Describe the effects of a charging in Rome	Decrease by 15% on the total flow of incoming traffic.	
	Jong *et al.* (2004)	Simulated the impacts of road pricing through the use of a meta-model (EXPEDITE)	The authors concluded that with an increase of lorry costs, there's a reduction of external costs (emissions, noise, road damage), a reduction in time costs and an increase on driving costs and on the total costs, which were the sum of driving costs, time costs and external costs.	
	Runhaar and Heijden (2005)	Netherlands In-depth-interviews Shippers' responses identifying adaptations that they would make to the stated scenarios	Manipulation of transport costs is not very effective in reducing the negative effects of freight transport, although it would lead to a more efficient operational use of transport resources.	
	TfL (2005)	Describe the effects of a charging in Singapore	The benefits of this scheme was an immediate reduction of 24,700 cars during peak and rise of traffic speed by 22%, a total reduction of traffic in zone during charging period by 13% from 270,000 to 235,100, a reduction of the number of solo drivers and a shift of vehicle trips from peak to non-peak periods.	
	Pimentel *et al.* (2008)	Analyzed the effects of the implementation of a road pricing system to the first ring of Porto Metropolitan Area	Results showed reductions of CO2 emissions and fuel consumption of about 8% and decrease on travel times and delay times of 14%. Other pollutant emissions would also have improvements (CO8%, PM7%, VOC's 9%) for all the traffic types inside of the delimited road pricing area.	

Legislative and organizational measures (cont.)

Initiative	Author (s)	Description	Results	Remarks
Fuel Taxes	Jong *et al.* (2004)	Simulated the effects of a fuel price increase policy	They concluded that with a lorry fuel cost increase, it would have a decrease in external costs and time costs and an increase on driving times. A policy of increase the fuel price would have a high effectiveness on modal shift from road to other modes, would imply a big cost increase for users, would require a low investment and would imply government revenues.	It is not realistic anymore to suggest an increase in fuel taxes in Portugal to influence demand. Stakeholders to be considered: PU, PR, C
Vehicle emissions	Browne *et al.* (2004b); Ruesch and Glücker (2001)	Experiment based weight and load factor regulations in Stockholm (Sweden)	The measure led to a reduction of emissions (particles: 15 to 20%, hydrocarbons, 5 to 10% and NOx: 1 to 8%).	Operators will only follow regulations established by public stakeholders if they are forced to do it or if they get benefits from it. Such facts highlight two crucial situations to be consider on the implementation of regulation: a) carefully analyze if the expected benefits are relevant enough to compensate the labor and equipment costs required to implement and control the initiate as well as the operational costs imposed to suppliers, b) as much as possible, to consider the private stakeholders interests to assure no counter intuitive effects will happen. Stakeholders to be considered: PU, PR
Weight restrictions	LT and BCI (2002)	Describes the effects of access regulations based in weight limitations in Amsterdam (Holland)	2 years after the implementation of this regulation, there was a 43% increase in the number of deliveries by vehicles lighter than 7.5 tones and a 9% decrease in vehicles heavier than 7.5 tons.	
	Browne and Allen (1998)	Modeling of the effects of Banning access to heavy lorries to examine its potential in the reduction of the negative impacts of London's road freight transport in comparison with the situation in 1991	Increases by 9% the number of trips, by 20% the vehicle-kilometers, by 16% the fuel use and by 21% CO_2 emissions. This measure combined with load consolidation would decrease by 9% the number of trips and by 3% the fuel consumption. Authors note that if several terminals (instead of one) were constructed at different entry points to the city, trip lengths would be reduced and this would reduce the total vehicle-kilometers performed, the fuel consumed and the carbon dioxide and other pollutants emitted.	
	Anderson *et al.* (2005)	Simulated the effects of weight regulations in Basingstoke, Birmingham and Norwich	Companies operating light goods vehicles would be completely unaffected, while companies operating heavy goods vehicles with a gross weight of 12 tons or more would have to make significant changes to their distribution patterns in order to comply. These changes would result in increases in total vehicle operating costs, fuel consumptions and pollutant emissions.	

Legislative and organizational measures (cont.)

Initiative	Author (s)	Description	Results	Remarks
Control of Load Factors	Taniguchi and Heijden (2000)	Simulated the impacts of load factor regulation on CO_2 emissions	The normalized CO_2 emissions with the regulation of load factor were reduced by 18.2% from that without the regulation, when the demand was doubled.	Operators will not implement it by themselves unless they will be forced to do it, once the scenario of increasing load factors is "contrary to industry trends towards lower load factors and just in time deliveries, which are likely to increase emissions" (Marquez *et al.,* 2004). Stakeholders to be considered: PU, PR
	Browne and Allen (1998)	Modeling of the effects of Improve load consolidation to examine its potential in the reduction of the negative impacts of London's road freight transport in comparison with the situation in 1991	17% reduction of annual freight vehicle trips, annual freight vehicle kilometers, annual fuel consumed by freight vehicles and annual CO_2emissions by freight vehicles.	
	Ruesch and Glücker (2001)	Describe the voluntary introduction of a certificate system for freight vehicles in Copenhagen	86% of the 80 voluntary companies (300 vehicles) revealed that would like an obligatory arrangement. It is expected that the obligatory project would lead to a reduction of the number of lorries and trucks entering the city center (about 30%) and to a reduction of emissions (particles 25%, NO2 5%, NOx 10%), (Ruesch and Glücker, 2001).	
Time Windows	Musso and Coraza (2006)	Estimated the impacts of access restrictions to downtown in Rome	Results estimate a decreasing traffic during the day by 10%, by 20% during the restriction period and by 15% in the morning peak-hour. An increase in two wheels is expected (10%) as higher evening flows. Reduction of pollutant concentration levels (CO-20%, PM10-10% and benzene – 30%).	Regulation must be established according with the local conditions: cultural habits, opening schedule of the stores and local pattern of distribution. Stakeholders to be considered: PU, PR
	Holguin-Veras *et al.* (2005)	New York, USA Focus group, in-depth-interviews and Internet surveys to private sector stakeholders Private sector stakeholders' perception of challenges and potential of off peak deliveries to congested urban areas	(1) receivers' willingness to participate is crucial for the success of off-peak delivery initiative (2) carrier centered initiatives will provide an incentive for carriers to push receivers to do off-peak deliveries (3) tax incentives to receivers committed to do off-peak deliveries would foster participation in off-peak delivery programs.	
	Huschebeck (2003)	Cites a study carried out by PTV for a real business case with a commercial trip planning application	Results showed that without time restrictions 559 orders of the case study could be delivered within 20 trips resulting in a total of 2840 km. Imposing a delivery time window of 1 hour would result in 114 trips and 9605 km driven.	

Legislative and organizational measures (cont.)

Initiative	Author (s)	Description	Results	Remarks
Time Windows (cont.)	Huschebeck (2004)	Refers to the example of a Dutch company operating night deliveries	Operators assess up to 20% savings in transport costs.	
	Baybars and Dablanc (2004)	Experience of regulation of access for a specific time window in London: Central London Congestion Charge	The first six months monitoring showed that traffic delays inside the charging zone have decreased by an average of 14%. Journey time reliability has improved by an average of 30%. About 60000 fewer car movements per day now come into the charging zone. Car movements have reduced by about 30%. Van and lorry movements have reduced by about 10%.	
Reserved capacity strategies	Nam and Lee (2003)	Evaluated the impacts that would result from providing reserved capacity for trucks in the Seattle region	Results showed nearly 10 million dollars in annual travel savings for the trucking industry, a saving of about 2.5 minutes per average truck trip and almost 30 million dollars in annual travel time savings for single occupancy vehicles.	Although there are many factors to consider, one key concern is whether suppliers could take advantage of reductions in travel time and travel time variance that would result from the implementation of reserved-capacity strategies. This is a difficult question to answer and the author believes not even the trucking industry itself can answer. It is the recommendation of this study that the idea of reserved-capacity strategies for trucks continues to be presented to suppliers, to the public, and to other impacted agencies for discussion and consideration. Stakeholders to be considered: PU,C, PR
	Pimentel *et al.* (2008)	Evaluated the effects of a shared lane (public transport and freight traffic in Porto Metropolitan Area (Portugal)	Private transport would have an increase in fuel consumption (and CO2 emissions) of about 14%. Public transport wouldn't feel significantly the effects of such measure and freight transport would have decreases of about 24%. Similar variations would occur in what concerns CO2 emissions. Delays and travel times would follow this tendency: private transport would have increases resulting from the reduction of one lane of circulation, public transport would hardly feel any change and freight traffic would feel improvements of about 6% (for all the road network). In the long term the effects on public transport are expected to be more positive through potential transfers from private transport to public one.	

Legislative and organizational measures (cont.)

Initiative	Author (s)	Description	Results	Remarks
Licenses	Huschebeck (2001)	Practical Copenhagen	In Copenhagen, it was carried out a voluntary scheme, where vehicles would only get the license to access to preferred loading and unloading zones if their capacity use would be at least 60%. For one year and a half, almost all of the 80 companies were able to achieve the required 60% use of capacity (Huschebeck, 2001) and about 20% of the companies had to change their daily planning of goods during the experiment. The increase of the average load factor leads to less vehicles entering the city and consequently to less congestion, noise and pollution. It also contributed to reduce the operational costs of the suppliers once it forced them to change their planning in order to maximize the load factor of their trucks.	
Cooperative Delivery Systems	Ieda *et al.* (1992))	Estimated, based on modeling the benefits of Tenjin-District Joint Distribution Programme	Decrease of number of trucks in the served area by 65%, decrease of total distance travelled (km/day) by 28%, decrease of total distance travelled within Tenjin district (km/day) by 87%, decrease of total frequency of parking (times/day) by 72% and decrease of total parking time (h/day) by 17%.	Despite cooperative freight systems can reduce transport costs as well as environmental impacts, the number of carriers that are will to join this system only represent a very small part of freight traffic. Thus, the benefits achieved with this system in the overall traffic might not be significant. The author recommends, based in literature (Nemoto, 1997) the implementation of CDS as a complimentary measure with other initiatives in order to improve its profitability. Stakeholders to be considered: PU, PR
	Taniguchi *et al.* (1995)	Describes the results of a survey in Osaka-Kyoto-Kobe on CDS	57 of the 445 that reply to the questionnaire were involved in some kind of cooperative freight transport systems. 72% of the companies recognized that these systems lead to a reduction of costs and 56% to an improvement of reliability on pickup/delivery time.	
	Köhler (1997;2004)	Practical experiment in Kassel (Germany) and modeling the effects	With co-operation, carriers achieved a traffic reduction of about 60% in the city centre and the number of trucks driving into the city per day was reduced from 15 to 2 or 3 trucks. Through model calculations, it was shown that the loading volume for deliveries to the city center of Kassel improved from 40% without co-operation up to 80-90% with co-operation (Köhler, 2004). After introducing this system the total time traveled by trucks was reduced and queues of trucks for waiting to deliver goods on streets was also reduced.	

Legislative and organizational measures (cont.)

Initiative	Author (s)	Description	Results	Remarks
Cooperative Delivery Systems (cont.)	IRU (2004)	Describe a practical experiment carried out in Évora (Portugal) of a Ecoefficient Distribution	Authors indicate a decreasing on the number of trips per day and vehicle by 35%, a reduction on emissions by 35% if the system uses diesel fuel, and zero emissions if the fleet uses bio-diesel.	
	Taniguchi and Heijden (2000)	Taniguchi and Heijden (2000) analyzed the effects of cooperative systems on CO2 emissions within a small road network using dynamic traffic simulation	The level of CO2 emissions produced by the freight carriers involved in cooperation remains at almost at the same level as the base case when doubling the demand for freight transport, while it doubles from the base case without cooperation. The normalized CO2 emissions with cooperation were reduced by 51.8% from that without cooperation, when the demand was doubled.	
	Taniguchi *et al.* (2003a)	Simulated, based on modeling, the effects of cooperative systems combined with vehicle routing and scheduling	The total costs of carriers would be reduced by 19%, a rate largely attributable to the reduction of the distance traveled. Freight carriers not included on CDS would enjoy a reduction in total costs of 6,1% due to less congestion as a result of cooperation.	

4 Selection of an Indicator Set to Assess Goods Distribution Initiatives Performance

4.1 Introduction

The current chapter proposes a set of indicators which may serve as a framework for the assessment of goods distribution initiatives performance and for the analysis and comparisons of policy scenarios/strategies to mitigate negative impacts originated from goods transport and distribution activities.

The chapter begins with a short preface on section 4.2 about the conceptual criteria of mobility and sustainability. With this conceptual criteria in mind, it is emphasized in the following three sections the qualitative and quantitative criteria underlying good practice in the selection of indicators. Freight-factors scheme (included on the quantitative criteria analysis) helps to identify the causal linkages among the various factors within the framework and thus, to understand which factors can and should be measured. The consideration of the mentioned factors supports a general first set of indicators (Table 4.1) to be identified along section 4.6.

In section 4.7, the first list of indicators is combined and refined by one main feature: stakeholders' interests. The respective selection of indicators that better fit with the interests that should be considered (Table 4.2) is presented in section 4.8.

The second list of indicators, after being validated in section 4.9, includes both stakeholders' main interests and mobility and sustainability criteria, taking into consideration the essential qualitative and quantitative principles which based their selection. The result of the described methodology leads to a final compilation of indicators to be adopted on the micro simulation exercise described in Chapter 6 (Table 4.3).

4.2 Scope of measurement: mobility and sustainability criteria

To consider mobility and sustainability criteria on the development of a general set of indicators, it was established first, which mobility is expected to achieve and second, what issues from the 3 dimensions of sustainability are to be considered (Figure 4.1).

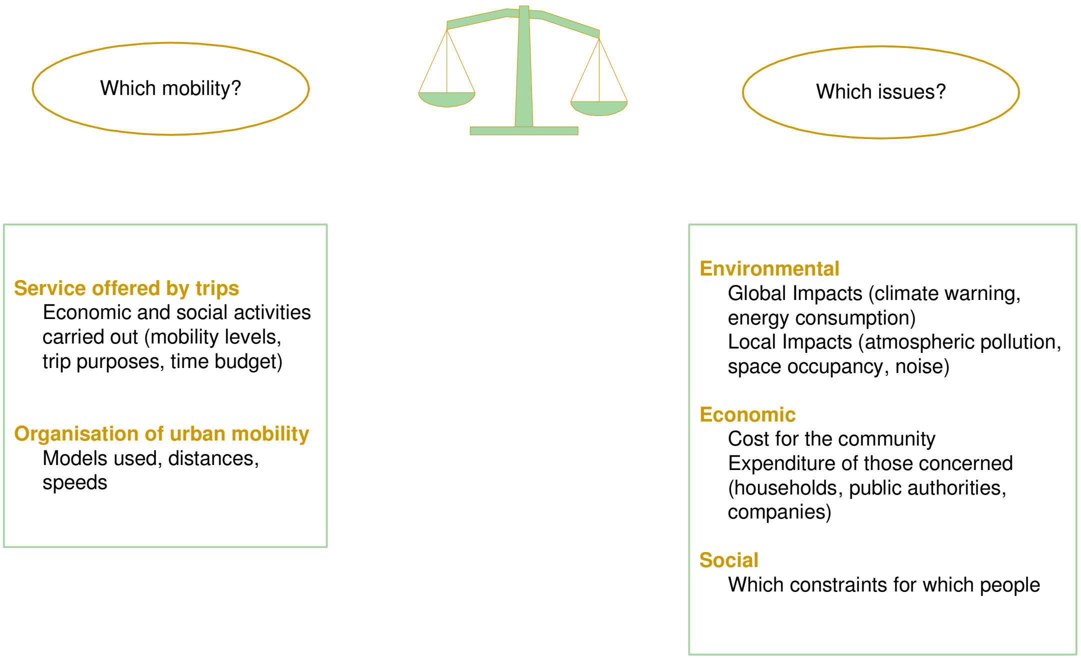

Figure 4.1. Mobility and sustainability challenges

Source: Adapted from Nicolas et al. (2003)

Both concepts strongly rely on a negotiated balance between private interests (operations efficiency) and public interests (economic costs, environmental pressure and social equity). The ideal mobility is the one which allows economic and social activities to be carried out with a minimum external cost to society. The expected sustainability is the one that corresponds to the transport and distribution of goods with lower environmental impacts within the city, minimum costs for city and industry and minimum externalities for society. Following these purposes, two brief comments must be added on the background of the selection of indicators and the assumptions that supported it.

First, because sustainability involves trade-offs between generations, all objectives listed on this work, even if they are taken to apply only to the present generations, are legitimately sub-objectives of sustainability. It is a fact that ideally, they should apply both to the present and to every future generation. However, once it is seen as impossible to predict and measure the level of sustainability at some distant point in the future, special emphasis is attached to the objectives whose current level will mean the most for the welfare of future generations. The respective indicators will reflect this tendency. Moreover, in what concerns to the three dimensions of sustainability (environmental, social, economic), some notes must also be made: a) the environmental indicators considered two sets of issues: those of global greenhouse effect and energy consumption and local issues of local atmospheric pollution. The pollutants were attributed to their place of emission on the basis of the trip which produced them; this allowed to estimate rates of emission per km (and per area) within the city. b) the economic indicators should in an ideal approach analyze the global costs of UGD system. Due to technical restrictions and as well to the fact that such analysis was not an objective of this study, the economic indicators will be more focused on operational and internal costs of the community as a whole and also of the different stakeholders: suppliers, public authorities and citizens. It should also be noted that the environmental pollution, such as atmospheric pollution, although it has been considered, has not been taken into account economically. The intention is to avoid the same element being taken into account twice, in the environmental sphere and in the economic sphere in the same target-analysis. The social indicators tried to consider which constraints and benefits would be attained for which stakeholders, in a period on which social equity issues are receiving a careful attention.

Second and last, mobility measurement is also evaluated to a specific period and it is not developed a prediction of its level in the future. Mobility indicators will differentiate passengers and freight mode and try to reproduce different tendencies for each of the considered stakeholders. Mobility is understood as an ease of movement and the chosen indicators will reflect that interpretation (cf chapter 2).

4.3 Definition and functions of indicators

Indicators reflect society's values and goals and are key tools to measure the performance of a system, the evolution of a process or to evaluate the results of a particular action on a complex system.

There are many different definitions of indicators, usually resulting from different perspectives. A definition adapted from the Organization for Economic Cooperation and Development (OECD, 1994) reads as follows: "*a statistic or parameter that, tracked over time, provides information on trends in the condition of a phenomenon and has significance extending beyond that associated with the properties of the statistics itself.*" Unlike simple statistics, indicators provide a summary indication of a condition or problem, and allow the observation of progress or change. This progress can be measured over time or against benchmarks, targets or visions for the future.

From other literature sources, indicators are defined as tools that can illustrate and communicate complex phenomena simply, including trends and progress over time (Henderson, 1996; Eckersley, 1997; Gilbert and Tanguay, 2000; EEA, 2005). Jacksonville Community Council[19] (1992) quoted by Ditor *et al.* (2001) presented a similar definition in quite a rather simple way: *"indicators are a way of seeing the 'big picture' by looking at a smaller piece of it. They tell us which direction we are going: up or down, forward or backward, getting better or worse or staying the same*". Indicators are quantities that give schematic information by means of several representations of a complex and wide phenomenon, thereby making clear a situation or a characteristic that is not directly perceivable. They help to reduce a large quantity of data down to its simplest form retaining essential meaning for the questions that are being asked of the data (Ott, 1978). Additionally, indicators provide a useful tool for policy making and for assessing policy implementation, (Mega and Pedersen, 1998). They represent an empirical model of the reality, implicitly assuming that a complex phenomenon could be represented by a limited number of variables (Musu *et al.*, 1998).

While the definitions vary, there is a consensus that an indicator should be more than just a simple statistic or measurement. The primary purposes of indicators are: a) to reduce the number of measurements needed to give an exact representation of a process or a situation and b) to facilitate the information communication process to the end-users and stakeholders. Indicators purposes are then reflected in several functions, such

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[19] *http://www.jcci.org/default.aspx*

as helping to identify trends, predict problems, assess options, set performance targets, and to evaluate a particular system.

On this particular study, the goal is to measure mobility and sustainability, using indicators that properly illustrate the performance of specific measures. To achieve such purpose, the selection of indicators will be carried out considering quality and quantitative criteria.

4.4 Quality criteria for indicators

Although indicators can be very different, varying to the use for which they had been elaborated, there are common criteria used by a range of groups and organizations in its selection. In general, indicator quality criteria mentioned in policy documents of some relevant international organizations (EU[20], Eurostat[21], EEA[22], UN[23] and WHO[24]) and in scientific literature (Mitchell *et al.*,1995; Mega and Pedersen, 1998; Ditor *et al.*, 2001; Cybernetix and STRATEC, 2003; Nicolas *et al.*, 2003; Marsden and Snell, 2006; Litman, 2007) commonly state that indicators must be clear and understandable, policy relevant, significant, accessible, and reliable and should aid in comparison, evaluation and prediction and decision-making at various levels.

In terms of quality criteria, indicators must also cover the most essential issues at stake, have strong coherence with the statistical database, be simple in its presentation so that they may be used by all those concerned and be adequate to represent the selected geographical or political area.

Results from the mentioned literature sources lead to the definition of the following principles (to ideally be applied) when selecting performance indicators:

a) Scientific validity

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[20] *"The EU Sustainable Development Strategy: A framework for indicators" and the Communication from Mr. Almunia to the member of the commission "Sustainable Development Indicators to monitor the implementation of the EU Sustainable Development Strategy"(EC, 2005)*

[21] *"Assessment of quality in statistics" report (2003, Methodological documents: definition of quality in statistics".*

[22] *"EEA Core Set of Indicators - Guide" (2005, EEA)*

[23] *"Indicators of Sustainable Development: Guidelines and Methodologies" (UN, 2001)*

[24] *"Monitoring reproductive health: Selecting a short list of national and global indicators" (WHO, 1997)*

Scientific validity is an important factor to consider particularly when using causal frameworks (as it is on this work), because a scientific basis for links between the stress indicators and the condition indicators selected must be established (see Figure 4.2). Some degree of uncertainty is inevitable when establishing these relations and thus it is important to understand: How well will it describe the impacts accurately? How big is the consensus on the legitimacy of the indicator? How big is the ambiguity of the calculations?

b) Representativeness

A representative indicator is one which is representative of the issue of concern (mobility and sustainability). Representativeness is an important characteristic because of the frequently-stated condition that the number of indicators should be manageable and therefore relatively small (Ditor *et al.*, 2001).

c) Relevance and easy to understand

Indicators should actually measure what they are supposed to measure. The selected indicators should represent something there is the need to know and should be of easy understanding to decision makers and to the general public. How well the indicator demonstrates a move towards or away from sustainability and mobility? How useful is the indicator for the end-users? How well the indicator is comprehensible to the public/decision makers?

d) Evidence of links of cause and effect

A good indicator is not only representative of an topic but highlights the links and interrelationships on the stress–condition–response sequence (like the ones shown in Figure 4.2).

e) Responsiveness to change

A responsive indicator can be expected to respond to changes in external stimuli, such as policy interventions. An example of responsive indicator often used is the air pollutants emitted resulting from the implementation of an initiative in comparison with a ‘do-nothing’ situation.

f) Comparability to target, thresholds or standards

The use of thresholds or targets in indicator development is an effective tool for measuring progress towards a variety of goals and is therefore important from a policy perspective. Data collection should be standardized so the results are appropriate for comparison between diverse times and groups.

g) Transferability

An indicator that can be used at different time and geographical scales can help users relate their own behaviors and decision-making to the local context and regional and national issues. How well the indicators can be used at different time periods? How well the indicators can be used at different geographical areas?

h) Accuracy, time-series data availability or collection

Indicators must be measurable and the uncertainty on the measure must be as small as possible. It is useless to have a conceptually very good indicator, if the methods used to measure its values give very uncertain results, from which no conclusion can be drawn.

i) Cost-effectiveness

The set of indicators should be cost effective to collect. The decision-making worth of the indicators must compensate the cost of collecting them.

j) Net Effects

Indicators should distinguish between net (total) impacts and transfers of impacts to different locations and times.

The final selection of indicators will try to accomplish these principles, validating them through a survey. It will likely be complex to find indicators that satisfy all selection principles simultaneously. Consequently, judgments will have to be made about the relative importance. Meaningfulness to stakeholders should be given first place in the list of selection criteria. Data availability limitations will exclude certain otherwise attractive indicators.

The following section identifies the quantitative criteria for transport indicators and urban goods distribution in particular. The defined quality criteria (section 4.4) will be used, together with quantitative criteria (section 4.5), as guidelines for the development of the first indicator set (section 4.6).

4.5 Quantitative criteria for indicators

In an attempt to identify quantitative criteria for transport indicators, it were previously defined what consequences or impacts need to be measured and how those effects were related with a set of causes. On the transport area and to the mobility and sustainability criteria, this approach typically leads to the measurement of safety, congestion, fuel consumption and environment. Due to a lack of adapted data, this work will not integrate questions linked to road safety. Consequently, the scope of the analysis will be narrowed to the one shown in Figure 4.2.

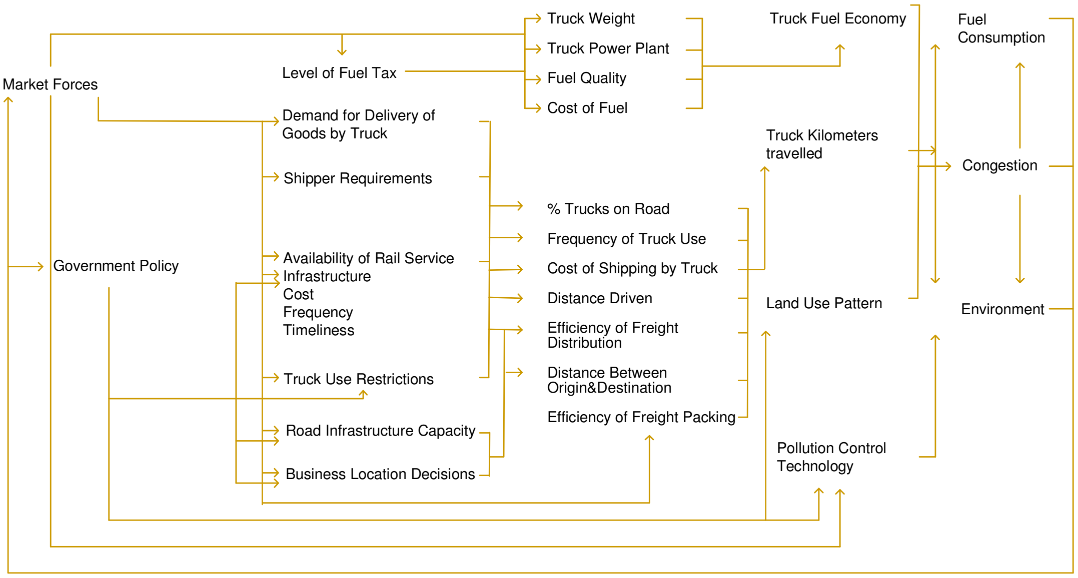

Figure 4.2. Freight factors affecting sustainability of the distribution system

Source: Richardson (2005)

Figure 4.2 presents a causal-based framework representing the influence of urban goods movement on the society and environment. Each of the referred impacts has variables which affect them, and factors affecting those variables, and so on. The arrow associated with each variable represents its direction of influence. On this way, to select indicators in a positive direction towards a better mobility and sustainability, it is necessary to change those variables that influence the impacts, measured by indicators. Fuel consumption, congestion and environment are impacts influenced most directly by land use, truck fuel economy and truck vehicle kilometers traveled. Behind these factors, many other (some even inter-related) can be found, but the illustration is a first step to understand the causal linkages among factors, reflected on the respective impacts that can be measured with indicators. Just giving a simple example of how the diagram should be interpreted, through a government policy, truck use restrictions can be implemented. Transporters and suppliers will predictably adapt themselves to those rules changing for instance, the frequency of truck use to supply the inner centre. This action has consequences on the number of truck kilometers traveled and as a result varies the fuel consumption, congestion of the area and the quality of the environment. To this example, possible indicators to evaluate a truck use restriction policy would be travel times (unit of time), fuel consumed on the area (liters), vehicle delays (unit of time) and CO2 emissions, respectively. Travel times and vehicle delays can be a measure of mobility, CO2 emissions can be a measure of social and environmental impacts and fuel consumption can be a measure of economic and environmental impacts (driver costs and natural resources depletion).

The quantitative comparison of these indicators between a scenario ex-ante and ex-post would allow to evaluate if the policy that was implemented was positive or not in terms of mobility and sustainability targets. Chapter 6 presents examples of the evaluation of potential scenarios, following this causal linkage methodology and using the set of indicators defined on this chapter.

The selection of indicators (section 4.6) is obtained considering the relations shown in figure 4.2 and the conditions and key points mentioned above.

4.6 Selection of general indicators

Table 4.1 presents a general list of **mobility and sustainability** (economic, social and environmental) indicators based on the relations shown in Figure 4.2 and on a review from qualitative and quantitative criteria already established. This review identified common indicators sets from EC Sustainable Development Strategy, the EC ETIS, the EEA TERM, Eurostat, OECD, US EPA, World Bank, UNECE, VTPI and JRC Well-to-Wheels study, and was complemented with scientific inputs from Dobranskyte-Niskota *et al.* (2007), Nicolas *et al.* (2003) and Schoemaker *et al.* (2006). Differences among the organizations and authors are thought to provide a sufficient degree of diversity and offer the overall comprehensive picture needed for the definition of an indicator set.

Table 4.1. Indicator framework for the evaluation of transport sustainability and mobility performance

Dimension	Theme	Indicators
Economic	Transport Demand and Intensity	1.Volume of transport relative to GDP (tonne-km; passenger-km) 2. Road transport (passenger and freight; tonne-km and passenger -km) 3. Railway transport (passenger and freight; tonne-km and passenger-km) 4. Maritime transport for goods and passengers (tonne-km and passenger-km) 5. Inland waterway transport (passenger and freight; tonnekm and passenger-km) 6. Air transport (passenger and freight; tonne-km and passenger-km) 7. Intermodal transport (tonne-km and passenger-km)
	Transport Costs and Prices	8. Total per capita transport expenditures (vehicle parking, roads and transit services) 9. Motor vehicle fuel prices and taxes (for gasoline and gas/diesel) 10. Direct user cost by mode (passenger transport) 11. External costs of transport activities (congestion, emission costs, safety costs) by transport mode (freight and passenger) 12. Internalization of costs (implementation of economic policy tools with a direct link with the marginal external costs of the use of different transport modes) 13. Subsidies to transport 14. Taxation of vehicles and vehicle use 15. % of GDP contributed by transport 16. Investment in transport infrastructure (per capita by mode/ as share of GDP)
	Infrastructure	17. Road quality - paved roads, fair/ good condition 18. Total length of roads in km 19. Density of infrastructure (km-km2)
Social	Risk and Safety	20. Persons killed in traffic accidents (number of fatalities -1000 vehicle km; per million inhabitants) 21. Traffic accidents involving personal injury (number of injuries – 1000 vehicle km; per million inhabitants)
	Health Impacts	22. Population exposed to and annoyed by traffic noise, by noise category and by mode associated with health and other effects 23. Cases of chronic respiratory diseases, cancer, headaches. Respiratory restricted activity days and premature deaths due to motor vehicle pollution
	Affordability	24. Private car ownership 25. Affordability (portion of households income devoted to transport)
	Employment	26. Contribution of transport sector (by mode) to employment growth
Environmental	Transport Emissions	27. NOx emissions (per capita) 28. VOCs emissions (per capita) 29. PM10 and PM2.5 emissions (per capita) 30. SOx emissions (per capita) 31. O3 concentration (per capita) 32. CO2 emissions (per capita) 33. N20 emissions (per capita) 34. CH4 emissions (per capita)
	Energy Efficiency	35. Energy consumption by transport mode (tonne-oil equivalent per vehicle km) 36. Fuel consumption (vehicles-km by mode)
	Impacts on Environmental Resources	37. Habitat and ecosystem disruption 38. Land take by transport infrastructure mode
	Environmental Risks and Damages	39. Polluting accidents (land, air, water) 40. Hazardous materials transported by mode
	Renewables	41. Use of renewable energy sources (numbers of alternative-fuelled vehicles) - use of biofuels 42. Total expenditure on pollution prevention and clean-up 43. Measures taken to improve public transport
Mobility	Mobility	44. Average passenger journey time 45. Average passenger journey length per mode 46. Quality of transport for disadvantaged people (disabled, low incomes, children) 47. Personal mobility (daily or annual person-miles and trips by income group) 48. Volume of passengers
	Service Provided	49. Daily number of trips 50. Structure of trip purposes 51. Daily average time budget
	Organization of Urban Mobility	52.Modal split 53. Daily average distance traveled 54. Average speed (global and per person)

To be used on the case study (Chapter 6)

The categorization illustrated on table 4.1 results from a review of the sources mentioned above. In the categorization proposed on this work (Table 4.3), indicators such as ‘external costs’ may be considered on the social and mobility dimensions rather than on the economic dimension (Table 4.1). Such difference of ‘categorization’ between tables, results from the adopted approach on this research, which regards the impact of congestion (external costs) more as a social effect rather than and economic effect. Such distinction does not invalidate the monetary quantification of the external costs that will be carried out along Chapter 6.

The list provides an indicator framework for the evaluation of **transport sustainability and mobility performance** in general. It includes all the modes of transport and even themes which will not be analyzed along the thesis. Such a detailed list gives an overall picture of the indicators framework and simultaneously allows the extraction of the ones to be used on chapter 6.

Despite the added value of the selection of a large number of indicators to the case study, only the ones with colored font in Table 4.1 will be adopted on the case study. The selected (colored) indicators 1) better reflect the mobility and sustainability challenges illustrated in Figure 4.1. and 2) better fit on the causal framework illustrated in Figure 4.2. Other indicators will complement this first selection (cf Table 4.2).

4.7 Interests and criteria of stakeholders

In section 4.6, it was selected a set of indicators according to their interpretability and relevance to the criterions in which the thesis is focused on. Now, the first set of indicators must be complemented by selecting those which are relevant to answer the stakeholders’ objectives and those which are easily available. Section 4.7 presents the role of stakeholders and its coordination in urban goods processes, so that it is easier to establish indicators in which stakeholders will recognize their interests. These indicators (Table 4.2) added to the first general list of selected indicators presented on Table 4.1 will lead to the list presented in section 4.8 (Table 4.3).

Figure 4.3 illustrates a simplified scheme of the urban goods distribution system and identifies some of the strongest relations between stakeholders. The overall system is constituted by stakeholders interacting according to their own interests, influencing and being influenced by the urban environment in which regional economy, legal conditions, transport infrastructure and surrounding environment play a relevant role.

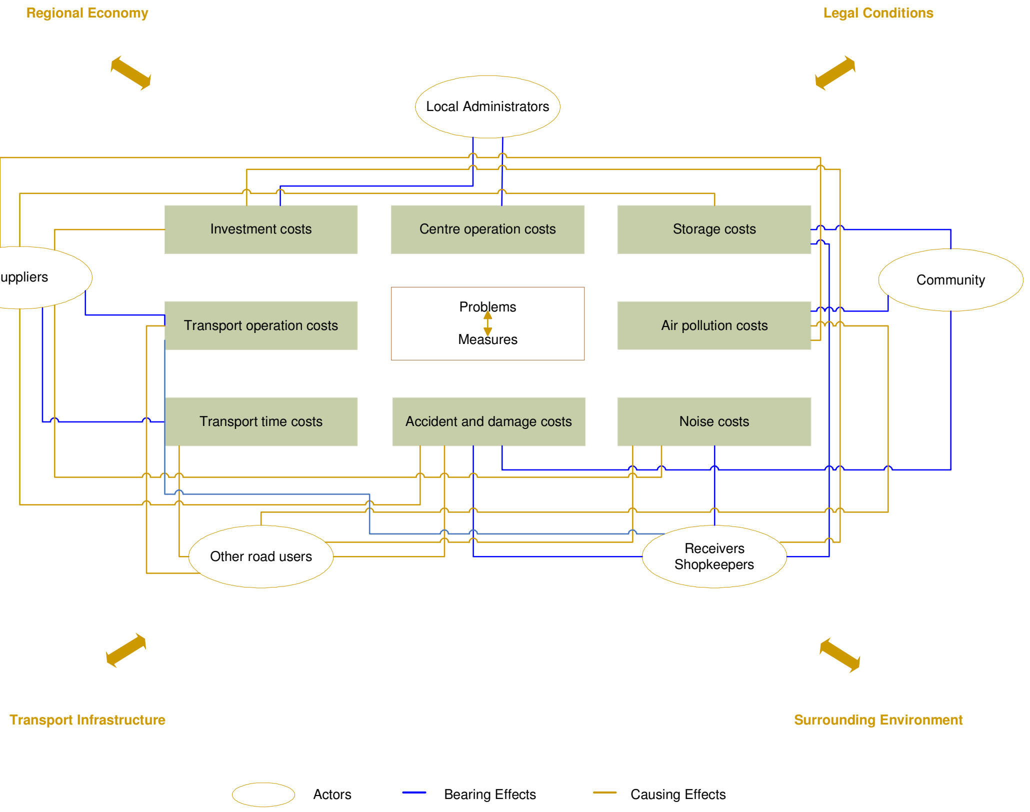

Figure 4.3. Urban goods distribution system

In their interaction those stakeholders try to find a balance between the impacts they create (causing effects) and the ones which affect them (bearing effects). The main challenge on the study of urban goods distribution system, under the approach focused on this work, is that the bearing effects of one group of stakeholders might be the causing effects of another group. Therefore, finding a balance between different stakeholders' interests requires understanding their role and preferences within the system.

Figure 4.3 complemented with the description presented bellow tries to explicitly and sufficiently reflect stakeholders' preferences, their relative role and expectations.

Regarding the organization of goods distribution system, sustainability and mobility may have a different meaning and content for each group of stakeholders, which may depend on their short-and long-term objectives and preferences. The main group of stakeholders to be considered in city logistics includes suppliers, residents (community), receivers/shopkeepers, other road users and (local) administrators, all of them with different and complex transportation and consumption needs.

The following description tries to reflect their needs and concerns. The group of stakeholders labeled as **suppliers** includes shippers and freight carriers. Shippers (manufacturers, wholesalers, retailers) operate from warehouses and are the customers of transport companies who send or receive goods from companies or persons. Shippers usually determine the pickup time, although they do not have absolute control of the delivery time. Freight carriers (transporters, warehouse companies) usually decide on the time and route that is more efficient for them to meet the delivery constraints imposed by receivers. Freight carriers establish the connection between shippers and receivers and have to satisfy both. Freight carriers are usually contracted in out-sourcing agreements and are expected to provide higher levels of service within the framework of just-in-time (JIT) transportation systems with lower costs. The main interests of **suppliers** are to minimize the costs of collecting and delivering goods to customers and to maximize their profits, within a given regulatory framework and a given transport infrastructure. They try to provide higher levels of service (profitability, safety, user satisfaction and shipper satisfaction) at the lowest cost.

Residents and users **(community)** are the people who live, work and shop in cities. Their wish is to minimize traffic congestion, noise, air pollution, and accidents close to their homes, work and recreational areas. Residents and users perceive goods vehicles in a negative way: those are the vehicles which obstruct passenger's circulation, make noise, park illegally, pollute, etc. So, they do not welcome goods vehicles using local roads, even if these vehicles carry goods that are to be consumed by them.

Goods are delivered to **receivers**. They are the ones that set delivery times, most frequently in mutual agreement with the carriers. Receivers want goods to be delivered on time and according with what it was established. Usually they do not care much about how goods get there as long as their requirements are fulfilled. They prefer a smooth, frequent, easily accessible, relatively cheap, punctual, reliable, safe and secure

door-to-door service and at the same time a minimum disturbance caused by goods transport.
They mainly establish delivery requirements based on their needs and profits. So, they are difficult to involve in initiatives which do not prove in advance to be profitable for them. Examples of receivers are individual consumers and shopkeepers.

Administrators and, in particular local authorities and policy-makers try to create and implement policies regulating the system operations at local (community) level, and subsidizing some services of public interest. They are mostly interested in raising the overall socio-economic welfare and controlling the externalities of transport operations (Janic, 2006). By one hand, they attempt to promote the economic development of the city, which requires considering the industry stakeholders interests. By the other, they want to alleviate traffic congestion, improve the environment and reduce road crashes, which can require the implementation of restrictions to suppliers' operations. This is a quite difficult role to play, particularly to make some politically difficult decisions on transport and to implement effective—but vote losing—initiatives (Begg and Gray, 2004).

Each actor, in its own role, tries to optimize its functioning, according to its own interests, deferring from the interest of its neighbor. This generates problems and conflicts to the achievement of consensual initiatives to be implemented in a limited space and infrastructure within urban area. These difficulties, originated by the diverse interests of stakeholders can be narrowed to a simple distinction of public (actors in the city) and private (actors in the transport chain) objectives (STRATEC, 2005).

Public objectives reflect administrators, receivers, residents and users (visitors, tourists, employees) concerns about promoting the public good. Public objectives are often related to the well-being of all stakeholders in a specific area, such as a) quality of life (accidents, noise, emissions, nuisance, etc.), b) sustainability, c) mobility and d) economic vitality.

Private objectives reflect suppliers and transport industry worries about improving the efficiency and profits of their service. Private objectives are often related to turnover levels like sales levels, customer levels, costs levels (operation and driving), service levels, and competition.

The balancing act of considering both public and private objectives for the establishment of more sustainable strategies in UGD, has proved to be difficult to achieve. It involves bringing together stakeholders with different expectations and objectives, who usually suggest different approaches and measures. Therefore, the challenge of develop and promote initiatives on these circumstances "*is not only finding an appropriate strategy but also one that all stakeholders will want to own and invest in*" (Henscher and Brewer, 2001). Stakeholders, not depending of their public or private interests, must want to be involved and participate in UGD decisions in order to easier find consensual strategies and indicators play a determinant role on their perception about the initiative. The best way to get their support is first, to understand and care for their needs and concerns, and second, to get them involved throughout the whole process: problem analysis, objectives definition, and selection of solution, implementation and evaluation (STRATEC, 2005).

Chapter 6 presents the evaluation of potential scenarios considering first, public objectives. When a scenario indicates a positive contribution towards an increasing (environmental and social) sustainability and mobility, it is then estimated the effect on private objectives (mainly cost level).

Table 4.2 illustrates the set of indicators which better serve the purpose of public and private interests and objectives for the evaluation of urban goods distribution sustainability and mobility performance.

Table 4.2. Indicator framework for evaluating UGD initiatives considering stakeholders interests

Adapted from Schoemaker et al. (2006)

Dimension	Theme	Indicator	Interests
Economic	Transport Demand	Volumes Transported into urban areas	PU, PR
	Logistics	Goods receivers Logistics costs Share of urban transport costs compared to total supply chain Salaries in urban freight transport	PR
	General Delivery Characteristics	Combined shipments Delivery days and times Regularity of trips Origin of delivery trips Number of stops per tour per day Trip length Distance between shops Trip times Travel time to and within city centre	PU, PR
	Employment percentage in transport and logistics	Number of jobs in transport Number of transport related companies	PU, PR
Social	Freight vehicles	Number of vehicles according to GVW and age Proportion of goods vehicles in total traffic Ownership of vehicles Vehicles operating in cities	PU
	Accidents and causalities in urban freight transport	Number of accidents Number of fatalities Involvement of freight vehicles in accidents Weekly distribution of accidents involving HGV's	PU
	Road user type	Cyclists Pedestrians Car drivers	PU
Environment	Energy use	Typical fuel consumption by vehicle type Energy consumption in urban freight transport Consumption of non-renewable fuel resources	PU , PR, C
	Exhaust emissions	Typical emission factors by vehicle type Share of urban freight in exhaust emissions	PU, PR, C
	Noise	Noise levels driving truck Noise levels loading/unloading truck	PU, PR
Mobility	Urban traffic flow	Number of vehicles entering cities Distribution of freight vehicles movements over day	PU, PR
	Performance	Freight vehicles kilometers Use of load capacity	PU, PR
	Home delivery	Home delivery services offered by shops Number of km covered by inhabitant	PU

PU – Public Interests

PR – Private Interests

C – Citizens (community), in some situations their interests are private, public or both

To be used on the case study (Chapter 6)

Table 4.2 provides an indicator framework for the evaluation of urban goods distribution initiatives performance considering **stakeholders interests**. It includes specific goods distribution indicators and takes into account the mobility and sustainability dimensions.

The 'interests' identified on the last column refer to the ability of the indicator to measure the main (public or private) stakeholder interest. For instance, on the mobility dimension, one of the proposed indicators is the use of load capacity. The use of load capacity reflects the efficiency of the service and on that way it is a good indicator to illustrate private interests. By other side, a low use of load capacity has impacts on the overall mobility and thus, affects society in terms of congestion and air pollution. On that way, this indicator is also adequate to illustrate public interests. The interests labeled as merely 'private' or simply 'public' do not exclusively concern only one of them, but concerns mostly the chosen label. This categorization is mainly based on the information obtained along chapter 3.

4.8 Selection of indicators

Based on literature review, results from Chapter 3 and on previous sections of this chapter, participation in meetings, discussions devoted to this topic and empirical evidence, it were chosen the indicators listed in Table 4.3. This set corresponds to the final selection to be validated by the survey and later, adopted on the case study.

The selection presented on the table should be interpreted, considering as stated by Litman (2007) that:

- indicators are an evaluation tool and should always come up together with other scientific information to avoid wrong interpretations;
- indicators should always be interpreted in the original context, considering the specific environmental, social and economic conditions;
- the use of indicators is one step on the whole planning process, which includes seeking advice from stakeholders, defining problems, setting up goals and objectives; identifying and evaluating alternatives, developing policies and plans, implementing plans, establishing performance goals and measuring impacts.

Table 4.3. Indicator Framework for Evaluating UGD initiatives mobility and sustainability performance considering stakeholders interests

	Indicator (unit)	Stakeholders	Description of the use of the indicator	Examples of project/organization using the indicator
Economic	Delivery times Supplier operational costs Deliveries/day Trip Lenght	PR	Delivery service is subdivided into the components of delivery time, delivery reliability, delivery condition and delivery flexibility. Delivery time can therefore be used as parameter of supplier delivery performance; it extends from the point at which the supplier parks to the point at which he leaves. Delivery times are related with supplier operational costs in a direct way: Lower delivery times can contribute to lower operational costs. Lower delivery times and lower operational cost are better. Deliveries/day and trip length are descriptive indicators.	Schoemaker *et al.* (2006);
Environmental	Energy Intensity (Fuel Consumption in liters by vehicle type)	PU,PR	As motor vehicles are the main users of transport fuel, the indicator is highly correlated with motor vehicle usage, which in turn measures indirectly the pressure on the environment through use of resources, energy consumption, air pollutant emission (particularly ozone, particulate matter, carbon monoxide and nitrogen oxide), noise pollution. This indicator has many linkages to other, for example, to the emission of sulphur oxides (SOx) and nitrogen oxides (NOx), reductions in the emissions of greenhouse gases, energy use, and land use change. In consequence, there are implications for ambient concentration of pollutants in urban areas, human health, ozone depletion, and expenditure on air pollution abatement. No international targets have been established, although some countries have fuel consumption targets for the automobile vehicle fleet. Lower fuel consumption is better.	(Henry and STRATEC, 2003) DfT TEBPP projects
	Emissions g per area or km by vehicle type (like NOx; VOCs, CO)	PU,PR, C	There are non-CO2 emissions limits established by EU directives (see case study) Nitrogen oxides are good marking elements of combustion engine processes, having at the same time various impacts on all levels. The exhaust of NOx emissions results in the souring which affects historic buildings in cities. For heavy, diesel engines the current EU level of 0.7–0.9 g/t.km could be reduced by 70% to 0.2–0.25 g/t.km, which is a feasible level for sustainability. VOC emissions are characterizing the fuel verticum. Many of them have direct toxic effect on humans and ecosystems, first of all, benzene and butadiene have carcinogen effects, while most of them have greenhouse and photochemical impacts. Carbom monoxide (CO) is a toxic gas which results from an incomplete combustion of diesel. High concentrations can be lethal, small concentrations can result in cardiovascular disorders and the corrosion of the repiratory tract. The higher the number is, the more damaging emissions are emitted.	Mészáros (2000); Litman (2007); Schoemaker *et al.* (2006); *see Chapter 3*

	CO2 emissions (g per area or km) Share of urban freight in exhaust emissions		The fossil CO2 is a basic indicator of energy use and greenhouse effects. The European Parliament has suggested to introduce mandatory CO_2 emission standards[1] to replace current voluntary commitments (140g/km by 2008) by the auto manufacturers (see ACEA agreement) and labeling. In 2007, the European Commission proposed for a new law to limit CO2 emissions by 120gCO2/km (COM 2007 – 856 final) for passenger cars and light-duty vehicles. The higher the number is, the more damaging emissions are emitted.	Mészáros (2000); Litman (2007)
Mobility and Sustainability (Social)	Average Speed *(excluding stops to make deliveries – km/hour)* Average vehicle journey time on the area Travel time *(sec/km)* Delay time *(sec/km)*	PU,PR, C	The lack of mobility has a number of consequences, such as causing delays and making journey times unreliable and thus it is many times measured by speed, vehicle journey time, travel time, delay time, among others. Reduced urban congestion and delays deliver economic benefits which cut operator delivery costs and generate regional multiplier impacts. Potentially, urban decongestion generates time savings for operators and other road users. Higher average speed is better (to analyze the improvement on mobility). Lower average vehicle journey time on the area, travel time and delay time are better. The selected indicators are also descriptive indicators.	Dinwoodie (2006) Litman (2007); Lomax *et al.* (1997); Cybernetix and Stratec (2003); Litman (2007); TSS (2007) *see Chapter 3*
	Distance Travelled by HGV, LGV and car (Veickm)	PU,PR	Reductions in lorry Kilometers in urban areas offer environmental benefits and fewer vehicular emissions of airborne pollutants. Motor vehicle travel (measured as Vehicle Kilometers Traveled [VKT], and Passenger Kilometers Traveled [PKT]) is sometimes used as a sustainability indicator, assuming that motorized travel is unsustainable because it is resource intensive and environmentally harmful.	Browne and Allen, (1999); Mega and Pedersen (1998); AEA Technology Environment et al. – The validity of Food Miles as an Indicator of Sustainable Development; Litman (2007) TSS (2007) Schoemaker *et al.* (2006) *see Chapter 3*
	Use of load capacity		Increases on vehicle load factor deliver mobility benefits which increases operator delivery efficiency and other road users. Likely, it also reduces environmental impacts.	
	Proportion of goods vehicles in total traffic		Descriptive indicator	
	Mean flow (veh/h)		Higher is better	
	Density (veh/km)		Lower is better	

PU – Public Interests

PR – Private Interests

C – Citizens (community), in some situations their interests are private, public or both

Important system boundaries worth it to be mentioned were that considerations were restricted to road transport and the focus on the effects of transports on the environment, economy and society does not consider possible interactions or indirect effects. It is also a limitation the fact that the only measured indicators of environmental sustainability are the energy conservation and emissions. Sustainability is much more than energy conservation (fuel consumption) and air pollution emission (CO2 emissions), which are highly correlated.

Although proper aggregation of indicators would simplify dealing with target conflicts and the prioritization of the various initiatives in the field of goods distribution, a scientifically valid method for the aggregation of environmental, economic and social indicators into a “sustainability index” does not yet exist. In addition, such aggregation would involve a loss of transparency and render the relative evaluation of the various indicators in the “negotial” process impossible.

On the basis of the current discussion, many more indicators could also enrich the set of suggested indicators and clearly there is room for discussion and debate on this choice. Virtually anyone can develop a different set of variables they consider to be indicators of sustainability and mobility performance. However, once the final definition of a set of indicators always depends on personal choices, there always can be a judgment error, not in the information represented by every single indicator, but in the overall view provided by the set. In an attempt to overcome the subjectivity inherent of personal choices, an inquire was carried out to validate the set of indicators illustrated in Table 4.3.

4.9 Validation of the selected indicators

The validation of the set of indicators illustrated in Table 4.3 was carried out with the assistance of scientific/technical experts. The support was obtained through a survey sent to 124 sampled people. This sample was selected from the list of participants of the *Grupo de Estudos em Transportes*, which gathers the main Portuguese research units on transports and related fields. The survey had 10 questions, as presented in Annex 4.1, and was available online in the period between 27th July 2008 and 27th August 2008 at http://FreeOnlineSurveys.com/rendersurvey.asp?sid=ex565b95lbmbk6z464272. 36 respondents (29%) evaluated and validate the set of indicators according with the following description.

The respondents were from transports, logistics and environment fields (50% working on research, 31% technicians/consultants, 13% were suppliers and 6% were public administrators). A significant majority of the respondents work on these topics for less than 10 years (88%), but 62% for more than 5 years, which assures a reliable technical knowledge. All respondents revealed to know the concepts of mobility and sustainability and 44% state their experience in projects and studies closely related to these concepts. A share of 19% even considered themselves experts on these topics. In what concerns to the knowledge of respondents on the selection of indicators to evaluate initiatives in terms of mobility and sustainability, results were encouraging: 87% of the respondents affirm to have experience on such task. Altogether, these figures provide a high degree of confidence on the knowledge of the respondents to validate the proposed set of indicators.

In what concerns to the principles listed on the section '*quality criteria*' (cf. 4.4), the ones that are identified more often on the set are: 'relevance' (22%), 'simplicity /easy to understand' (19%), representativeness (16%) and 'evidence of links and effects' (15%). All the indicators fulfill at least 6 of the 8 principles listed on the quality criteria section and 60% of the indicators even fulfill 7 of the 8 principles. The ones that fulfill more principles are the 'CO2 emissions', 'Fuel consumption' and 'Emissions NOx, VOCs and PM' as measures of 'Environmental Sustainability'.

It was considered that it would be helpful to use as many of these selected indicators as feasible in Chapter 6. However, after analyzing results from survey, it was decided that 'mean flow' was not a particularly appropriate indicator as: (i) 22% of the respondents state that would remove it from the set, and (ii) it was considered that indeed it wouldn't bring a relevant added value to overcome the negative evaluation results it got on the survey.

In an overall evaluation, the selected indicators were validated by respondents to measure mobility and sustainability in its three dimensions. 34% considered the indicators to be 'good' measuring the respective domain and 27% even considered them 'very good'. 24% did not considered them 'good' or 'bad'.

98% of the respondents considered the indicators from Table 4.3 to be a good tool of evaluation to reflect both, public and private interests and validated the categorization that has been done based on practices described in Chapter 3. 81% agree the selected set is effective and proper to measure mobility and sustainability on transports activities and 93% of them consider the use of indicators to evaluate the mobility and sustainability performance to be relevant to support policy statements and actions on urban transport systems.

Once proposed indicators have gone through this initial round of scrutiny, it is considered that the following set of selected indicators is validated to be used on the case study on the evaluation of initiatives on UGD:

- Delivery times
- Supplier operational costs
- Deliveries/day
- Energy Intensity (Fuel Consumption in liters by vehicle type)
- Emissions g per area or km by vehicle type (like NOx, VOCs , Particulate matter)
- CO2 emissions (g per area or km)
- Average Speed (excluding stops to make deliveries – km/hour)
- Average *vehicle* journey time on the area
- Travel time (sec/km)
- Delay time (sec/km)
- Distance Travelled by HGV, LGV, car, bus and taxi (Vehkm)
- Use of load capacity
- Proportion of goods vehicles in total traffic
- Density (veh/km)

Input indicators (mainly used to **describe** the distribution patterns of the area **and to select** plausible initiatives to be considered)

Output indicators (obtained through microsimulation as described in **Annex 5.1** and graphically illustrated along the case study in chapter 6)

5 Modeling Urban Goods Distribution and Transport

5.1 Introduction

In a context of increasing concern with congestion, pollution and issues regarding the road use in urban areas, decision makers have to decide between different alternatives in order to improve the quality of life of inhabitants and, at the same time, try to decrease energy consumption, pollutant and greenhouse gas emissions (Patier and Routhier, 2008). The more alternatives that can be generated, and the more completely potential outcomes can be evaluated, the better the chances for decision-maker to make the right choice. A great deal of effort has been devoted to the use of tools that can support decisions related to the evaluation of policy and planning of operational goods distribution initiatives. Among those tools, modeling has become very important for the quantitative evaluation of impacts deriving from alternative organizational/strategic and operational solutions.

Recent approaches about the methods to model goods distribution are very diverse from country to country and are mostly at an experimental stage (Ambrosini and Routhier, 2004). Thus, it is difficult to compare examples and to evaluate their respective outputs as reviewed by Patier and Routhier(2008): in France, the focus has been on large-scale data collection exercises (Routhier *et al.*, 2001); in Germany emphasis has been placed on experimenting city logistics schemes (Kohler, 2004); in United Kingdom, recent studies are focused on the definition of a methodological framework to understand urban goods movements (Allen *et al.*, 2003); in Japan the research focus has been on investigating the use of computer routing and scheduling systems with dynamic flow simulation to improve the efficiency of operations (Taniguchi and Thompson, 1999).

This diversity of approaches can be explained mostly by three main factors: a) the early stage of research on urban goods distribution, b) the complexity of modeling stakeholders' interests and c) the difficulty of defining evaluation criteria for assessing the impacts of alternative initiatives (Taniguchi *et al.* 2003b).

Chapter 5 has a determinant role on the structure of the dissertation and on its intrinsic objectives. It introduces microsimulation as a modeling technique and adopting the concepts of mobility, sustainability and urban goods distribution (defined in chapter 2), allows to evaluate the measures presented on chapter 3, making use of the evaluation criteria identified on chapter 4. Results from the application of microsimulation exercise are later presented on chapter 6.

Section 5.2 provides a rough overview on urban freight models in Europe. The synthesis of the review is presented based on a distinction between systemic and operational models. The compilation concentrates on the first ones and thus, it includes mainly models applicable by the local administration. The recent trend of the use of microsimulation on urban freight models, added to the consideration of stakeholders interests, and to the fact that there is not a systemic model developed for the case study area, justifies the choice of microsimulation as modeling technique on the current dissertation. Section 5.3 explains this option and Section 5.4 presents representative findings on the use of microsimulation tools, introducing the adopted model: AIMSUN. Section 5.5 emphasizes the relevance of data availability to urban freight modeling and outlines some difficulties on data collection in Europe. Last section concludes with a summary of the lessons and ideas from literature and sketch some perspectives about freight models.

5.2 Overview on urban freight transport and distribution models

Unlike the situation in passenger transport, most freight transport models are specified at the national or international level. There are numerous reviews of (national and international) freight models in the transport modeling literature. A comprehensive review of the existing freight models at larger scale is beyond the scope of this work as the number of published papers is vast and available books are numerous. Recent freight model literature reviews oriented towards either national or international level can be found in Pendyala *et al.* (2000), Burgess (2001), WSP (2002a), ME&P (2002a; 2002b), Jong (2004), Tavasszy (2006) and Transforum (2006).

The great importance of long trip distances in freight transport, added to the unavailability of freight model input data at the finer spatial levels, explains the fact that only a few freight models have been developed at urban scale (ME&P 2002b). Hence, in spite a comprehensive review of freight modeling at this geographical scale would be advantageous, literature on this topic is scarce. Consequently, on section 5.2 the thesis will be limited to the identification of examples on freight models at urban level in Europe and to the detailed description of few recent examples in city logistics. The overview does not claim to be exhaustive as it are mainly presented models applicable by (public) decision makers on the evaluation of alternative initiatives/strategies.

To simplify the description of the selected models, the available information was categorized, distinguishing two main model families: systemic models and operational models. Systemic models represent the city logistics system (activities, environment and stakeholders) and are mainly directed towards the improvement of liveability in cities. Operational models have a rather narrow scope, representing a specific group of stakeholders and respective activities, primarily directed towards the improvement of distribution efficiency. Other classifications available in the scientific literature (Boerkamps and Binsbergen, 1999; ME&P, 2002a; Taniguchi *et al.*, 2003b; Groothedde, 2005) could have been adopted, though it would be less suitable to the scope and objectives of the dissertation[25].

---

[25] *Boerkamps and Binsbergen (1999) suggest a classification based on the use of the traditional four-step approach, trip-based and the goods-flow based simulation models. Taniguchi et al.(2003b) categorizes it as supply models, demand models and impact models. ME&P (2002) differentiates truck models and commodity flow models. Groothedde (2005) uses as categorization element the function of the model, design (normative) or evaluation (descriptive).*

5.2.1 Systemic Models

An important distinction made along the dissertation has to do with two concepts, closely related and often used interchangeably: urban freight transport and goods distribution. Urban freight transport refers to the movement of products and goods in urban areas, no matter the mode of transport used. Goods distribution concerns with the activities of delivering and collecting goods in towns and city centers, including the ‘last mile’ transport and it is mainly carried out by road transport. It is also often referred to as ‘city logistics’ as it can also entail other processes (like handling and storage of goods, management of inventory, etc) inside urban areas.

The two concepts cannot be viewed in isolation but rather in the context of the entire system. However, in what concerns to freight modeling, urban freight transport and goods distribution can sometimes be represented in different ways.

The overview on freight modeling presented along the chapter highlights the difference between the concepts, although it does not ignore the many existent overlapping features. When the distinction between both concepts is clear, both urban freight transport and goods distribution models are presented separately, with a more detailed description of the latter ones. When the separation of the concepts implies a loss of coherence, the overview is provided as a whole as *‘urban freight models’*.

In the last years, specific modeling tools, both for goods distribution and freight transport, have been developed (Boerkamps and van Binsbergen, 1999; ME&P (2002b); Russo and Comi, 2004; Ambrosini and Routhier, 2004). Table 5.1 provides a list of *urban freight models* developed in Europe.

Table 5.1. Review of urban freight models in Europe

Adapted from: Patier and Routhier (2008)

Name	Initiator	Data collection	Carrying out		Funding		Maturity
			development	*implement*	*development*	*implement*	
FRETURB (F)	3	1	1	2/4	3	2	4
VISEVA (Ge)	4	1	1/4	4	2	2	4
GOODTRIP (NL)	1	1	1	nc	1	nc	1
GENMOD (NL)	2	#	2	2	2	2	3
MODUS (F)	2	2	2	2	2	2	3
CITYGOODS (It)	2	1	2/4	2/4	2	2	4
FRESCRA (It)	2	1	1	1	2/4	2/4	1
FRCA (It)	1	1	1	1	1	1	1
National Model (UK)	3	2	4/1				3
IRIS (B)	2	1	4	4	3	3	3
SEVILLA (Es)	1	2	1	nc	1	nc	1 or 3
ZARAGOZA (Es)	1	2	1	1	1	2	1
LEGEND	1: academics	1: specific (primary data)	1: academics	1: academics	1: academics	1: academics	1: prototype
#: unknown	2: local authorities (social demand)	2: secondary data	2: local authorities	2: local authorities	2: local authorities	2: local authorities	2: in progress
nc: aimless	3: country level	3: both	3: national authorities	3: national authorities	3: national authorities	3: national authorities	3: national authorities
	4: both		4: consultancy	4: consultancy	4: Europe	4: Europe	4: Several implementations

On the topic of urban goods *distribution* modeling, examples like FRETURB, VISEVA and GOODTRIP provide potential tools to analyze the impacts of alternative scenarios/strategies and support decision making on urban goods distribution.

FRETURB is a statistic-descriptive model developed in France. This model obtains the vehicles required for restocking in each traffic zone from the socio-economic data of each traffic zone of the study area. The model calculates the traffic volume in and between each zone, according to three types of vehicles, the type of transporter and the type of activity delivered. It allows the implementation of prospective schemes (Ambrosini and Routhier, 2004) to assess the impact of logistics, regulation and industry location measures on persons and goods (Patier, 2001; Routhier, 2001; Ambrosini and Routhier, 2004). The assessment is mainly based on measuring the contribution of urban goods distribution to air pollution, noise and traffic (Ambrosini and Routhier, 2004). Currently, several local authorities use it for diagnosis and simulation in their Master Plan (among which Paris, Lyon, Lille, etc.).

The second example is VISEVA and derives from WIVER, developed to the cities of Berlin, Munich and Hamburg (Germany). The survey data of WIVER is associated with structural data per area, thus delivery operations are generated per area according to the industrial sectors and the number of employees. Traffic between areas is calculated based on the types of round organization described by the drivers. Using the main approach of WIVER, Lohse (2004) developed VISEVA - W (Table 5.1) to compute simultaneously and interdependently the traffic volumes of different branches and vehicle types. The model starts with rates for mobility, modal split and assignment to vehicle classes/transport modes (behavioral data) as well as spatial data of the involved traffic zones, networks and conditions. After the generation of O/D relations the trip generation is calculated on the basis of a series of interdependent equilibrium formulas (Patier and Routhier, 2008). Currently, it is being used for analyses and support of planning steps in a specific city or region like truck guidance networks, action plans regarding commercial transport and calculation basis for the pre-test of traffic organization and fiscal measures (Ambrosini and Routhier, 2004; Patier and Routhier, 2008).

GOODTRIP, the example from The Netherlands, was developed to evaluate different steps of urban freight distribution using geographical, economic and logistical data. The model builds logistical chains by linking activities of consumers, supermarkets, hypermarkets, distribution centres and producers. A vehicle loading algorithm then assigns the flows of goods to vehicles. A shortest route algorithm assigns all tours of each transportation mode to the corresponding infrastructure networks. The results are logistical indicators, vehicle mileage, network loads, emissions and finally energy use of urban freight distribution. GOODTRIP is currently not implemented, although as a conceptual and theoretical model, it brought some valuable insights to the development of urban goods distribution modeling.

On the specific topic of urban freight *transport* modeling, besides the good example from the Table 5.1 of GENMOD (Amsterdam), tools like the Copenhagen model, VENUS (Germany) and the NATRA (Stockholm), described by ME&P (2002), are applied in a successful way in Europe and seem to be good attempts to model freight flows. GENMOD was developed to identify freight flows within the city area to support the accuracy of the existing passenger model. The Copenhagen model was used to forecast the impacts of a new infrastructure in combination with a pricing regime. The German model VENUS was/is used an add-on to the existing passenger model and the Stockholm model is based on telephone survey data and forecasts freight transport within the city conurbation.

Additionally to the previous examples, specific urban freight models are described in scientific literature. Due to the intrinsic characteristics of these models which usually allow a onetime experiment, either because they are just theoretical exercises, or their aim is to solve a specific issue in a certain area, scientific references are to a certain extent specific. Kraus (1998), Ma (1999) and Russo and Carteni (2006) present examples of those models. Kraus (1998) describes a model for estimating the length of trunk tours of freight vehicles for evaluating the environmental and economic impacts of distribution systems. This model determines the tour length from the central warehouse to customers related to the average distance between them, the size of the order and the vehicle capacity, average vehicle load, and the average number of customers in a tour. The test results have good accuracy compared with the real tour length. Ma (1999) presents a model that predicts the air pollution and noise generated by freight vehicles at intersections. It was used to estimate the environmental capacity of a major freight route in Osaka, Japan. The effects of controlling access during peak hours and promoting low emission vehicles are determined. Russo and Carteni (2006) propose a simulation model to apply in Campania region (Italy). The model estimates the goods movements of town zones (occupancy of the roads, just as by vehicle flows as by on-road parking vehicles) according to the logistic strategy of the shippers and of the haulers/transporters, the environment and the characteristics of the establishments and the urban land use.

From the systemic models briefly described, it is noticeable that in spite of different framework methods, similar trends emerge at the output level. Systemic models focus on the prediction of environmental, economic and social impacts from the movement of goods in cities. From an environmental point of view, they analyze local harmful effects like noise, pollution and traffic congestion. From an economic point of view, they aim either at revitalizing urban centers, developing regional economies and reducing operational costs (usually referring to travel times and delays experienced by passenger vehicles as well as freight operators). From a societal point of view, they seek for improvements on quality of life. Altogether, these effects are reflected on the ones intended to evaluate on this work: the impacts of urban goods distribution solutions in terms of sustainability and mobility. This focus basis the orientation of the thesis to systemic models, even if not neglecting the important role of operational models on urban freight transport system.

5.2.2 Operational Models

The goals of operational models used by private companies are different from systemic models used by public authorities. Operational models are primarily directed towards the improvement of distribution efficiency and consequently, include elements of logistic organization. They usually assist operations and logistics managers in the formulation of competitive operations and logistics strategies, like the number of warehouses in the network, the inventory policy and transport planning, etc.

The list of operational issues and modeling solutions is vast and some of the models aimed at each of these areas have been reasonably effective in their limited domains (Wigan and Southworth, 2006). For a detailed description of operational models applicable by companies it is recommended to read Raicu and Taylor (2004) for Decision Support System (DSS) used to manage the real time operation of the trucks in the fleet; ME&P (2002a), Bodin *et al*. (1983), Golden and Assad (1988) for optimizing route and call sequence in vehicle routing and scheduling (VRS); ME&P (2002a) for the optimization of the full range of costs including warehousing/transhipment, MHE, stockholding, handling and transport; Scapparra and Scutella (2001) for facility location models and Silver *et al*. (1998), Scarf (2002), Smits (2003) and Sussams (1995) for inventory models.

5.3 Modeling technique

Urban freight models described above were categorized in systemic and operational models. Such distinction reflects the main aim of the modeling exercise but does not directly indicate the modeling technique to be used. Section 5.3 makes a brief introduction to the technique adopted on this work.

Over the last decades, freight transport models considerably evoluted in terms of techniques employed. A detailed description of the main lines of development in freight modeling can be found in Chisholm (1973), Williams (1977), Bergman, (1987), Crainic *et al*. (1990), Tavasszy (1996), quoted by Tavasszy (2006). The summary of those developments, illustrated in Table 5.2, reveals that despite the diversity of approaches, an increasing harmonization in methods and techniques used can be observed.

Table 5.2. Developments on freight models approaches

Source: Tavasszy (2006)

<table>
<tr><th>Decision problem</th><th>Typical modeling challenges</th><th colspan="3">Typical techniques employed</th></tr>
<tr><td>Production and consumption</td><td>Trip generation and facility location
Freight/economy linkage
Consumption patterns</td><td rowspan="2">LUTI (‘70s) and SCGE (‘90s) models</td><td colspan="2">Trip generation models, I/O (‘70’s)</td></tr>
<tr><td>Trade</td><td>International trade
Value of volume conversion</td><td>Gravity models, synthetic O/D</td><td rowspan="4">Agent based simulation models (‘90’s)</td></tr>
<tr><td>Logistics services</td><td>Inventory location
Supply chain management considerations</td><td colspan="2">Logistics choice models (‘90’s)</td></tr>
<tr><td>Transportation services</td><td>Choice of mode
Intermodal transport
Light goods vehicles</td><td>Simple trip conversion factors (‘70’s), discrete choice (‘90’s)</td><td rowspan="2">Multimodal networks (‘80’s)</td></tr>
<tr><td>Network and routing</td><td>Routing and congestion
Tour planning
City access</td><td>Network assignment (‘80’s), simulation (‘90’s)</td></tr>
</table>

The typical techniques employed on freight modeling along the last decades reflect, first of all, a general trend of increasing integrative treatment of *stakeholders* perspectives, and secondly increasing detail of the behavioral content of models, down to the level of *microsimulation*[26]. Both factors derive from the challenge to make explicit different single decisions of heterogeneous stakeholders with different roles without distortions.

Despite this increasing harmonization, there is yet no universal approach, neither it is expected to be, capable of dealing with all variables, all situations and all possible scenarios in urban freight. However, considering a) the fact that there is not a specific

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[26] *The prefix micro indicates that the simulation model is formulated at the disaggregate or micro level of individual decision-making agents or other units, such as individual persons, households, vehicles and firms.*

(systemic) model developed for the case study area, b) the recent increasing use of microsimulation on freight models (Table 5.2) and c) the scenarios which are intended to be analyzed on chapter 6, microsimulation was chosen as the best approach to deal with the topic.

Microsimulation is a modeling technique widely used within the field of logistics (Groothedde 2005) and transportation (Babeliowsky 1997; Manivannan 1998). Law and Kelton (1991), Banks (1998), D'Este (2001) and Austroads (2006) offer an overview of the benefits of using simulation as a research approach. The use of microsimulation as technique to describe the behaviour and perspectives of stakeholders in the system has emerged in the last decade (Groothedde, 2005; Dowling *et al.*, 2002; Liedtke *et al.*, 2006b) and its potential to evaluate prospective scenarios makes it a powerful tool for studying solutions that are not yet available in practice (Patier and Routhier, 2008; Groothedde, 2005).

Microsimulation is especially suited to 'what if' modeling and testing distribution systems that involve complex system dynamics and inherent variation. By creating a representation of the system, it can be assured a much better control over the experimental conditions than would generally be possible when experimenting with the system itself. It models the performance of scenarios one at a time; neither generates alternatives nor chooses the best. Potential solutions are evaluated until the performance of one or more is acceptable. There are no guarantees that the chosen alternative – the best alternative that has been evaluated – is the best solution.

In the particular case of this work, the strength of the microsimulation technique is in being able to provide decision makers within explicit choice contexts with respect to:

a) Relevant characteristics of the stakeholders involved (representing synthetic actors with relatively simple behavior rules, based on observations and assumptions on cost-rational behavior). Stakeholders, not depending of their public or private interests, must be involved and participate in UGD decisions in order to easier find consensual strategies and microsimulation can play a determinant role on their perception about the initiatives.

b) Relevant characteristics of the choice context (in terms of the options involved, the constraints faced by the stakeholders, etc.)

c) Any context-specific rules of behavior that may apply.

Successful applications and case studies on the use of simulation modeling on urban goods movements are described on the following examples.

In The Netherlands, the design of automated underground freight systems was supported by simulation modeling. It provided a fast and flexible decision support tool for the early phases of design for a complex system where experts from several areas were required to interact. It also allowed a number of alternatives to be evaluated, and consequently, increased the quality of alternatives that were developed (Taniguchi *et al.*, 2003 b).

At the Randstad, a dense urban conglomerate of municipalities in the Netherlands, simulation modeling was used to evaluate an intermodal system for transporting solid waste (van Duin and Ham, 2001). Simulation was used to determine optimal routes of ships to minimize the number of containers required. Changes in traffic congestion as well as in the economic feasibility and environmental effects were estimated.

5.4 Microsimulation tools

Microsimulation is a powerful tool for analyzing solutions that are not yet in practice, describing in a synthetic way the behavior and perspectives of stakeholders in the system. Traffic simulators reflect that primacy, being used as a general rule in local or theoretical cases to simulate changes to improve the efficiency of the transport system (Groothedde, 2005). A survey reported by Algers *et al.* (1997) states that 84% of microsimulation users use traffic simulation for the evaluation of schemes, design and testing of strategies as the most common application. Traffic simulators are particularly appropriate to assess alternative scenarios and to study complex situations when analytic approaches may not be suitable, without changing the actual system, which may be costly and/or unsafe (Fang and Elefteriadou, 2004). **Considering there is not a specific systemic model developed for the study area, it will be used a traffic simulator to test alternative scenarios, which reproduces the same conditions as the first ones.**

There are a large number of traffic simulators commercially available, which quantify detailed performance measures to aid the decision-making process to evaluate an alternative solution (Haas, 2001). Examples of well-known microsimulation software models are VISSIM, Simtraffic, Paramics, CORSIM and AIMSUN. There are other packages that are also capable of simulating goods distribution. These examples were mentioned because they are representative of the wide variety of commercially available microscopic and stochastic traffic simulators.

It is beyond the scope of this work to evaluate commercial traffic simulators. Such procedure would very quickly become obsolete because even though the current version of a traffic simulator would not support a particular feature, future versions of that package may incorporate it.

More relevant than to select the model of the market with wider functions is to examine whether particular characteristics are present in a specific simulator. Different needs dictate different weights by the user further differentiating the simulators. Therefore, the selection of the most appropriate model for a given case should be based on specified factors, including the characteristics and requirements of the problem, the objectives of the study, ease of use and the familiarity of the user with the model (Fang and Elefteriadou, 2004).

The characteristics to be considered in the choice of a package can be supported by technical and non technical factors. (Xiao *et al.*, 2005) identify as technical issues relevant to the choice of a package the: a) experience in applying a package, b) suitability of the features and parameters in a package to simulate the phenomenon that the user wishes to investigate, c) sensitivity of the required parameters on specific features to be analyzed in proposed scenarios and d) accuracy of vehicle movement logic such as lane changing and car-following maneuvers. Non-technical (and complimentary) factors include the level of: a) training and expertise with the model, b) support from the software supplier and c) transparency of the package structure and outputs so that meaningful interpretation of model results and hence decision making are possible

The consideration of the previous technical and non-technical factors, complimented with an analysis of the ability of the features of the chosen package to study urban goods distribution in Porto, lead to the choice of the micro simulation model AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks).
AIMSUN was developed by the Universidad de Catalunya, Spain (1995) and is a model able to reproduce the real traffic conditions in an urban network. This dynamic

simulation model tracks individual vehicles, reproducing the monitoring of fleet vehicles in a real time fleet management system, gathering dynamic data (i.e. current position, previous position, current speed, previous speed, etc.) while following the vehicle, in a similar way that in real life an equipped vehicle could provide (Barceló *et al.,* 2005).

The number of vehicles using the network is defined by specifying origin-destination (O-D) data, which can be done using an assignment model or a simple dynamic route choice model buid-in. AIMSUN is able to function either as a stochastic model or a traffic assignment model using O/D tables. This is more advanced than other models like SimTraffic which is purely stochastic, CORSIM with limited O/D capabilities and a static trip assignment throughout the simulation or Paramics which uses and relies on origin-destination matrices to derive traffic volumes (Fox, 1997; Gettman and Head, 2003; Jones et al., 2004).

AIMSUN, as most of traffic simulators like VISSIM, Simtraffic, Paramics or CORSIM, uses a time stepping approach where the vehicles are moved along the road network using a fixed time step, typically at one-second intervals (Gettman and Head, 2003; Jones *et al.,* 2004). Each vehicle is moved according to the physical characteristics of the vehicle, the fundamental rules of motion and rules of driver behavior (Dowling *et al.,* 2002). The behavior of each vehicle on the network is continuously simulated, and traffic conditions are identified by the composition of network flows in the access points and in the links. The microscopic simulation approach is based on reproducing individual vehicles according to car-following, lane-changing, gap acceptance[27] and other behavioral models, which have been calibrated in a wide variety of circumstances (Barceló *et al.*, 2005). As a consequence of the ability to reproduce realistically traffic flows on a network by simulating individual vehicles, AIMSUN can generate many type of dynamic information for any component of the model, including the goods distribution vehicles.

AIMSUN, in a similar way to other traffic simulators, provides outputs that allow efficiency and environmental indicators to be measured. Such feature is achieved allowing to attach specific models to particular classes of vehicles, which simulate the impact by each individual vehicle travelling through the network. The policy scenarios

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[27] *The gap-acceptance behavior of drivers in AIMSUN is modified based on the delay time, which distinguishes it from most of the models.*

to be tested are transformed to 'model language' by changing some of the model parameters or the model database and replications are run. The outcome evaluates each scenario and initiative/strategy. The outputs provided by AIMSUN include a continuously animated graphical representation of the traffic network, a printout of statistical data (flows, speeds, journey times, delays, stops, fuel consumption, pollution emissions), and data gathered by the simulated detectors (counts, occupancy, speeds, queue lengths). The package does not produce outputs to measure safety or comfort indicators, a usual weakness of microscopic simulators. Such limitation was not considered relevant or restrictive to the study of urban goods distribution in Porto. AIMSUN will be calibrated on the case study, incorporating all the required data in order to become and behave as a systemic model for the city of Porto.

5.5 Data Availability

Problems experienced with urban freight models are often attributed to political and technical reasons. In political terms there’s a lack of awareness of the importance of the topic as well as a lack of motivation to interfere in urban deliveries optimization, often considered a private industry issue. In technical terms, it is difficult to model urban freight mostly due to its particular features and to the lack of knowledge and adequate input data.

This section emphasizes the relevance of data availability to urban freight modeling and outlines some difficulties on data collection in Europe.

In most of the European countries, there are **no specific on-going urban freight activity surveys**, which mean that available data is not exhaustive and comprehensive enough, and that it is difficult to be compared. An enquire to 43 medium sized European cities revealed that about 58% were not collecting data on urban freight transport (Ruesch and Glücker, 2001). Usually freight related data is collected by national government departments and other major public institutions and it is included in large transport surveys. Different structures set up in urban freight data collection lead by consequence also to different objectives, views, approaches, priorities and results so that it is very difficult to compare different exercises.

Table 5.3 summarizes the types of data used for urban freight knowledge.

Table 5.3. Available UGM data and their utility

Source: Patier and Routhier (2008)

Type of data collection	Countries	Concerns	Level	Useful for UGM	Condition for Modeling
Commodity flows (O/D)	Belgium, Sweden, Switzerland	Exchanges between regional areas	N	No	
Site/Land Use/Establishment surveys	Belgium, Germany, France, UK, Netherlands	Movement generation	N SUS R	Yes	Large stratified sample
Goods vehicle activity surveys (including driver diary surveys)	All countries, except Hungary, Netherlands	Vehicle use and traffic	N SUS	Yes	To know the link with the generator
Shipper surveys	France, Switzerland, Belgium, Germany, Spain, Italy	All sending	N, OUS, SUS, CD	Yes, if we find the consignee	Only for supply chain models
Receiver surveys	France, Switzerland, Belgium, UK, Germany, Spain, Italy, Netherlands	All deliveries	SUS N N	Yes	Road occupancy models
Good Vehicle fleet licensing data	All, Except Hungary Spain	All vehicles	N SUS R	Yes	For calibration
Traffic counts	Germany, Portugal Sweden Belgium, France, UK Hungary, Italy, Netherlands, Spain, Switzerland	All vehicles	N AUA SUS SUS SUS	Yes	For calibration
Distribution industry surveys	Germany, Italy, Netherlands, UK	Logisitcs chain	CD	No	
Vehicle operating cost	Belgium, France, Italy Germany, Netherlands, Switzerland Spain	Cost	N CD R	No	
Loading/unloading/parking infrastructures data for goods vehicles	Belgium, Hungary France, Portugal, Spain Netherlands	Way of deliver	OUS SUS AUS	Yes	If linked to nearby activities
Data on road accidents involving goods vehicles	All, except Hungary, SPain	Security	N OUS	No	
Data on lorry/lorry load thefts	Belgium, France, Netherlands, UK, Germany, Switzerland	Security	N CD	No	
Employment surveys in freight transport and logistics industry	All, except Hungary, Sweden, Switzerland	Employment	N	No	
Land use databases for town/city needed for freight modeling	France, Germany, UK Italy Portugal	Location, Road Occupancy	N OUS SUS	Yes	Zonal analysis
Port freight traffic data in the urban area	Netherlands, UK Belgium France, Germany	Contribution of port to UGM	N OUS CD	Yes	If urban activity can be extracted
Rail freight traffic data in the urban area	UK Netherlands Germany	Modal share of UGM	N OUS CD	Yes	If urban activity can be extracted
Inland waterway freight traffic data in the urban area	UK, Netherlands France, Germany	Modal share of UGM	N CD	Yes	If urban activity can be extracted
Airport freight traffic data in the urban area	Belgium, France, Germany UK, Netherlands	Contribution of airport to UGM	CD N	Yes	If urban activity can be extracted
Freight NTIC data (from cameras, sensors&other automatic data capture devices)	Netherlands, UK	Movements of vehicles, traffic	CD	Yes	For calibration

Key to Table 5.3

For each line, countries are facing the level key.

?	uncertainty exists about whether freight data is collected		
N	national survey/data collection	SUS	survey in some urban areas
R	regional survey/data collection	OUS	survey in one urban area
AUS	survey in all urban areas		
CD	data collected by companies, trade associations or other commercial organization		

There are some important factors that might explain the lack and the inappropriate freight related data that is currently collected. First, organizations who collect data, namely urban authorities, need to know what data to collect and how best to achieve it. Due to the frequent lack of communication between urban authorities and industry about urban freight issues, no advices are given and consequently, many types of data are not currently collected or are not suitable for its purpose (Browne, 2005). Second, there are restrictions on data sources and on provided data. Some data sources only provide data at a national or regional level and when data is provided at a city level, the small sample size of the data can affect its **reliability**. Additionally, urban freight surveys that have taken place tend to be one-offs and consequently, regularly updates of the model are not carried out and so their usefulness vanishes rapidly over time (Emberger, 2004). Therefore, it is difficult to make links and comparisons between data from different sources/surveys. Lastly, large freight vehicles operators such as express and parcel carriers have detailed data about their operations, which they use for planning purposes. However, despite its potential in understanding urban freight activity in specific sectors of the freight sector, this data is usually not available due to **commercial confidentiality** (Guglielminetti, 2005).

Besides these main restrictions, there are some specific gaps in urban freight data. There's usually scarce information about vehicle routing/journey, journey time/reliability of journeys, environmental impacts at supply chain/sectoral level, information/data on loading/unloading activity, lack of linkage about freight intermodal actions, available freight data does not provide detail about supply chain stages between which freight is transported (it provides snapshot of vehicles at unspecified point of chain), existing survey work tends to lack detail about land uses between which goods movements take place, quantitative data about home delivery, operating cost data, urban management flow data, traffic generated by warehouse activity, consumer purchasing behavior data and commercial data that is confidential (Browne, 2005; Routhier, 2005).

The lack of urban freight data collection in Portugal contributes to the frequent adoption of benchmarking solutions, without further studies to support its implementation. The modeling exercise described in Chapter 6 makes use of specific data collected for the case study and evaluates solutions that were already labeled as ‘good practices’ in other contexts. The approach adopted on the current dissertation can play a determinant role to support decision making and to improve the awareness of the importance of urban freight data collection.

5.6 Remarks/Key findings

The complexity of modeling freight at urban scale has been the subject of a growing body of literature, and the associated research being both conceptual in nature, due to the complexity of the problem and the numerous actors, such as retailers, suppliers or consumers involved in the transactions, as well as analytical.

The literature review on urban freight transport and distribution models does not identify guidelines to the use of a common approach in urban freight models, neither it is expected to be achieved at some point, but it allows to recognize some common ideas and difficulties (Ogden, 1992; Reagan and Garrido, 2000; Routhier *et al.*, 2001; Ambrosini and Routhier, 2004; Patier and Routhier, 2008). The following paragraphs emphasize those findings.

The intensity of the policies and research are closely related to the perceived urgency of the problems. Freight transport has often been considered to be a private sector issue rather than a matter for the involvement of urban authorities (Patier and Routhier, 2008). These facts contributed for urban freight transport to be rather overlooked in the work carried out by urban planners and researchers. Urban freight transport and distribution are often seen merely as a cause of problems in cities, and the awareness of its importance to the urban economy and society seems to be low, among the general public, local administrators and city planners. This **lack of knowledge** contributes for policy makers and technicians to only take action to oppose the bad effects of urban freight deliveries. There’s not a proactive position or a real strategy. Moreover, this lack of expertise contributes for modeling to be often considered by local authorities and decision makers as a tool they cannot (or need to) use (Patier and Routhier, 2008).

Freight models are strongly influenced by personal transport modeling (traditional travel behaviour models and land use and transport models), but there is still a lag in freight modeling compared with personal transport modeling (Lautso *et al.*, 2004; D'Este, 2008). This lack of awareness and knowledge on freight topics has often led to transport policies being planned mainly from the perspective of passenger transport, without adequate consideration of the special features of freight transport. Consequently, the fact that urban goods transport and distribution operate within integrated supply chain management whereas passenger transport serves individual needs has been disregarded in most transport policies in Europe.

There is a lack of detailed studies on freight modeling and in particular, on the behavior of different actors. Urban freight transport and distribution involves a complex and diverse number of stakeholders, with specific goals and heterogeneities among them, which are often poorly identified on models.

Some of the unease over the current state of freight modeling is due to the wider range of clients they are asked to serve, and to a lack of correspondence of their goals with traditional transport planners and policy forecasters (Wigan and Southworth, 2006). Public authorities and decision makers make policies and restriction rules without taking suppliers requirements into account.

The diversity of patterns of origins and destinations, the short distances and the time sensitive nature of many deliveries, promoted urban freight trips to be mainly carried out by road. The road mode and its inherent flexibility lead to trip patterns that can vary from single direct trips to multiple rounds. Such diversity of patterns makes it problematical to model urban freight as a single market and raises the issue of data availability.

Lastly, it should be emphasized that the success of any freight model is not based solely on the range of variables represented, the number of complicate characteristics included or the elegance of the formulation and solution technique employed. These are important criteria, but they alone do not suffice in assessing alternative initiatives. Rather, modeling exercises should also be judged based on their ability to address the real concerns of stakeholders, decision makers, managers and planners. This was the aim during the research; a primary focus of this work is to show microsimulation as a tool to support the decision-making process and provide the actors with an actual perspective on the evaluation and implementation of alternative solutions. In Chapter 6 the case study will incorporate multiple actors and multiple objectives.

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6 Assessment of Goods Distribution Initiatives Performance

6.1 Introduction

Chapter 2 defined the criteria of mobility and sustainability as the main pillars of the evaluation of good practices on UGD. Chapter 4 established a set of indicators to make those criteria operational and chapter 5 described the simulation tool to provide those measurements. Chapter 6 unites the analysis carried out along the previous chapters and, selecting initiatives described on Chapter 3, assesses the performance of alternative UGD solutions. The prediction to the present described in chapter 6, evaluates the improvements towards sustainability and mobility, through the simulation of alternative practices. Such evaluation supports decision making in an objective way.

Chapter 6 is mainly divided in 2 parts, corresponding to 8 sections.

The first part, constituted by six sections, presents the background of the case study. Section 6.2 describes the area from a macro geographical level to a micro level in terms of population, employment, daily movements and mobility. Such characterization helps to define the case study area on section 6.3 and 6.4. After establishing the case study geographical boundaries and identifying the units studied in the project, the network base conditions are presented on section 6.5. Section 6.6 defines the evaluation framework, making it explicit the methodology to be used along the following part.

The second part, constituted by sections 6.7 and 6.8, describes the simulation of scenarios and the comparison of all initiatives. Section 6.7 evaluates seven initiatives, correspondent to 16 scenarios and implemented at different areas:

(1) cooperative distribution systems

(2) collaborative systems
(3) regulation of access based on time
(4) alternative fuels with a penetration rate of 10% and 20%
(5) pricing policies (road pricing)
(6) reserved-capacity strategies (shared usage of a bus lane by freight vehicles),
(7) enforcement

The effects are measured privileging the environmental and operational impacts as well as the respective geographical coverage. The assessment follows two distinct approaches, based on geographical coverage and on stakeholders' impacts, respectively. The first one distinguishes the impacts of the initiative at street level, axle level, unit level and on the overall system (city). The second one distinguishes the respective impacts by stakeholder group: suppliers on LGV's, suppliers on HGV's, citizens and users, public transport and administrators. The evaluation (based on microsimulation) is complemented with empirical knowledge in order to assess the effects of each initiative as a 'best practice' for the specific area of implementation. In the few cases an alternative is validated as 'best practice' towards the improvement of mobility and sustainability, a further detailed evaluation is carried out. A summarized quantification of the operational financial impacts complements the general evaluation based on the indicators defined in Chapter 4. The thinking behind each of these scenarios, together with the assumptions used in the modeling, is discussed along the chapter.

6.2 Background of the study

To easier understand the context of the study, a description of the area is presented, starting from a macro geographical level (metropolitan) to a micro-level description (street/block).

The North Region of Portugal, with 3 million inhabitants from which 2.5 live in urban areas, is constituted by sub-systems strongly interconnected with different dimensions and profiles. Porto Metropolitan Area[28] (PMA) is one of those subsystems, with a population of 1.2 millions and concentrating the main activities of all region (CMP, 2003).

As it is shown in Figure 6.1, Porto is the municipality with higher population and commercial densities as well as higher traffic flows, which means that it is also a potential area of demand for freight transport and distribution.

With a population of 224 795 inhabitants over 42 Km^2, Porto has a population density of about 4 times the metropolitan average, while the density of buildings is 3.5 times higher. The average number of daily trips per person on weekdays is of about 3.2 in Porto and of 2.4 in the metropolitan area. The concentration of enterprises is of about 6.5 times the metropolitan one. These results point out Porto as the economic heart of PMA.

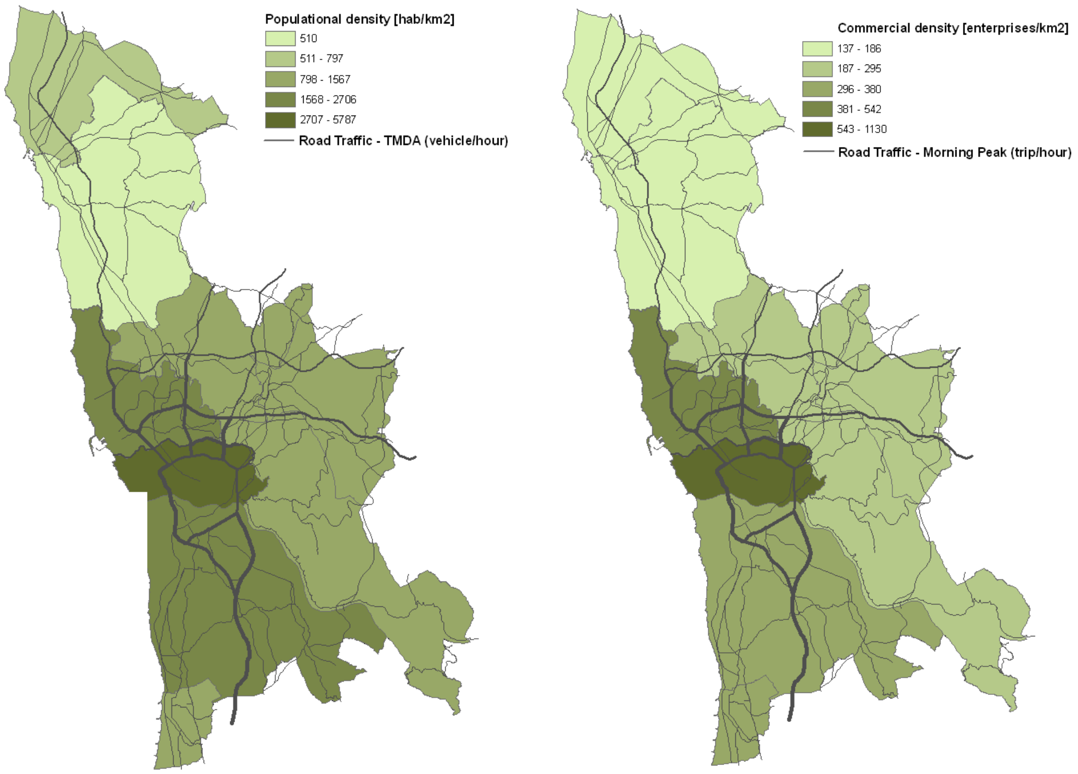

Figure 6.1. Populational densities, commercial densities and goods flows at the main PMA road infrastructures

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[28] *Since the 30th July 2004 and according with what was stablished in Diário da República, III Série, the municipalities of Arouca, Santa Maria da Feira, Santo Tirso, São João da Madeira and Trofa joined the metropolitan area, which is now called Grande Área Metropolitana do Porto. This work only considers the 9 former municipalities (Espinho, Gondomar, Maia, Matosinhos, Porto, Póvoa de Varzim, Valongo, Vila do Conde and Vila Nova de Gaia) in what was called Área Metropolitana do Porto due to its similar urban characteristics and consequent needs in terms of goods distribution.*

The economic importance of Porto in the metropolis contributes to a large number of daily movements from other municipalities into the city centre. A particular focus of the trips home-work per day, illustrated in Figure 6.2, shows that Porto is the stronger pole of the metropolis in terms of employment. With exception to Espinho, the remaining municipalities of PMA daily generate a larger number of flows to Porto (with the purpose 'work') than from Porto with the same purpose.

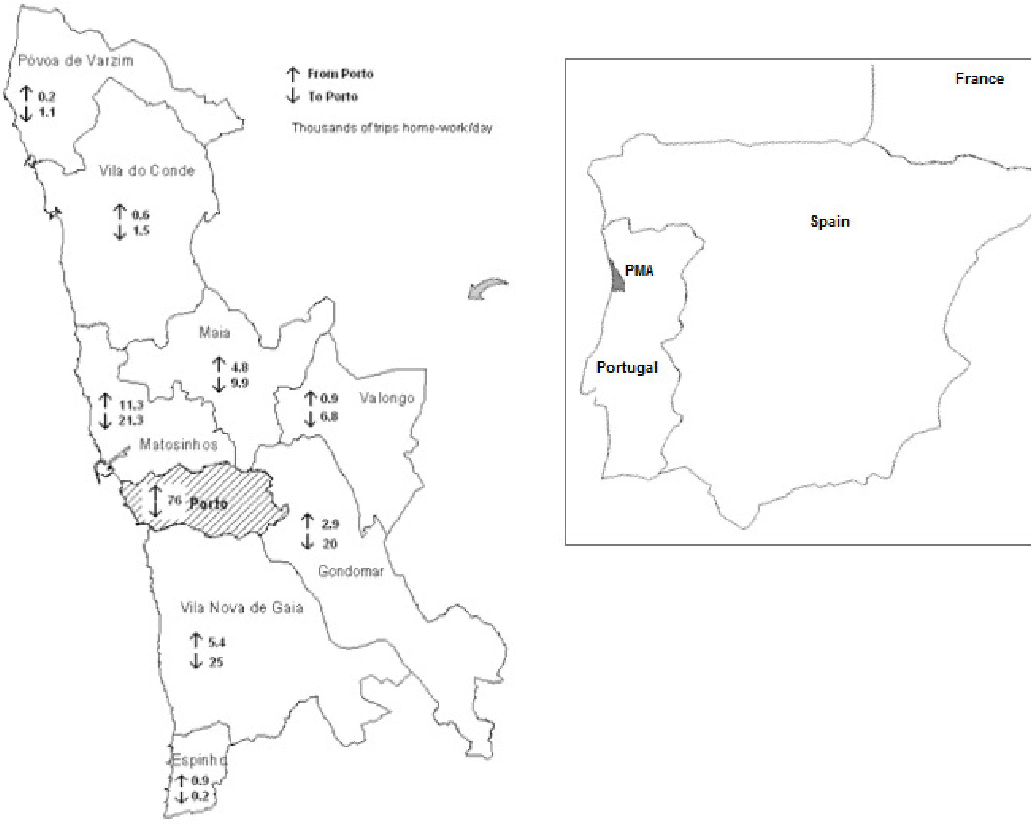

Figure 6.2. Geographical location of PMA and home-work daily flows

The brief description presented above until this point made clear that: a) PMA has a strong pole, which is the municipality of Porto; b) the dominant economic position of Porto makes it an interesting generator of demand for freight flows.

These characteristics, together with the information presented on Table 6.1, were determinant to choose Porto to be the city where the case study of the thesis will be carried out.

Table 6.1. Characterization of Porto and PMA

Source: INE - Censos 2001 and INE/ GEP-CMP - Inquérito Mobilidade 2000

Population and Employment				
PMA	1,26 Millions inhabitants- area 800 km2			
Porto	0,22 Millions inhabitants – area 42km2			
PMA	590 Thousand Jobs		53% in Services	
Porto	200 Thousand Jobs		75% in Services	
Daily Movements				
PMA	1,18 Millions	Home/work/home	41%	Trips inside PMA in work days according with the purpose
	0,40 Millions	Home/study/home	14%	
	1,32 Millions	Others	45%	
	2,90 Millions	All		
Porto	0,20 Millions	Home/work/home	36%	Trips inside the city in work days according with the purpose
	0,08 Millions	Home/study/home	15%	
	0,27 Millions	Others	49%	
	0,55 Millions	All		
Other 8 municipalities from PMA	0,83 Millions	Home/work/home	48%	Trips inside the 8 municipalities in work days according with the purpose
	0,26 Millions	Home/study/home	15%	
	0,65 Millions	Others	37%	
	1,74 Millions	All		
Daily entrances/exits to/from Porto according with the purpose	115 Thousand Ent.	Work	35 Thousands Exits	
	55 Thousand Ent.	Study	5 Thousands Exits	
	140 Thousand Ent.	Others	265 Thousands Exits	
	310 Thousand Ent.	All	305 Thousands Exits	
Mobility				
PMA	2,4			Average number of trips/person/day
Porto	3,2			
Other 8 Municipalities	2,3			
PMA	53% TI (individual motorized transport)			Modal split in workdays in 2000
	19% TP (public transport)			
	28% TI (individual non motorized transport)			
	13% STCP			Public transport share
	5% Private Operators			
	2% CP			
Porto	43% TI (individual motorized transport)			Modal split in workdays in 2000
	25% TP (public transport)			
	32% TI (individual non motorized transport)			
	24% STCP			Public transport share
	0,5% Private Operators			
	0,5% CP			

Moving from a metropolitan to an urban level analysis, it is necessary to understand at a more detailed scale which are the areas of Porto municipality that generate more flows. Figure 6.3 illustrates the number of trips per day with an origin in PMA and destination at a *freguesia*[29] of Porto.

Figure 6.3. Daily metropolitan movements to Porto administrative divisions

Source: adapted from CMP (2003)

The illustration shows that in general there are more trips to the central divisions of the city than to the other ones. According with CMP (2003), the most central administrative divisions (Bonfim, Cedofeita, Massarelos, Miragaia, Santo Ildefonso, Sé and Vitória) located in '*Baixa*'(downtown) and '*Boavista*' areas, are the destination of 40% of the daily metropolitan movements to Porto.

On the particular study of urban goods flows, the attraction of movements also needs to be analysed together with the movements that are made with the purpose 'shopping and service' (Figure 6.4).

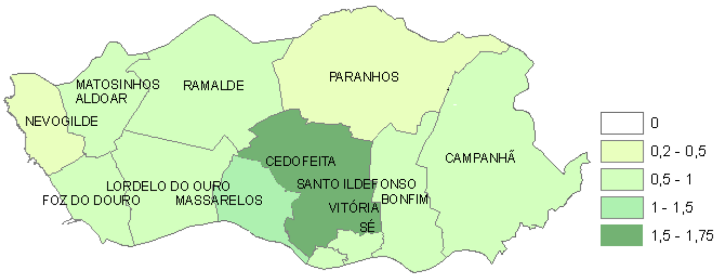

Figure 6.4. Daily metropolitan movements to Porto administrative divisions with the purpose 'shopping'

Source: adapted from CMP (2003)

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[29] *The smallest administrative divisions of the municipalities in Portugal are called 'freguesias'.*

Again, in Figure 6.4 the central area appears as a strong anchor of flows. The central divisions Cedofeita, Santo Ildefonso and Vitoria located in downtown (*Baixa*) present high number of flows for the referred purpose. At least 66% of the trips arriving to *Baixa* are coming from other divisions (CMP, 2003).

Additionally to the description of the movements within the territory, it is also crucial to consider the land use of the area. Figure 6.5 illustrates the land use of the municipality. It is clear that the internal road ring (VCI) establishes the separation between the consolidated urban space and disperse land occupation on the municipality of Porto. On the zones classified as 'historical', 'consolidated' or 'under consolidation' there is a higher concentration of buildings, equipments and historical structures. Therefore, those zones have a more strict and exhaustive regulation and are simultaneously more demanding in terms of goods distribution than the remainder territory. All the scenarios will be simulated in areas located on those zones.

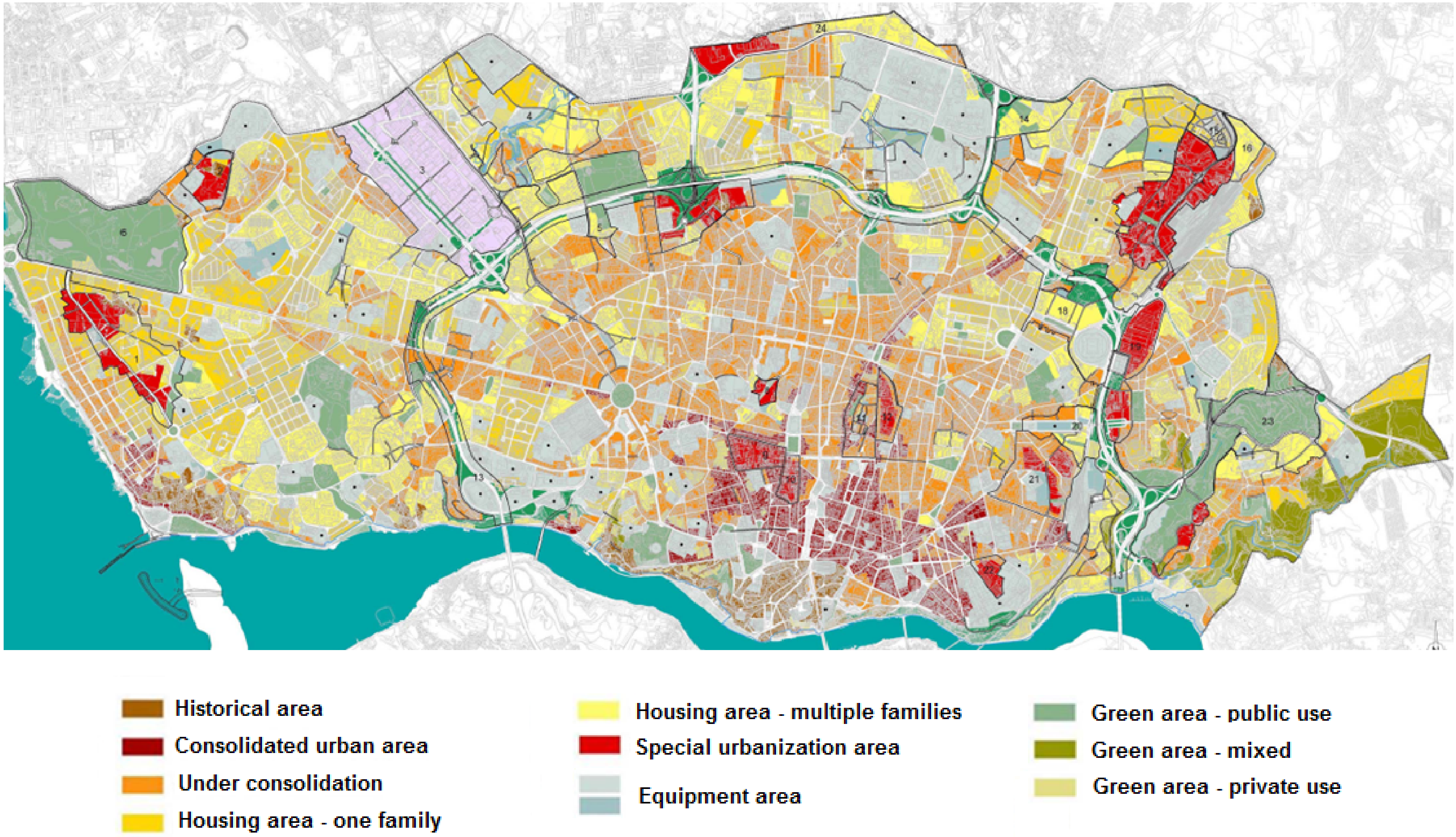

Figure 6.5. Land (urban) use of the municipality of Porto

Source: adapted from CMP (2003)

6.3 Definition of the area

The analysis described in section 6.2, complemented with an overview of the land use of the municipality of Porto (Figure 6.5) shows that the area which better fits on the purpose of the case study is the one limited by the road infrastructure labelled as VCI (Figure 6.6).

Inside that limit it were identified the zones, blocks and streets with problems of mobility and simultaneously, with high pressure of freight vehicles. This detection was done based on daily observations during the peak periods for freight traffic within the city. Between 9:30 a.m. and 11:30 a.m. from the 20th August 2007 to the 7th September 2007, all the area located inside VCI was analyzed. The collected data lead to the results graphically illustrated in the figure 6.6.

The illustration shows that there are areas where freight vehicles cause pressure in a small stretch of the street and others where this effect seems to be spread along a larger pole/axle. The first situation is usually associated with a specific store location like a hypermarket or with restrictions of the street layout. The second situation is typically associated with a strong concentration of activities and passengers movements, like '*Baixa*', '*Marquês*' and '*Boavista*'.

The thesis will analyze one of the many examples of 'concentrated' pressure in Porto using the example of Camões Street (C1). It will also analyze three larger poles: Baixa (Unit 1), Marquês (Unit 2), Boavista (Unit 3) and in one of the scenarios it will analyze the effect of one specific initiative inside VCI limits.

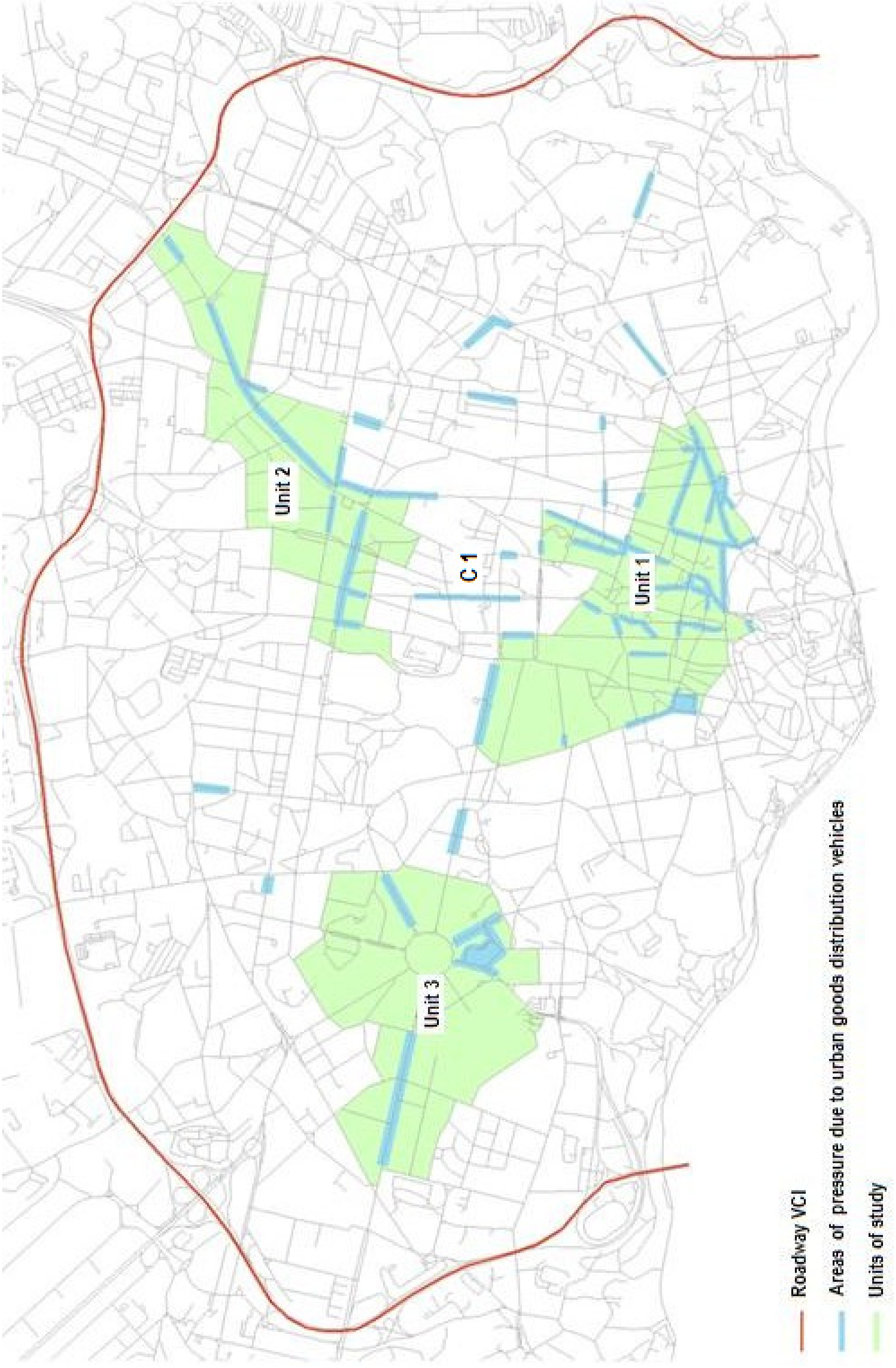

Figure 6.6. Identification of the units of study and areas of pressure of urban goods distribution vehicles in Porto

Within the four areas, 16 scenarios will be simulated, as illustrated in Table 6.2.

Table 6.2. Scenarios of the case study

Scenarios	Initiative	Domain	Stakeholders	Main Cause
Scenario 1: Unit1 **Scenario 2: Unit 2** **Scenario 3: Unit 3**	Cooperative distribution systems	Technological and operational measures	Citizens, Road Users and Suppliers	Many suppliers delivering a small cargo suggest the need for consolidation
Scenario 4: Unit1 **Scenario 5: Unit 2** **Scenario 6: Unit 3** **Scenario 7: Axle**	Collaborative delivery systems	Legislative and organizational measures	Citizens, Road Users and Suppliers	Concentration of activities belonging to the same commercial branch, generating additional pressure on a limited infrastructure
Scenario 8: Unit 2 **Scenario 9: Axle**	Regulation of access based on time	Legislative and organizational measures	Public transport operators, Citizens, Road Users and Suppliers	Disturbance caused by suppliers in sensitive areas and peak hours
Scenario 10: Unit1	Alternative fuels with a penetration rate of 10% and 20%	Technological and operational measures	Public transport operators, Citizens, Road Users and Suppliers	Air pollution and respective impacts associated with road traffic
Scenario 11: City	Implementation of road pricing	Legislative and organizational measures	Public transport operators, Citizens, Road Users and Suppliers	Congestion and respective impacts in central areas
Scenario 12: Unit 2	Shared usage of a bus lane by freight vehicles	Legislative and organizational measures	Public transport operators, Citizens, Road Users and Suppliers	Limited infrastructure
Scenario 13: Unit1 **Scenario 14: Unit 2** **Scenario 15: Unit 3** **Scenario 16: Axle**	Enforcement	Legislative and organizational measures	Public transport operators, Citizens, Road Users and Suppliers	Limited infrastructure Visible transgressions

6.4 Units studied in the project

Considering the distribution activity pressure illustrated in Figure 6.6, the different features of the units in terms of urban form (Figure 6.5) and the commercial pattern of each of the units, three units and 1 stretches were selected for specific analyses of initiatives:

- Unit 1 (Downtown)
- Unit 2 (Marquês)
- Unit 3 (Boavista)
- Camões Axle

The quantification of the effects of measures will be obtained to all system inside VCI, to the units in which the initiative will be simulated and to the street level. Such procedure allows considering the geographical coverage of each initiative.

The effects will also be evaluated by type of vehicle, assuming the changes on LGV's and HGV's patterns are a feasible manner to quantify suppliers' impacts. Buses and taxis reflect the public transport interests and passenger's vehicles translate citizens and city user's interests. The effects on all type of vehicles reflect impacts to society in general and whose interests are defended by public administrators. Such procedure allows considering the impacts by stakeholder group.

6.4.1 Unit 1: Downtown

6.4.1.1 Overview of the area

Unit 1 refers to a very distinct historical centre, where the streets are narrow and the distance between intersections is short, making it difficult to accommodate delivery operations.

Figure 6.7 shows a map of the unit, respective streets and buildings. At its core it is illustrated the main square of Porto, *Aliados,* surrounded by streets with high pressure from freight vehicles (blue stretches).

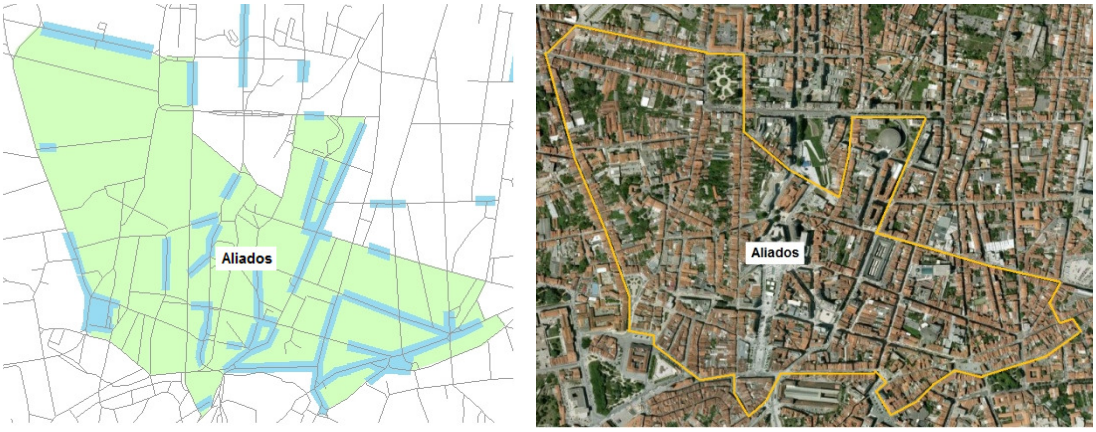

Figure 6.7. Illustration of Unit 1

The unit is mostly a service and recreational area, facing in the last years the common phenomena of downtown desertification. Additionally to the decrease of population, followed by the closing of commercial stores and the building decadence, lately the area is also losing its economic importance.

Figure 6.8 illustrates the commercial activities located in Unit 1.

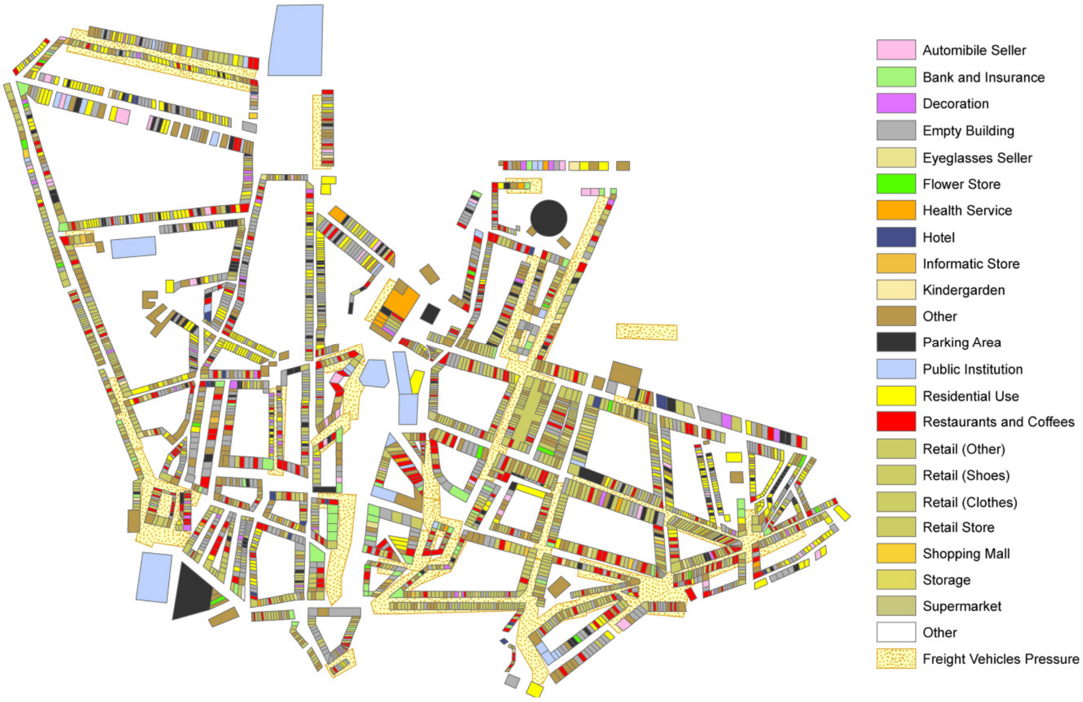

Figure 6.8. Commercial activities of Unit 1

(October, 2009)

Commercial activities located in Unit 1 reveal a) an high concentration of small retail stores, mainly belonging to the fashion sector (shoes, clothes and accessories), which represents 32% of the stores located on the unit; b) a considerable share of restaurants and coffees, representing 14% of the commercial use, c) a pattern of desertification in downtown close to the central square of *Aliados*, with 19% of the buildings included on the survey being empty or neglected and d) a significant area reserved for parking use (8.5%).

Figure 6.9 illustrates the current density of vehicles on Unit 1.

Figure 6.9. Density of vehicles on Unit 1

The illustration shows the streets of the unit, according with its density (vehicles/km). Cedofeita Street and Passos Manuel Street are selected (from the ones with higher density than the average of the network) to be analyzed within the case study. Both streets are characterized by a strong affluence of movements with the purpose of shopping. Moreover, both streets have high pressure from freight vehicles and have a high density of commercial activities. Initiatives to be simulated on Unit 1 will take place on these streets.

The small width of the streets of Unit 1, together with poor traffic regulations and lack of enforcement cause widespread transgression of the rules. Furthermore, the existence of buildings of high architectural quality prevents physical changes in the infrastructure layout, which could allow reducing the impacts of urban goods distribution activities. Considering these restrictions to change the infrastructure layout, alternatively it were evaluated urban goods distribution initiatives belonging to the operational and organizational domains in the specific context of the study area: cooperative systems, collaborative systems, alternative fuels and enforcement.

6.4.1.2 Goods distribution pattern

To better characterize goods distribution and freight traffic in Unit 1, a survey was carried out. The data collection of the survey included the following indicators: traffic counting by direction and type of vehicle (bicycle, motorbike, car, van, coach, bus and truck), parking time/delivery, frequency of deliveries according to the branch of activity, type of freight vehicle (truck, lorries, vans, car), traffic freight flows, use of capacity of the vehicle (full, 50%, less than 50%) and the share of cars and vans in the freight traffic.

4823 buildings, including 860 with residential use, 960 abandoned or empty and 3003 with the main commercial use were included on the survey. These commercial activities have an estimated average of 1727 deliveries/day and mainly belong to the food and fashion branches. 32% of the stores located at Unit 1 are related to fashion branch (shoes, clothes and other accessories) and 14% are restaurants and coffees. These types of activities are usually associated with a high number of deliveries and long parking times.

Table 6.3. Data collection of the main commercial activity branches in Unit 1

(September, 2009)

Commercial activity	Share of the activity on the study area (%)	Average parking time (minutes)	Deliveries by activity/day (numbers)
Retail	32%	13	2
Restaurants and coffees	14%	17	3
Automobile seller	2%	-	-
Bank and Insurance	2%	-	-
Supermarket	2%	-	-
Decoration	2%	21	1
Public Institution	1%	-	-
Optic	1%	-	-
Health Services	1%	-	-
Lodging	1%	-	-
Florist	1%	-	-
Informatics' store	1%	-	-
Kinder garden	<1%	-	-
Shopping mall	<1%	-	-
Other	39%	-	-
Total / Average	**100%**	**17**	**-**

Legend:

– unknown or with a high variability of values

As illustrated in Table 6.3, the survey revealed that the average[30] parking time in the area is of 17 minutes per delivery. Goods vehicles accounted for 16% of all movements between 7:30 and 19:30 in the unit, split by 5% of HGV and 11% of LGV.

The transport mode split between the three categories of freight vehicle is approximately light vans (76%), trucks (20%) and cars with a share of less than 1% in freight traffic. About 75% of the freight vehicles that supply the area have a load factor < 50%.

It was also collected other additional data, like the identification of the store that received the goods, the exact location where the supplier stopped the vehicle and the parking solution adopted (bus lane, ramps, double lane, pavement). This information was used to characterize in detail the delivery patterns of the area.

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[30] *The average parking time in the area was calculated considering the information obtained from the commercial branches identified in Table 6.3.*

6.4.2 Unit 2: Marquês

6.4.2.1 Overview of the area

Unit 2 refers to a traditional and dynamic area in Porto. Figure 6.10 shows a map of the unit and its respective streets and landscape. At its core it is illustrated the important square *Marquês,* surrounded by streets with high pressure from freight vehicles (blue stretches).

Figure 6.10. Illustration of Unit 2

Marquês is mostly a residential area with traditional commercial stores, which faced in the beginning of the decade the phenomena of population's aging. In the last years, a new dynamism was provided from an increase of youth population (mainly from Brazilian and Eastern-European immigrant communities), which has been followed by a new vitality and diversity on the commercial activities located on the unit. Currently, it is one of the areas with higher density of commercial activities in the city, although with a small diversity of commercial branches.

The dynamism in terms of commercial activities and recreational functions has been supported by good public transport service coverage. The level of service and the provided infrastructure were not yet accompanied by proper conditions to accommodate delivery operations.

Figure 6.11 illustrates the commercial activities located in Unit 2.

Figure 6.11. Commercial activities of Unit 2

(October, 2009)

The commercial pattern of unit 2 has some similarities to the one observed in Unit 1 (Downtown). It is a traditional area with a significant share of stores related with the fashion sector (44%) and with restaurants and coffees (16%). It has a predominant residential use and the stores located on the unit mostly supply the respective neighbourhood. The area does not have enough and adequate unloading facilities. Deliveries are usually unloaded by suppliers parked in double lane as close as the store to be supplied as possible.

Figure 6.12 illustrates the current density of vehicles on Unit 2.

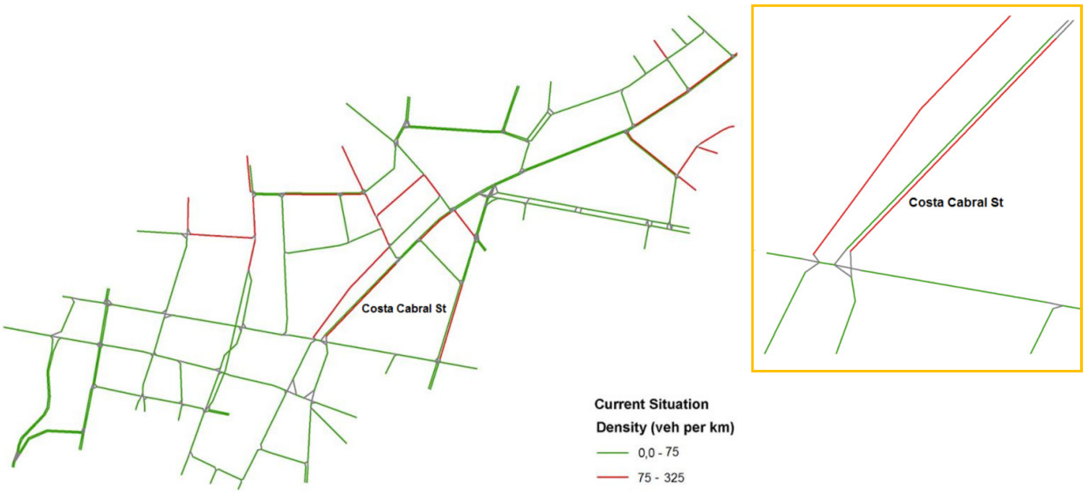

Figure 6.12. Density of vehicles on Unit 2

The illustration shows the more congested street of the area is Costa Cabral Street, which links two dynamic poles within the city of Porto. Costa Cabral Street is characterized by its ancient buildings and by its high density of commercial activities (Figure 6.13). Initiatives to be simulated on Unit 2 will take place on this street.

Figure 6.13. Commercial activities of Costa Cabral Street

Costa Cabral street has a bus lane in one direction (NorthEast to SouthWest) and it allows general road circulation in the opposite direction (SouthWest to NorthEast). Currently, freight vehicles can access to the study area at any time to make deliveries and park (illegally) on the direction that allows road circulation for every type of vehicles (Southwest-Northeast). Once there are not unloading facilities in the area and there's no enforcement, each time a supplier stops, it creates an obstacle to the road circulation, and the other drivers are forced to invade the bus lane to pass him. Figure 6.13 identifies the main critical areas where suppliers usually park to deliver.

The small width of the streets of the Unit 2, together with poor traffic regulations and lack of enforcement cause widespread transgression of the rules. Furthermore, the existence of buildings of high architectural quality prevents physical changes in the infrastructure layout, which could allow reducing the impacts of urban goods distribution activities. Considering these restrictions to change the infrastructure layout, alternatively it were evaluated urban goods distribution initiatives belonging to the operational and organizational domains in the specific context of the study area: cooperative systems, collaborative systems, regulation of access based on time, alternative fuels, shared usage of a bus lane by freight vehicles and enforcement.

6.4.2.2 Goods distribution pattern

To better characterize goods distribution and freight traffic in Unit 2, a survey was carried out. The data collection of the survey included the following indicators: traffic counting by direction and type of vehicle (bicycle, motorbike, car, van, coach, bus and truck), parking time/delivery, frequency of deliveries according to the branch of activity, type of freight vehicle (truck, lorries, vans, car), traffic freight flows, use of capacity of the vehicle (full, 50%, less than 50%) and the share of cars and vans in the freight traffic.

121 commercial stores with an average of 14 deliveries/day, mainly belonging to the food and fashion branches, were included on the survey. 44% of the stores located there are related to fashion branch (shoes, clothes and other accessories) and 16% are restaurants and coffees.

Table 6.4. Data collection of the main commercial activity branches in Unit 2

(October, 2009)

Activity branches	Share of the activity on the study area (%)	Average parking time (minutes)	Deliveries by activity (%)
Fashion	44%	4	10%
Food	16%	27	64%
Perfumeries	9%	10	<1%
Decoration	8%	11	8%
Bookstores	4%	7	<1%
Pharmacy	3%	7	10%
Other Products	14%	4	8%
Total / Average	**100%**	**10**	**100%**

As illustrated in Table 6.4, the survey revealed that the average parking time in the area is of 10 minutes per delivery, with the fashion branch having the lowest average parking time (4 minutes per delivery) and the largest one being registered by the food branch (27 minutes per delivery). The food branch is also the one which registers the highest share of deliveries to the area (64%).

Goods vehicles accounted for 12% of all movements between 7:30 and 19:30 in the area, split by 3% of HGV and 9% of LGV. The transport mode split between the three categories of freight vehicle is approximately light vans (71%), trucks (23%) and cars have a share of less than 1% in freight traffic. About 75% of these freight vehicles that supply the area have a load factor < 50%.

It was also collected other additional data, like the identification of the store that received the goods, the exact location where the supplier stopped the vehicle, the parking solution adopted (bus lane, ramps, double lane, pavement). This information was used to characterize in detail the delivery patterns of the area.

6.4.3 Unit 3: Boavista

6.4.3.1 Overview of the area

Unit 3 is the business centre of Porto Metropolitan Area (PDM, 2003). The main structural axle of Unit 3 is *Avenida da Boavista,* which establishes the connection between *Rotunda da Boavista* and the western part of the city. Buildings located on Unit 3 have a lower occupation per family and streets are wider than in the other two units.

Figure 6.14 shows a map of the unit and its respective streets and landscape. At its core it is illustrated the important square/roundabout *Rotunda da Boavista*, close to streets with high pressure from freight vehicles (blue stretches).

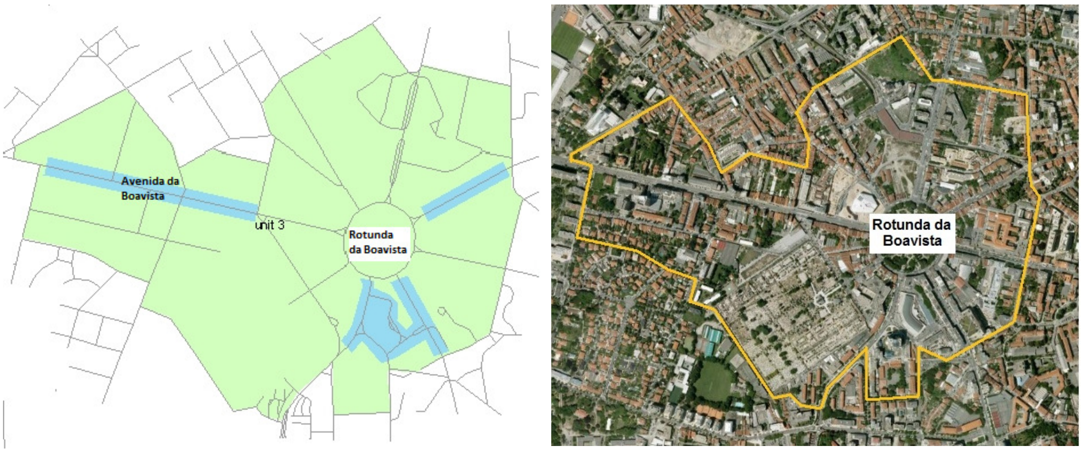

Figure 6.14. Illustration of Unit 3

The area is mostly a business area, with a high concentration of services and commercial stores, although it also has a significant residential use.

The dynamism of services and commerce is supported by good public transport service coverage. The good level of service and the provided infrastructure were not yet accompanied sufficiently by proper conditions to accommodate delivery operations.

Figure 6.15 illustrates the commercial activities located in unit 3.

Figure 6.15. Commercial activities of Unit 3

Unit 3 is characterized by an indistinct use with ancient buildings and modern offices, by high density of financial services and a high number of unoccupied buildings. The large diversity of commercial activities, illustrated in Figure 6.15, mainly supports the role of *Boavista* as a financial and service area. The pattern of commercial activities of *Boavista* shows a specific (high-income) target - customer and is clearly different from the ones observed in Unit 1 and Unit 2. Such difference on the land use and on the specificities of the respective commercial activities was one of the main factors which justified the choice of this third unit to be included on the case study.

6.4.3.2 Goods distribution pattern

To better characterize goods distribution and freight traffic in Unit 3, a survey was carried out. The data collection of the survey included the following indicators: traffic counting by direction and type of vehicle (bicycle, motorbike, car, van, coach, bus and truck), parking time/delivery, frequency of deliveries according to the branch of activity, type of freight vehicle (truck, lorries, vans, car), traffic freight flows, use of capacity of the vehicle (full, 50%, less than 50%) and the share of cars and vans in the freight traffic.

390 commercial stores located on the unit with an estimated average of 264 deliveries/day, mainly belonging to the food and fashion branches, were included on the survey. 22% of the stores are related to fashion branch (shoes, clothes and other accessories) and 17% are restaurants and coffees. Bank and insurance also have a high representativeness on the unit with a share of 11%.

Table 6.5. Data collection of the main commercial activity branches in Unit 3

(October, 2009)

Activity branches	Share of the activity on the study area (%)	Average Parking Time	Deliveries/activity
Retail	22%	11	-
Restaurants and coffees	17%	21	3
Bank and Insurance	11%	-	-
Decoration	7%	15	2
Car sales	5%	-	-
Informatics' store	4%	-	-
Public Institution	3%	-	-
Shopping mall	3%	-	-
Hotel	2%	-	-
Flower store	2%	-	-
Health services	2%	-	-
Supermarket	2%	-	-
Eyeglasses sale	1%	-	-
Other	20%	-	-
Total / Average	100%	-	-

Legend:

– unknown or with a high variability of values

The survey revealed that the average parking time in the area is of 27 minutes per delivery, with the retail having the lowest average parking time (6 minutes per delivery) and the largest one being registered by restaurants and coffees (33 minutes per delivery). Goods vehicles accounted for 9% of all movements between 7:30 and 19:30 in the area, split by 1% of HGV and 8% of LGV.

The split between the three categories of freight vehicle is approximately light vans (86%) and trucks (14%), which is a share quite different from the one observed in Units

1 and 2. About 85% of the freight vehicles that supplies the unit have a load factor <50%.

It was also collected other additional data, like the identification of the store that received the goods, the exact location where the supplier stopped the vehicle, the parking solution adopted (bus lane, ramps, double lane, pavement). This information was used to characterize in detail the delivery patterns of the unit.

Figure 6.16 illustrates the current delay times on Unit 3.

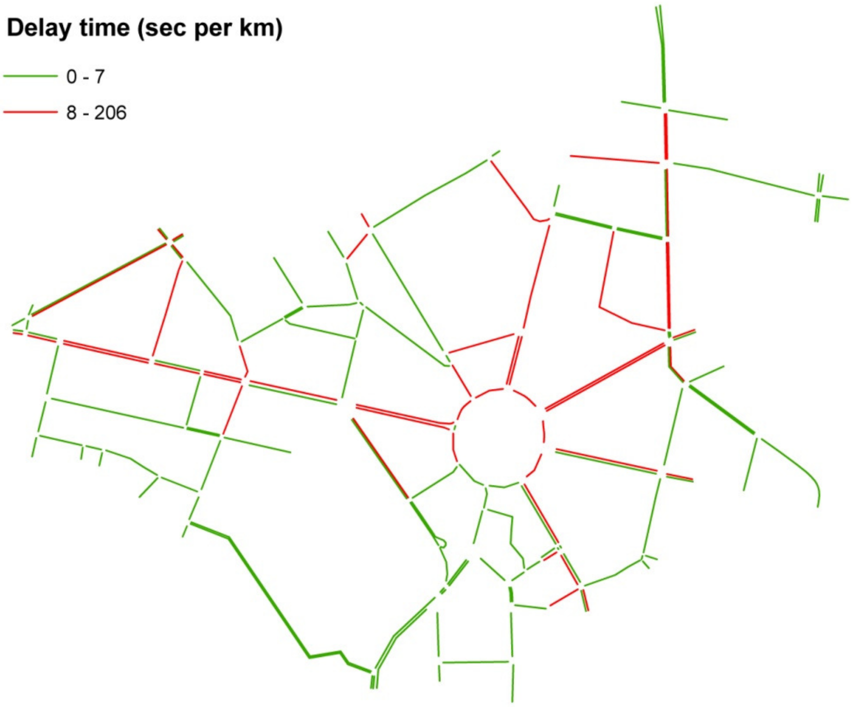

Figure 6.16. Delay times of vehicles on Unit 3

Figure 6.15 shows that to the north of the roundabout there is quite a dominant share of the residential use. Along *Avenida da Boavista (West-East)* and to the south of the roundabout the commercial use is more dominant. Moreover, Figure 6.16 shows that along the main road channel of the unit *(Avenida da Boavista)* there is a higher delay time (sec/km) than on the average. Both facts lead to the choice of *Avenida da Boavista* as the main test street of the unit (Figure 6.17). Initiatives to be simulated on Unit 3 will take place on this avenue.

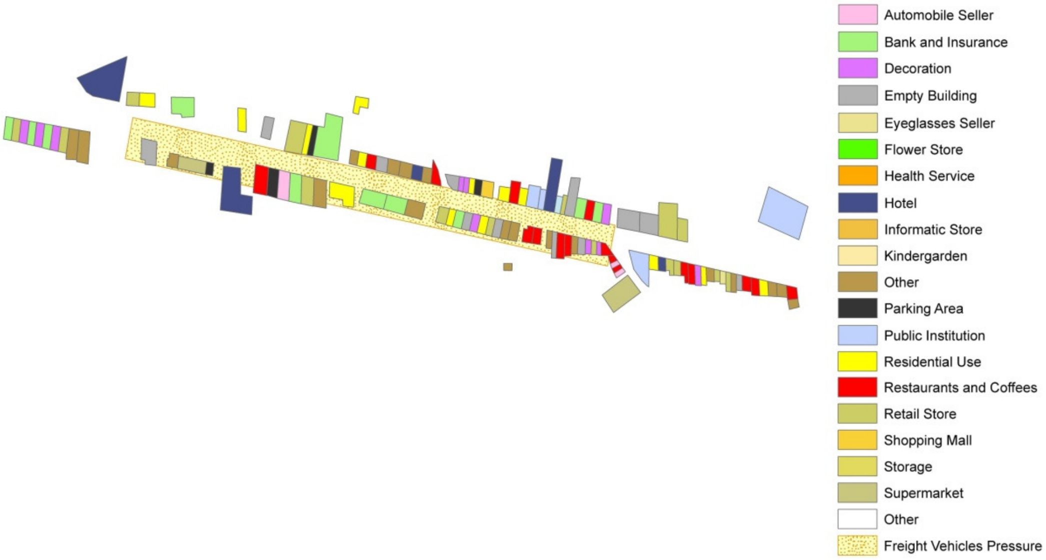

Figure 6.17. Commercial activities of Avenida da Boavista

Avenida da Boavista is the street test with a more diversified pattern of activities. Retail only represents 13%, a similar importance of the residential use (12%) and slightly higher than representativeness of the decoration and the bank and insurance activities (9%). Restaurants and coffees also have a relevant share of 15%, but clearly lower than the one observed at the other streets.

Figure 6.18 shows the circulation profile of the stretch of *Avenida da Boavista* analyzed on the case study.

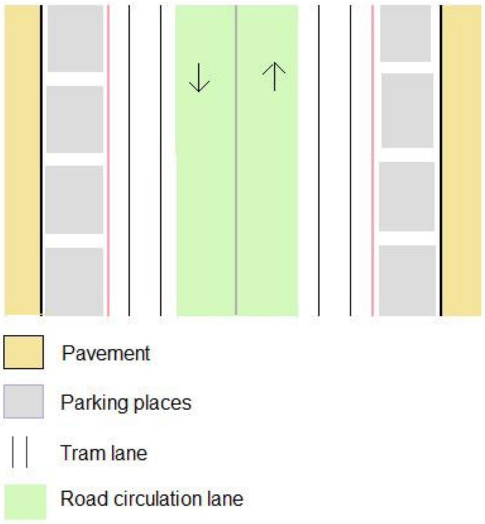

Figure 6.18. Avenida da Boavista circulation profile

Avenida da Boavista has legal parking places along both sides of the avenue, a deactivated[31] tram lane being used by road modes in both directions and an additional lane for road circulation. Currently, freight vehicles can access to the area at any time to make deliveries and mostly park legally on the available places or illegally on second lane (on the tram reserved lane). Once there are not unloading facilities in the area and there's no enforcement, each time a supplier parks illegally, it creates an obstacle to the road circulation.

Considering this layout profile and the goods distribution pattern observed on the survey, it were evaluated the following initiatives: cooperative systems, collaborative systems, alternative fuels and enforcement.

6.4.4 Camões Axle

6.4.4.1 Overview of the area

Camoes axle is part of Camoes Street. It is one of the streets in Porto often mentioned as a conflict area between road circulations and loading/unloading activities.

Figure 6.19 shows a map of the axle and respective landscape.

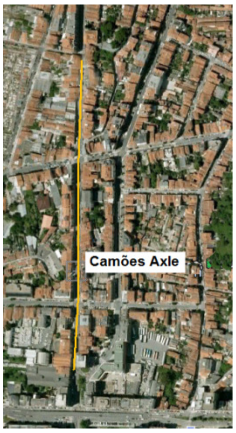

Figure 6.19. Illustration of Camões axle

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[31] *Despite the lane is not currently used by tram, the metallic tracks are still placed on the road (December, 2009).*

The street is located close to Unit 1 and has a mixed use. On the ground floor, buildings are occupied with either traditional retail activities or services and on the other floors the residential use prevails.

6.4.4.2 Goods distribution pattern

To better characterize goods distribution and freight traffic in Camões axle, a survey was carried out. The data collection of the survey included the following indicators: traffic counting by direction and type of vehicle (bicycle, motorbike, car, van, coach, bus and truck), parking time/delivery, frequency of deliveries according to the branch of activity, type of freight vehicle (truck, lorries, vans, car), traffic freight flows, use of capacity of the vehicle (full, 50%, less than 50%) and the share of cars and vans in the freight traffic.

30 commercial stores located on the axle with an estimated average of 16 deliveries/day, mainly belonging to the retail activity and automobile spare parts seller branches, were included on the survey. 31% of the stores are related to retail activity and 23% are automobile spare parts sellers. It is the only area of the case study in which the fashion branch is not dominant.

Table 6.6. Data collection of the main commercial activity branches in Camões

(October, 2009)

Activity branches	Share of the activity on the study area (%)	Average Parking Time	Deliveries/activity/hour
Retail	31%	14	6
Automobile spare parts seller	23%	6	5
Restaurants and coffees	15%	24	7
Pharmacy	15%	3	5
Health services	8%	1	2
Bookstore	8%	1	2
Total / Average	100%	12	3

The survey revealed that the average parking time in the area is of 12 minutes per delivery, with the health center and the bookstore having the lowest average parking time (1 minutes per delivery) and the largest one being registered by restaurants and coffees (24 minutes per delivery) as shown in Table 6.6.

Goods vehicles accounted for 11% of all movements between 7:30 and 19:30 in the area, split by 2% of HGV and 9% of LGV.
The split between the three categories of freight vehicle is approximately light vans (83%) and trucks (17%), which is a share quite different from the one observed in Units 1 and 2. About 85% of the freight vehicles that supplies the unit have a load factor < 50%.

It was also collected other additional data, like the identification of the store that received the goods, the exact location where the supplier stopped the vehicle, the parking solution adopted (bus lane, ramps, double lane, pavement). This information was used to characterize in detail the delivery patterns of the unit.

Figure 6.20 shows the circulation profile of the axle. *Camões Street* has legal parking places along the left side of the street, two lanes for road circulation (one of them being continuously used for double parking) and one reserved as bus lane. Currently, freight vehicles can access to the area at any time to make deliveries and park illegally on double lane. Despite there are unloading facilities in the area, they are not used and once there’s no enforcement, each time a supplier parks illegally, it creates an obstacle to the road circulation.

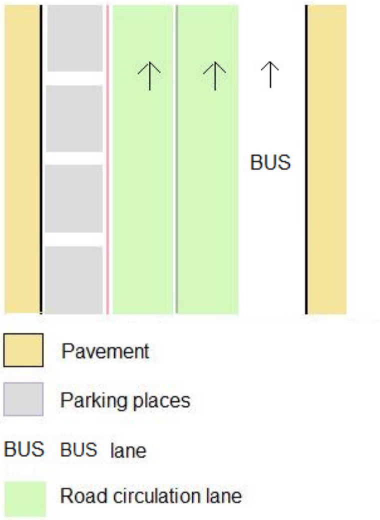

Figure 6.20. Camões street circulation profile

Figure 6.21 illustrates the current delay times on Camões axle.

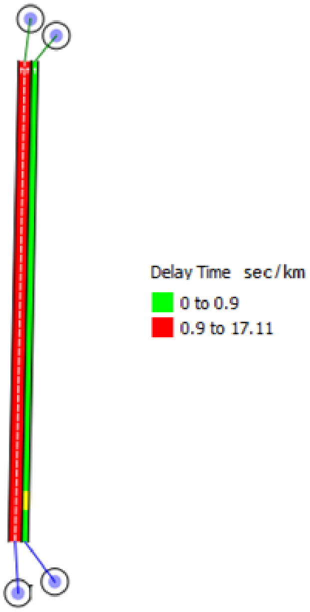

Figure 6.21. Delay times of vehicles on Camoes axle

Figure 6.21 shows that along the bus lane (right side) there's a lower delay time than on the average on the network. Along the main road channel of the street (left side of the illustration) there is a higher delay time (sec/km).

Considering the layout profile (Figure 6.20) together with the current delay times (Figure 6.21) and the goods distribution pattern observed on the survey, it were evaluated the following initiatives: collaborative systems, regulation of access based on time, alternative fuels and enforcement.

6.5 Definition of the Network Base Conditions

The main *network elements* used as an input in AIMSUN were: network design (sections, geometry specification, nodes, junctions, turnings, give-way and stop, pedestrian crossing, centroids), control plans, traffic states and O/D matrices, detectors, public transport stops, public transport lanes and vehicle types.

The network design is one of the tasks which requires a bigger effort and which precision can directly influence the results of simulation. On this sense, some particular base conditions used to define the network of the city are described in the following paragraphs.

For the purpose of designing the network, it were defined 231 intersections and 559 sections, with a total sections length of 54km and a total lanes length of 80km, respective geometry and movements, which were later confirmed in detail *in loco*. The road types were urban (and arterial) defined with a maximum speed of 50km/h, a visibility distance of 25 meters, a capacity (per lane) of 800 veh/h (900 veh/h per arterial), with a jam density of 200 veh/km and with the associated volume delay function ***1.2 * Linklength(S) * max((15 * 25.6 * 0.985 ^ 2.2 * (((Linkvolume(S) + LinkAddVolume(S)) / Linkcapacity(S)) - 0.985) + 1 + 8 * 0.985 ^ 3.2) , (1 + 8 * ((Linkvolume(S) + LinkAddVolume(S)) / Linkcapacity(S)) ^ 3.2)).***

Six **types of vehicles** were considered on the analysis according with the following categorization: car, bus, truck, van, taxi and other public transport. Pedestrian and bicycles were not included on the simulation exercise. The metro network was also not integrated.

Control plans were defined for the six types of vehicles with an actuated control. All the traffic signal groups were checked on the field. Control plans for each node were loaded with actuated types controlled by detectors.

Traffic states were defined according with the information obtained by counting and provided under a confidentiality agreement with the company TRENMO. A separate treatment of freight (vans and trucks) and passenger vehicles (cars) and public transport (taxis and buses) in the formation of origin and destination matrices and of traffic assignment procedures was carried out.

Public transport stops and public transport lanes adopted on the simulation were the ones obtained from the bus operator STCP. The bus lanes network and respective schedule used on the case study is the one implemented from the 1st February 2007. Table 6.7 shows the lanes that cross the units of the case study area.

Traffic demand was loaded on the network distinguishing the input flow (veh/h) and the turning info by vehicle type to the period of analysis.

Incidents representing illegal parking on the road were defined in a detailed way. Section where incidents occur, position on the lane and length of the event were defined according with real data obtained on a survey.

Table 6.7. Bus lane network

STCP Lane Number	Direction	Unit Areas	Number of stops at the unit or axle
55	Bolhão	U1	5
69	Bolhão	U1	6
70	Bolhão	U1	6
94	Bolhão	U1	6
200	Aliados	U1	6
201	Viso	U3	6
201	Sá da Bandeira	U3, U1	6 (U3), 3 (U1)
202	Infante	U3, U1	4 (U3), 2 (U1)
202	Castelo do Queijo	U3, U1	4 (U3), 3 (U1)
203	Marques	U2, U3	7 (U2), 5 (U3)
203	Castelo do Queijo	U3	5
204	Hospital S. João	U2, U3	3 (U2), 3 (U3)
204	Foz	U3	3
206	Viso	U2	2
206	Campanhã	U2, U1	3 (U2), 1 (U1)
207	Campanhã	U1	1
207	Mercado da Foz	U1	3
300	Hospital S. João	U2, U3, U1	2 (U2), 3 (U3), 7 (U1)
301	Hospital S. João	U2, U3, U1	2 (U2), 1 (U3), 3 (U1)
302	Damião de Gois	U2, U3, U1	3 (U2), 3 (U3), 4 (U1)
303	Constituição	U2, U1	3 (U2), 1 (U1)
303	Praça da Liberdade	U3	4
304	Santa Luzia	U2, U1	1 (U2), 2 (U1)
304	Aliados	U2	1
305	Cordoaria	U1	5
305	Hospital S. João	U1	3
402	Boavista	U2, U3	4 (U2), 3 (U3)
402	S. Roque	U2	3
501	Matosinhos	U3	2
501	Sá da Bandeira	U3	4
502	Matosinhos	U3	6
502	Bolhao	U3	5
503	Gatões	U3	8
504	Boavista	U3	9

508	Boavista - Cabo do Mundo	U3	4
600	Maia	U2	1
601	Aeroporto	U3	3
601	Cordoaria	U3	5
602	Cordoaria	U3	1
602	Aeroporto	U3	3
701	Bolhão	U2	6
701	Codiceira	U2	7
702	Bolhão	U2	6
702	Travagem	U2	7
703	Cordoaria	U2	6
703	Sonhos	U2	7
704	Boavista-Codiceira	U3	6
803	Boavista-Venda Nova	U3	5
805	Marques	U2	3
806	Marques	U2	3
902	Lavadores	U3	2
902	Boavista	U3	2
903	Laborim	U3	2
903	Boavista	U3	2
904	Constituição	U2	4

6.6 Evaluation Framework

The conceptual diagram of the case study is illustrated on Figure 6.22.

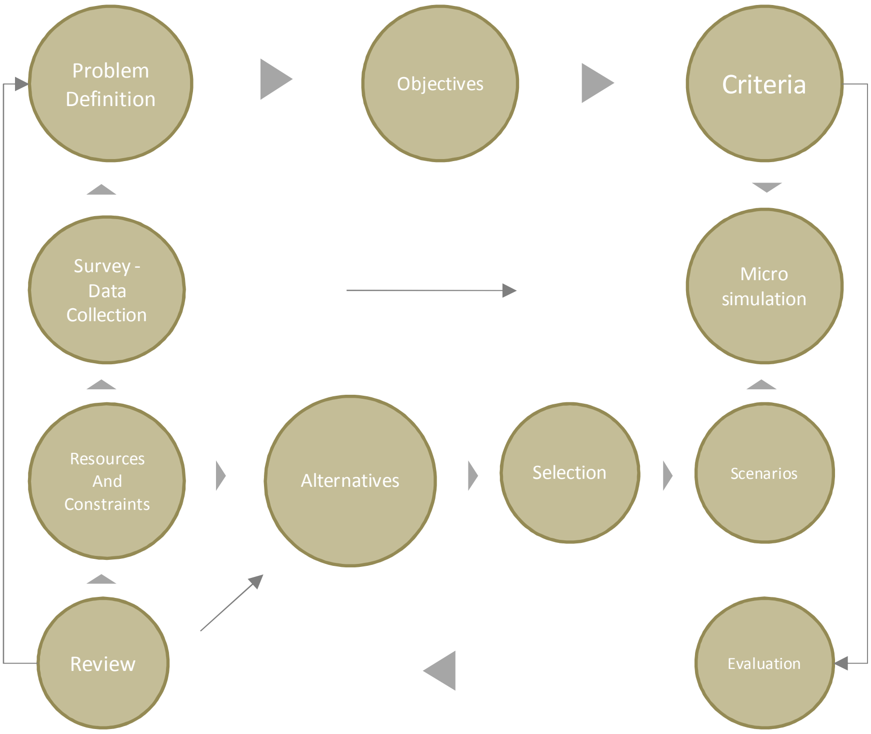

Figure 6.22. Conceptual diagram of the case study

The evaluation exercise starts with the definition of the problem, specifying objectives and determining criteria. Considering the constraints and available resources, a range of alternatives is generated and an appropriate level of data collection and modeling determined. The simulation predicts the performance of the alternatives and those results are then analyzed. If the initial problem has not been solved, other alternatives can be considered.

Surveys and data collection provide a reliable basis for decision making on a) the problem definition, namely on the existing **resources and conditions** and b) modeling exercise, particularly on the description of the land use and transport networks, of the delivery pattern, commercial activities location and on the evaluation and c) monitoring and review (Taniguchi *et al.*,2001).

Defining problems involves specifying the perceptions and interpretation of the actual situation of all interested groups, which involve the identification of the key stakeholders and the issues that affect them (traffic congestion, environmental impacts, fleet planning and management, etc).

Objectives ensure that the success of the initiatives can be checked. Examples of objectives are the reduction of operational costs or the reduction of environmental impacts.

Criteria reveal the concerns of stakeholders and society as a group. It is closely related with the establishment of the objectives. Common measures are, in the case of the improvement of mobility and sustainability criteria, the decrease of a) social impacts by alleviating traffic congestion (and crashes); b) economic impacts due to changes in fixed costs and operation costs; c) environmental impacts in terms of CO2 emissions; d) financial impacts by reducing costs to carriers and shippers; e) energy consumption by changing the amount of energy used.

Alternatives are the options having the potential to solve the problem. The selection of alternatives to be analyzed depends of the status and context revealed by the data collection and the feasible solutions to be implemented in the area.

Scenarios are reliable alternatives to a specific context, under particular objectives. Scenarios are simulated for the present and the validity of microsimulation is limited on time. Such modeling exercise is not appropriate to make forecasts for the future; its usefulness relies on its ability to support decision making and the establishment of strategies in a specific moment.

To evaluate the impacts caused by each of the scenarios towards the mobility and sustainability criteria, it were quantified the indicators chosen in Chapter 4: distance travelled, energy intensity (fuel consumption), pollutant emissions[32] (CO, HC, NOx, CO2), average speed (excluding stops to make deliveries), travel time, delay time and density. These indicators are the output of the microsimulation exercise as described in Annex 5.1.

The **evaluation** process is a determinant step for supporting decision making. The evaluation through microsimulation involves the methodological comparison of alternatives, based on economic, social, energy consumption and environmental grounds.

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[32] *In some of the analysis it were not presented the pollutants CO, HC, NOx due to the geographical scale being analyzed or due to the low (quantitative) dimension of the indicators.*

The evaluation is carried out at two different levels: geographical coverage and stakeholders impacts. The analysis of the geographical coverage of each initiative will be carried out through the comparison of effects at the entire system, unit level, street level and in some cases, direction of the street. The analysis of the stakeholders effects will be carried out through the quantification of the indicators by type of vehicle on the LGV+HGV's (transporters/suppliers), on passenger's vehicles (citizens and city users), on buses and taxis (public transport operators) and on the total system (society).

The acceptance of scenarios will depend, not only of the predicted effects towards the established criteria, but also on the financial viability and political acceptability of the measure.

6.7 Simulation of Scenarios

In the last years several initiatives have been proposed to achieve sustainable targets and some have even been pointed out as 'best practices', according with its theoretical or practical results at economic, environmental or social levels (sustainability dimensions). From those practices, seven initiatives applied to four areas, corresponding to 16 scenarios (Table 6.2) were simulated.

The evaluation was made through the simulation of the impacts of each of the initiatives being implemented separately, because the characteristics of the area and respective supply pattern do not require a complex solution evolving the harmonization of two or more initiatives. The impacts of the initiatives were compared in order to a) choose the one which would bring more benefits to the study area, b) evaluate whether the 'best practices' effects actually justify such label in Porto and c) better predict stakeholders perspectives and effects towards each initiative.

Additionally to a better knowledge of the Portuguese reality on urban goods distribution, it was intended to give a contribution to the use of microscopic traffic simulation to support urban goods distribution management decisions.

It was considered that the objective of this microsimulation exercise was to evaluate a micro-behavior of stakeholders but also the behavior of the all spatial system. Thus, the impact was analyzed at three geographical layers: the overall system (inside VCI, Porto first ring), the unit of the study (illustrated in Figures 6.7, 6.10, 6.14 and 6.19) and at the street level (where the initiative is implemented). Such analysis reflects the behavior of the all spatial system and allows having a broader view on the geographical coverage of each initiative. To complement this perspective, effects are also analyzed at a disaggregated level by stakeholder interest group. A major categorization is made at the micro-behaviour analysis distinguishing **public** and **private** objectives. Public objectives are often related to well-being of all stakeholders in a specific area, such as quality of life, economic vitality and mobility. Private objectives are often related to turnover levels like sales levels, customer levels, costs levels, service levels, and competition. To incorporate both categories in the microsimulation exercise, stakeholders are assigned to their main objective. Stakeholders whose main objective is public include (motorized) citizens and users of the city, public transport (city buses, intercity buses and taxis) and the total of the motorized society. Suppliers on LGV's and on HGV's reflect stakeholders whose main objective is private. Along the simulation process, priority is given in a first stage, to the evaluation of the initiative under the main criterion of public objective. If the initiative reveals to be a good practice to that set of indicators, a more detailed analysis is followed to confirm if it also fulfils the private objective criterion (vd 6.7.9). Such approach tries to make the different stakeholders interests more transparent and thus, optimize the process of decision making.

6.7.1 Outputs

Effects of each initiative will be simulated under the main criteria of public and private objective, towards an increasing mobility and sustainability. It is important to highlight that the distinction between public and private objectives is not associated with the group of stakeholders category. It is based on a distinction between 'public good' and 'private interests'. The improvement of urban quality environment and mobility through the reduction of pollutant emissions, congestion and delays are examples of what is referred as public good. Private interests can also take into account the public good, but they are mostly associated with the costs and effectiveness of the operations.

In order to consider both perspectives, initiatives will first be simulated and evaluated under the public good criteria. The ones validated as 'best practices' through a first analysis will also be analyzed under a (more) private interests perspective. This section supports the possible outputs of the simulation, under both perspectives (6.7.1.1 e 6.7.1.2).

6.7.1.1 Public Good

Indicators selected in Chapter 4 can be presented as outputs along chapter 6, combined in different ways according with the phenomena to represent. This section explicitly describes the main seven possible outputs and respective meaning, so that the interpretation of the diverse graphics and annexes along the chapter becomes easily readable and understandable.

The main aim of the description of phenomena is to make explicit the variation of a set of indicators that can occur at any of the three geographical layers in analysis (street, unit and city). Therefore, illustrations 6.23 to 6.29 do not have a quantitative scale of variation and are merely illustrative of the relations between indicators.

At the system level analysis (city coverage), it were calculated the levels of the pollutants NOx, CO and HC. At the other geographical levels, an accurate calculation would require to consider specific variables like the topography of the territory, layout of the streets, etc. Considering the scope of this work, such detailed calculation does not add enough value to be carried out along the thesis. For that reason, the following illustrations that are meant to be general and applicable to all the layers do not contain those three indicators.

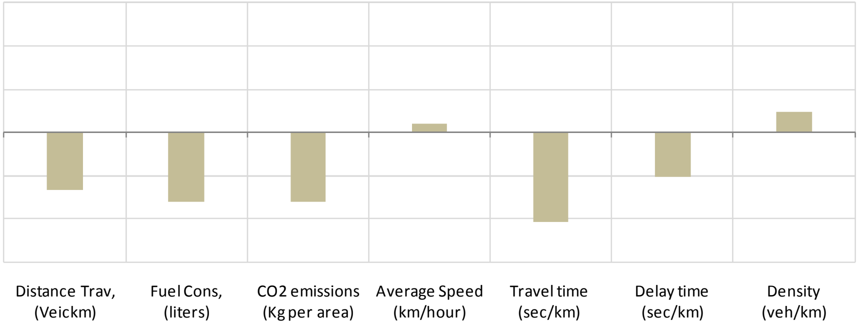

Figure 6.23. Output A: Better mobility and environmental sustainability

Output A describes scenarios that lead both to better mobility and (environmental) sustainability (Figure 6.23). Vehicles travel a lower distance, consume less fuel and thus emit less CO2 emissions. The increase on the average speed together with the decrease of the distance travelled comes with a decrease on travel time and on delay time. Under these conditions, the increase on the average speed implies (from a modeling perspective) that more vehicles can be within the system and thus, the indicator ‘density’ increases as well. In such scenarios and to the specific range of speed values that are being examined, the pollutants CO and NOx are expected to decrease. CO results from incomplete congestion of fuel in traffic engines. NO_x is a generic term for mono-nitrogen oxides (NO and NO_2), which is produced during combustion, especially combustion at high temperatures. In a lower congestion scenario, CO and NOx are expected to decrease.

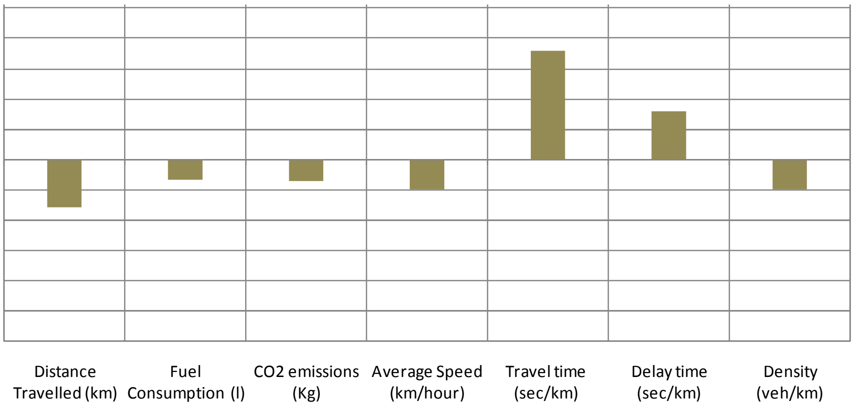

Figure 6.24. Output B: Worst mobility and environmental sustainability

Output B describes scenarios that are expected to lead to worst mobility and (environmental) sustainability (figure 6.24). Vehicles travel a lower distance, consume less fuel and thus emit less CO2 emissions. The decrease on the distance travelled together with the decrease on the average speed comes with an increase on travel time and consequent increase on delay time. Moreover, the increase on congestion levels that leads to a lower distance travelled and lower average speed implies that (from a modeling perspective) fewer vehicles enter the system during the period in analysis and thus, the indicator ‘density’ decreases as well. In such scenarios and to the specific range of speed values that are being examined, the pollutants CO and HC are expected to increase.

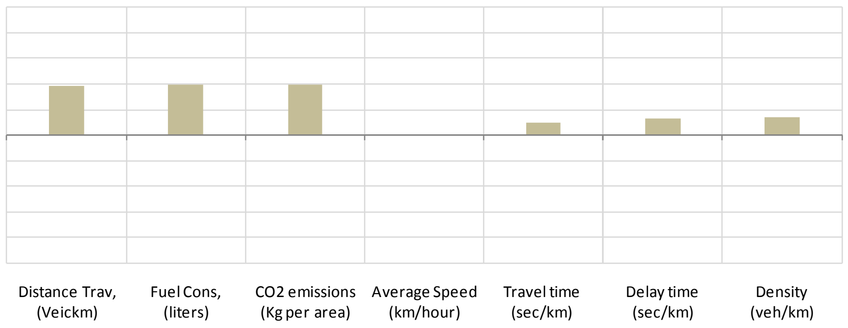

Figure 6.25. Output C: Worst mobility and environmental sustainability

Output C also describes scenarios that are expected to lead to worst mobility and (environmental) sustainability (figure 6.25). Vehicles travel a higher distance, consume more fuel and thus emit more CO2 emissions. The increase on the distance travelled together with a null variation of the average speed comes with an increase on travel time, mostly supported by the increase on the delay time. Moreover, the phenomena described until now indicates a more congested system and thus, there is also an increase on the indicator 'density', correspondent to more vehicles within the system. In such scenario and to the specific range of speed values that are being examined, the pollutants CO and HC are expected to increase.

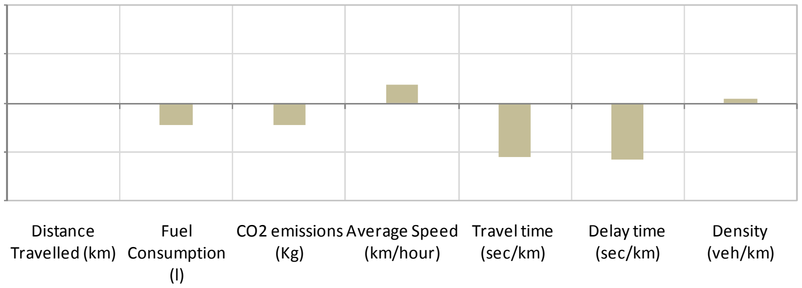

Figure 6.26. Output D: Better mobility and environmental sustainability

Output D describes scenarios that lead both to better mobility and (environmental) sustainability (Figure 6.26). It is a particular case of output A. Vehicles travel the same distance, consume less fuel and thus emit less CO2 emissions. The increase on the average speed together with the maintenance of the distance travelled comes with a decrease on travel time and on delay time. Under these conditions, the increase on the average speed implies (from a modeling perspective) that more vehicles can be within the system and thus, the indicator 'density' increases as well. In such scenarios and to the specific range of speed values that are being examined, the pollutants CO and HC are expected to decrease.

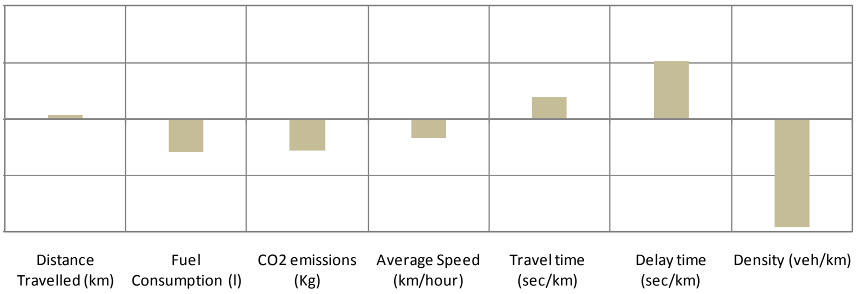

Figure 6.27. Output E: Worst mobility and environmental sustainability

Output E describes scenarios that are expected to lead to worst mobility and (environmental) sustainability (figure 6.27). It is similar to output B, although it includes the particularity of the fleet change. Vehicles travel a higher distance, consume less fuel and thus emit less CO2 emissions. The increase on the distance travelled together with the decrease on the average speed comes with an increase on travel time and consequent increase on delay time. Moreover, the increase on congestion levels that leads to a lower average speed implies that (from a modeling perspective) fewer vehicles enter the system during the period in analysis and thus, the indicator ‘density’ decreases as well. In such scenarios and to the specific range of speed values that are being examined, the pollutants CO and HC are expected to increase.

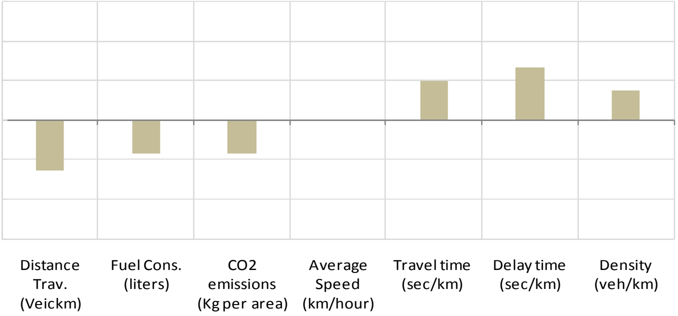

Figure 6.28. Output F: Worst mobility

Output F describes scenarios that are expected to lead to worst mobility (figure 6.28). Vehicles travel a lower distance, consume less fuel and thus emit less CO2 emissions. The decrease on the distance travelled together with the maintenance of the average speed comes with an increase on travel time and consequent increase on delay time. In such scenario and to the specific range of speed values that are being examined, the pollutants CO and HC are expected to increase.

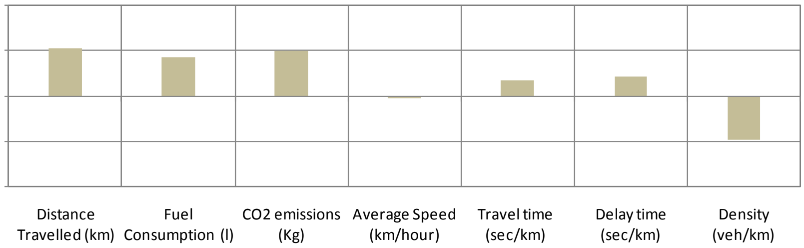

Figure 6.29. Output G: Worst mobility and environmental sustainability

Output G also describes scenarios that are expected to lead to worst mobility and (environmental) sustainability (figure 6.29). It is similar to output C, although it includes the particularity of the fleet change. Vehicles travel a higher distance, consume more fuel and thus emit more CO2 emissions. The increase on the distance travelled together with a null variation of the average speed comes with an increase on travel time, mostly supported by the increase on the delay time. Moreover, the phenomena described until now indicates a more congested system and thus, there is also an increase on the indicator 'density', correspondent to more vehicles within the system. In such scenario and to the specific range of speed values that are being examined, the pollutants CO and HC are expected to increase.

6.7.1.2 Private Objectives and Public Interests Compatibility

Towards the positive results of an initiative at a first analysis (stakeholders and geographical coverage), on the criteria of mobility and sustainability – public good - a more detailed analysis is followed to confirm if it also fulfills one of the most relevant private objective criteria: costs levels.

Considering the indicators used on the first analysis and the translation of those values to a economic reference, the cost impacts of the initiative are calculated. The quantification[33] of these costs is the result of the estimation of the operational costs (including driving costs and vehicle costs) and of the environmental externalities costs by stakeholder group to each geographical level.

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[33] *The values (euro/km) to each of these costs were obtained from scientific literature (Small, Kenneth A., Verhoef, Erik; The Economics of Urban Transportation, Routledge, 2007).*

With the quantification of the impacts of each initiative to all group stakeholders, two possible outputs can occur. The first one corresponds to a situation in which an initiative leads to a decrease of the total costs (operation plus externalities). This situation is considered to be positive towards social and economic sustainability. The second one corresponds to a situation in which an initiative leads to an increase of the total costs. This situation is considered to be negative towards social and economic sustainability.

6.7.2 Cooperative distribution systems

Cooperative Delivery Systems (vd Figure 6.30) are systems in which a reduced number of trucks is used for collecting or delivering the same amount of goods (Taniguchi and Heijden, 2000).

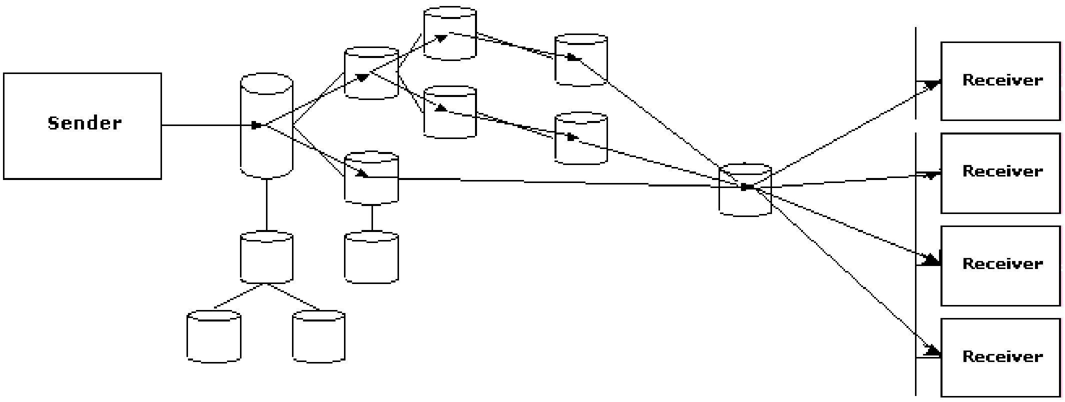
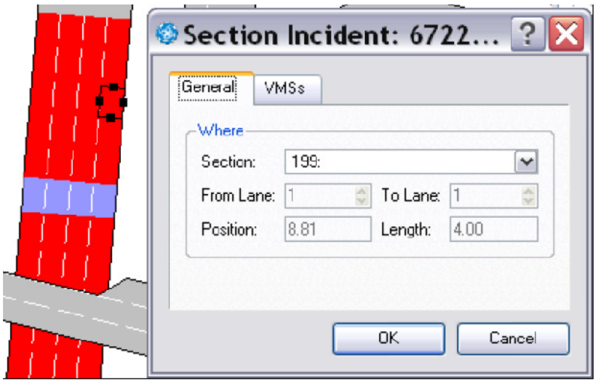


Figure 6.30. Cooperative delivery system

Such systems are reproduced on AIMSUN acting on the traffic incidents feature. In a first phase, following the delivery pattern observed during the survey, which based the modeling exercise, all the incidents are signalized (Figure 6.31).



Section Incident: 6722...

Where

Section: 199:

From Lane: 1

To Lane: 1

Position: 8.81

Length: 4.00

Figure 6.31. Incident definition on AIMSUN

The lane (or lanes) where it occurred, the ‘Position’ (distance from the beginning of the section) and the ‘Length’ of the incident (distance from the beginning of the incident until the end) are simulated on the network.

In a second phase, to simulate the effects of cooperative distribution systems and considering the majority of suppliers park illegally, incidents which would start within a 30 minutes period to supply that branch were aggregated. Such condition implies a new incident *v* will be created to replace the respective aggregated incidents *n*. The incident *v* will occur at a random position between the ones in which were occurring the respective *n* incidents. The extent of the incident *v* corresponds to the sum of duration of the respective *n* incidents (sum of the *n* delivery parking times). The length of the incident *v* is the most common from the sample of incidents *n* (depending of the type of vehicle used).

6.7.2.1 Scenario 1: Cooperative distribution systems on Unit 1

Physical limitations of the street to receive delivery operations added to the fact that 75% of the freight vehicles supplying the Unit 1 have a load factor <50%, lead to the consideration of cooperative delivery systems.

Scenario 1 represents a prediction of the effects of cooperative distribution systems applied in Cedofeita Street and Passos Manuel Street. It assumes that freight vehicles that supply the area, aggregate the deliveries with an arrival time difference not superior to 30 minutes. Such condition implies that about **65%** of the supply trips to the street would be reduced, but each delivery (new incident ***v***) and respective parking times would take longer. Quantitative effects of scenario 1 are presented on Annex A1.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The parking time of trips delivering aggregated loads is the sum of parking times of those same loads if they would be delivered separately. The consolidation of loads is carried out in a micro-platform located outside the unit. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

At the micro (street) level, the implementation of the initiative in Cedofeita Street has a negative impact for most of the stakeholders as illustrated in Figure 6.32. It is a typical case of output B – worst mobility and environmental sustainability. The reduction of the number of delivery trips with the implementation of CDS does not lead to an improvement on the mobility and sustainability of the street. Once the supplier has to make more than one delivery at the street, it takes more time to supply, implying a higher parking time and consequent stronger obstacle to the circulation. Such behavior affects in a significant and negative way all other stakeholders. On the total, delays increase by 24%, travel times by 22% and the average speed is reduced by 7%. Such signs of increasing congestion are confirmed by a lower distance travelled (-4%) and consequent reduction on fuel consumption levels and CO2 emissions (-3%). To all the stakeholders considered, increasing travel times and delays, together with decreasing distance travelled due to congestion and consequent reduction on fuel consumption vehicles and CO2 emissions, are the general tendency.

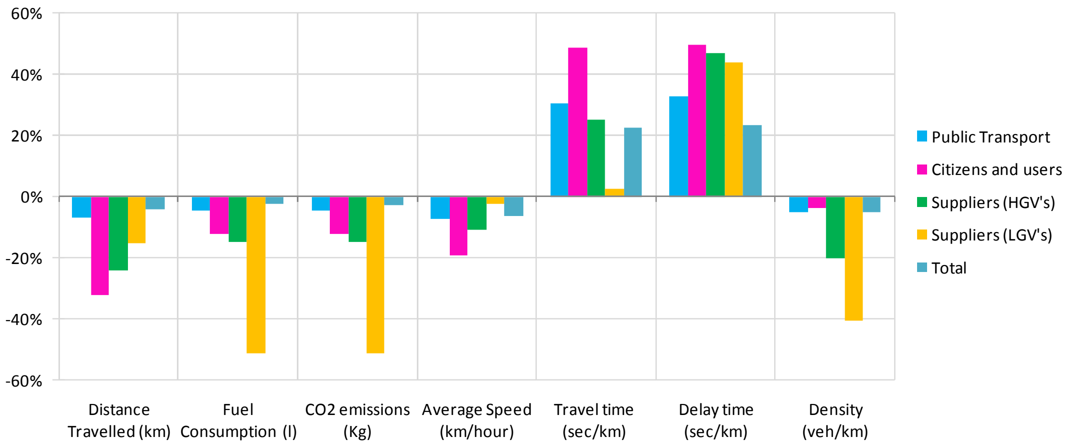


Figure 6.32. Cooperative systems at Cedofeita street in Unit 1

This scenario also simulated the effects of cooperative systems in Passos Manuel, other important commercial street of Unit 1. The effects in terms of stakeholders groups are very similar to the ones described to Cedofeita Street. Figure 6.33 shows the effects of the initiative in Passos Manuel Street.

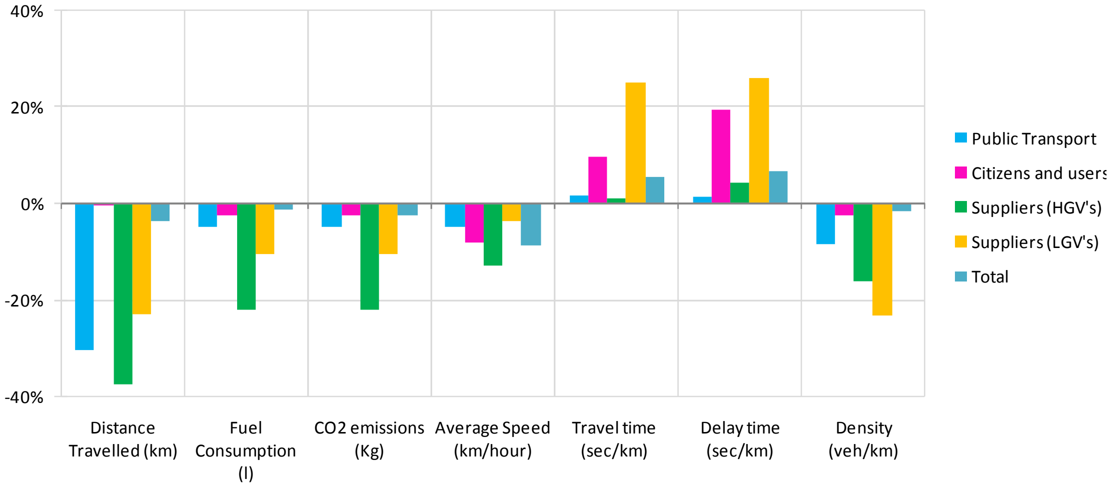


Figure 6.33. Cooperative systems at Passos Manuel street in Unit 1

Results illustrated on Figures 6.32 and Figure 6.33 in terms of traffic analysis are counterintuitive. It would be expected that a measure forcing suppliers to consolidate in order to privilege the other road users of the city, would benefit more the society in general. However, once it is assumed that the distribution pattern does not change (including parking behavior), the reduction of the number of supply trips is not followed by a reduction of the impact of incidents at the street. Thus, at this micro-level, cooperative systems cannot be considered a good practice to supply both streets.

At a higher geographical level, Downtown area (Unit level), results are positive in general, although with a low range of effects [-12; 4]%. It is a typical case of output D – better mobility and environmental sustainability.

The decrease of the number of delivery trips with the implementation of cooperative distribution systems leads to an decrease on delays (-12%) and on travel times (-11%). Such decrease on congestion, also followed by a slight increase on the average speed (4%) lead to a very slight decrease on fuel consumption (-5%) and CO2 emissions (-5%).

The positive effects felt at the unit level affect public and private stakeholders.

Private stakeholders have a positive and significant impact: for instance, suppliers on LGV's would have a decrease on travel times by -14% and delays would be reduced by -19%. Such improvement on mobility would lead to an increase on speed by 7%. Faster suppliers and a lower distance travelled (-2%) due to CDS contribute for a reduction on energy consumption (-5%) and on pollutants emitted.

Public stakeholders follow the same tendency of effects although with slightly lower effects.

Results by stakeholder group on the overall system (city coverage) reveal that the initiative is positive both to private and public stakeholders leading to better sustainability and mobility (output A). The range of total effects is low [-9; 2]%, with total delays being decreased by -8%.The general decrease on delays and travel times (-9%) together with a increase on the average speed (2%) indicates a better mobility in the overall system. Vehicles on the system travel a lower distance (-2%) and therefore, consume less fuel (-5%). CO2 emissions vary with the amount of fossil-fuel use and its mix, which leads to lower values (-5%). CO, which results from incomplete congestion in traffic engines, decreases by -16%. NOx also presents a general decrease of 17%. On the overall system, cooperative distribution systems are a positive measure towards mobility and sustainability.

6.7.2.2 Scenario 2: Cooperative distribution systems on Unit 2

Physical limitations of the street to receive delivery operations added to the fact that 75% of the freight vehicles supplying Unit 2 have a load factor <50%, lead to the consideration of cooperative delivery systems.

Scenario 2 represents a prediction of the effects of cooperative distribution systems applied in Costa Cabral Street. It assumes that freight vehicles that supply the area, aggregate the deliveries with an arrival time difference not superior to 30 minutes. Such condition implies that about **30%** of the supply trips to the street would be reduced, but each delivery (new incident ***v***) and respective parking times would take longer.

Quantitative effects of scenario 2 are presented on Annex A2.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The parking time of trips delivering aggregate loads is the sum of parking times of those loads if they would be delivered separately. The consolidation of loads is carried out in a micro-platform located outside the unit. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

At the micro (street) level, the initiative has a negative impact for most of the stakeholders as illustrated in Figure 6.34. The reduction of the number of delivery trips with the implementation of CDS does not lead to an improvement on the mobility and sustainability of the street. It is clearly an output B leading to worst mobility and (environmental) sustainability. Once the (cooperative) supplier has to make more than one delivery at the street, it takes more time to supply, implying a higher parking time and consequent stronger obstacle to the circulation. Such behavior affects in a significant and negative way all stakeholders. On the total, delays increase by 56%, travel times by 36% and the average speed is reduced by 10%. Such signs of increasing congestion are confirmed by a lower distance travelled and consequent reduction on fuel consumption levels and CO2 emissions.

The reduction of the number of vans used to move the same amount of goods implies that the fleet is different. The analysis of the variations to suppliers on LGV's should take this change into account. To all the others, increasing travel times and delays, together with decreasing distance travelled due to congestion and consequent reduction on fuel consumption vehicles and CO2 emissions, are the general tendency.

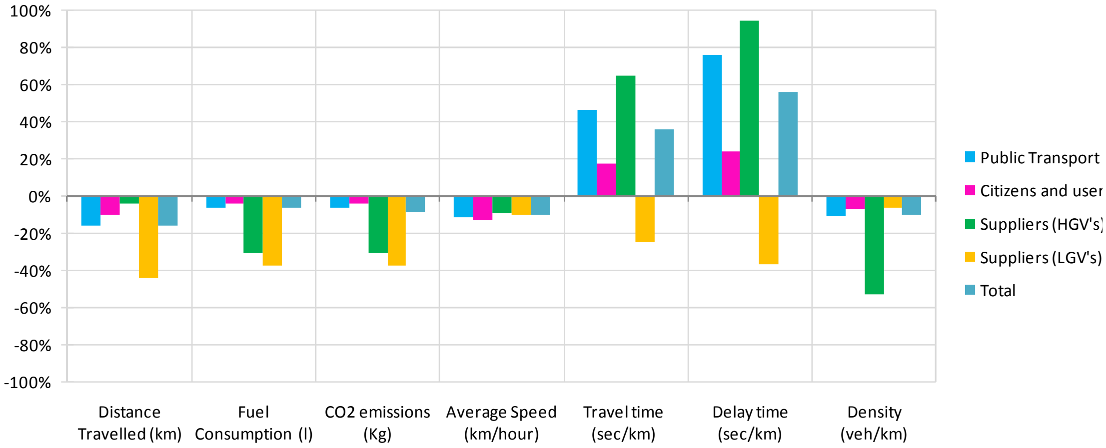


Figure 6.34. Cooperative systems at street level in Unit 2

Results illustrated on Figures 6.34 in terms of traffic analysis are counterintuitive. It would be expected that a measure forcing suppliers to consolidate to privilege the other road users of the city, would benefit more the society in general. Results from modeling show it affects negatively public transport (STCP plus intercity buses), citizens and users due to longer parking times to deliver and suppliers on HGV's and LGV's. The explanation is the same already given for the results illustrated at the previous scenarios.

At a higher geographical level, Marquês area, results are also negative in general, although with a lower range of effects on the street [-3; 10]%. This output for the motorized society is of type E – worst mobility and environmental sustainability.

The decrease of the number of delivery trips with the implementation of cooperative distribution systems leads to an increase on delays (5%) and on travel times (2%). Such increase on congestion, also followed by a slight decrease on the average speed (-2%) lead to a very slight increase on fuel consumption (-3%) and CO2 emissions (-3%). Such reductions due to congestion are also visible on the increase of CO by 14% and NOx by 13%, respectively.

The negative effects felt at the unit level affect public stakeholders and suppliers on HGV's. Suppliers on LGV's have a positive, although low, impact. Suppliers on LGV's would have a decrease on travel times by -7%, respectively, and delays would be reduced by -14%. Such improvement on mobility would lead to an increase on speed (+4%). Faster suppliers and a lower distance travelled (-3%) due to CDS contribute for a reduction on energy consumption and on pollutants emitted (-1%). Despite at the unit spatial level results show some positive potential, this low range of effects to a particular group of stakeholders is not enough to consider the measure as a 'good practice' at Marquês area.

Moreover, the implementation of cooperative systems implies the reduction of the number of vans (higher share on goods vehicles distribution) to move the same amount of goods. Thus, the change of the fleet can influence the indicators variations to suppliers on LGV's (under a modeling perspective).

Results reveal that on the overall system (city coverage) the effects of the implementation of cooperative systems in the area are negative (output B). Such impacts seem to derive from the additional flows generated by the need to consolidate, but there is not a clear evidence of it.

Results by stakeholder group on the overall system reveal that the initiative is negative both to private and public stakeholders. The range of total effects is low [-7; 7]%, with total delays being increased by 7%.The general increase on delays and travel times (5%) together with a decrease on the average speed (<1%) indicates a worst mobility in the overall system. Vehicles on the system travel a lower distance (-6%) due to congestion and therefore, consume less fuel (-4%). CO2 emissions vary with the amount of fossil-fuel use and its mix, which leads to lower values (-4%). CO, which results from incomplete congestion in traffic engines, increases due to congestion (+4%). NOx also presents a general slight increase of 3%. On the overall system, cooperative distribution systems are a negative measure towards mobility and sustainability.

6.7.2.3 Scenario 3: Cooperative distribution systems on Unit 3

Physical limitations of the street to receive delivery operations added to the fact that 85% of the freight vehicles supplying Unit 3 have a load factor <50%, lead to the consideration of cooperative delivery systems.

Scenario 3 represents a prediction of the effects of cooperative distribution systems applied in Avenida da Boavista. It assumes that freight vehicles that supply the area, aggregate the deliveries with an arrival time difference not superior to 30 minutes. Such condition implies that about **60%** of the supply trips would be reduced (the double of the reduction achieved in Unit 2), but each delivery and respective parking times at the street would take longer.

Quantitative effects of scenario 3 are presented on Annex A3.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The parking time of trips delivering aggregate loads is the sum of parking times of those loads if they would be delivered separately. The consolidation of loads is carried out in a micro-platform located outside the unit. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

At the micro (street) level, the initiative has a negative impact of type C for public stakeholders and a positive one of type A/D to private ones as illustrated in Figure 6.35. The dimension of total impacts is rather low [-1;1]%, which might be explained with the large width of the street and the fact that 100% of suppliers park on the deactivated tram lane, not causing a relevant disturbance on the road traffic circulation. On the total, delays increase by 1%, travel times by 1% and the average speed is reduced by 1%. In such conditions the initiative cannot be considered a ‘good practice’ at street level.

With CDS, (cooperative) suppliers have to make more than one delivery at the street, taking more time to supply, which implies a higher parking time and consequent stronger obstacle to the circulation. Such behavior affects in a significant and negative way public stakeholders (public transport, citizens and users).

Private stakeholders (suppliers) would predictably achieve a better mobility and sustainability while public ones would have negative effects. Suppliers on LGV's achieve a reduction on delays and travel times by -8% and -7%, respectively. Such improvement on mobility is confirmed by an increase by 7% on the average speed. Due to the aggregation process associated with CDS, the total distance travelled by LGV's decreases by -9% and therefore it also occurs a decrease on the fuel consumption levels (-10%). Suppliers on HGV's also benefit from CDS: due to the aggregation there are less HGV on the street (the density of these vehicles shows a decrease by -14%) and thus, travel lower distances (-15%). The decrease on the distance travelled explains the decrease on the fuel consumed by HGV's by -14% and respective CO2 emissions (-15%).

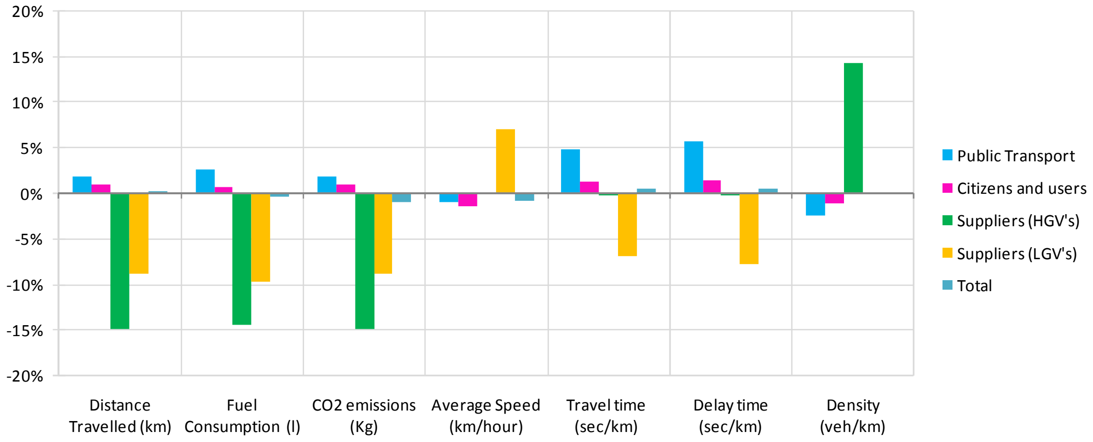


Figure 6.35. Cooperative systems at street level in Unit 3

At a higher geographical level, Boavista area, results are negative in general (output G), although with a lower range of effects [-5; 5]% than the ones observed at Unit 2.

The decrease of the number of delivery trips with the implementation of cooperative distribution systems leads to an increase on delays and travel times (2%). Such increase on congestion lead to a very slight increase on fuel consumption (4%) and CO2 emissions (5%). Values from CO2 are slightly higher than the ones of fuel consumption due to changes on the suppliers fleet resulting from the implementation of CDS.

The negative effects felt at the unit level affect all stakeholders, particularly public transport. Public transport would have an increase on travel times by 7% and delays would increase by 8%. Such decrease on mobility would lead to a decrease on speed by

-1%. Longer distances would be travelled and therefore, higher fuel consumption levels as well as higher pollutants would be emitted.

Despite the low (but negative) dimension of the effects, the homogeneity of the effects to all group of stakeholders labels cooperative systems as a negative deliver practice to supply the area. Results obtained in Unit 3 are similar in terms of tendency to the ones observed in Unit 2, although with a different range of values. Such negative output in both areas can be mostly explained by the longer parking times that suppliers (coming from the consolidation infrastructure) take to make the deliveries. Once it was assumed a) they keep the same distribution pattern (including parking behavior) and b) the consolidation is carried out on the neighborhood, which implies more traffic around the infrastructure, results at the unit level are negative.

Lastly, on the overall system (city coverage) the effects of the implementation of cooperative systems in the area are slightly negative (and lower than at Unit 2). Such impacts seem to derive from the additional flows generated by the need to consolidate, but there is not a clear evidence of it. Impacts of this measure are very low, varying between 0 and 3% and thus, any direct explanation is fragile to sustain.

Results by stakeholder group on the overall system reveal that the initiative is negative both to private and public stakeholders. The range of total effects is low, with total delays being increased by 1%. The minor increase on delays and travel times (1%) indicates a slightly worst mobility in the overall system. Vehicles on the system travel the same total distance and therefore, consume the same total fuel. On the overall system, cooperative distribution systems are a slightly negative measure towards mobility and sustainability.

When comparing results described at the street level with other geographical levels, the outcome can, at first, seem counterintuitive. It would be expected that a measure forcing suppliers to reduce the number of trips to the street, would benefit more the local stakeholders and with a higher range of effects than at the unit and at the system levels. Such fact does not happen in Unit 3 and the low effect at the street level is explained first, by the layout of the street (vd figure 6.18). Suppliers park over the deactivated tram lane in a wide street. Thus, all the other users are not significantly affected by the transgression as they are not considerably influenced by initiatives which reduce the number of suppliers parking on those conditions. Second, the consolidation is carried out in a platform located within the unit and therefore, at this level it is generated more traffic around the platform from suppliers who want to consolidate. Such facts lead to higher effects at the unit level than at the street level.

Table 6.8. Summary of effects of cooperative systems on mobility and sustainability

	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society (Total)
Scenario 1: Unit 1					
Cedofeita Street	🟥	🟥	🟥	🟥	🟥
Passos Manuel Street	🟥	🟥	🟥	🟥	🟥
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Scenario 2: Unit 2					
Street	🟥	🟥	🟥	🟩	🟥
Unit	🟥	🟥	🟥	🟩	🟥
System	🟥	🟥	🟥	🟥	🟥
Scenario 3: Unit 3					
Street	🟥	🟥	🟩	🟩	⬜
Unit	🟥	🟥	🟥	🟥	🟥
System	🟥	🟥	🟥	🟥	🟥

🟥 Unfavorable
⬜ Not conclusive
🟩 Favorable

The estimated impacts of **cooperative distribution systems** reveal the initiative cannot be considered a best practice at none of the spatial levels considered on this study, neither to any particular group of stakeholders. Moreover, the implementation of this initiative would not minimize the problems of circulation on any of the areas, despite the significant reduction on the number of delivery trips. On the contrary, it would aggravate the existing problems due to longer illegal parking times and to a consolidation infrastructure which would generate new local traffic problems. Furthermore, in the present study it was assumed that once the platform already existed, no additional operational costs would occur, which is an optimistic assumption.

The previous facts, together with the small number of carriers that are (expectably) willing to join such system, leads to low benefits on the overall system. Moreover, the simulation of the four scenarios showed theoretical reductions of supply trips by 65%, 30% and 60%) corresponding to modest impacts due to illegal parking. With such numbers, it is raised the question whether decision-makers should be worried with the reduction of the supply trips or with the reduction of the illegal parking.

With such effects, scenarios 1, 2 and 3 cannot be considered a best initiative to supply the respective areas, under mobility and sustainability criteria, and considering public and private objectives.

6.7.3 Collaborative systems

Collaborative systems are promoted by shops belonging to the same business segment and by shops that sell products with similar physical and marketing characteristics, located within close proximity of each other's (Melo and Costa, 2007).

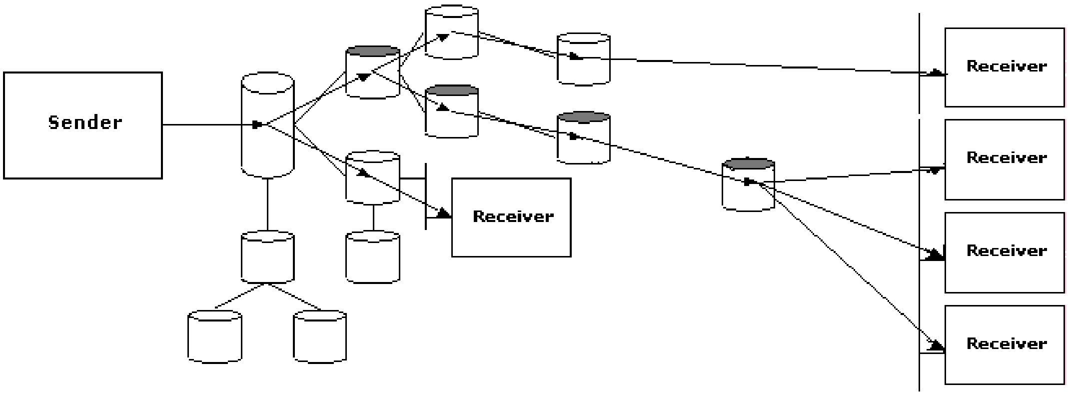


Figure 6.36. Collaborative delivery systems

Such systems are reproduced on AIMSUN acting on the traffic incidents feature[34]. In a first phase, following the delivery pattern observed during the survey, which based the modeling exercise, all the incidents were signalized (Figure 6.31).

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[34] *In AIMSUN, a traffic incident is any traffic event that causes a lane blockage over a certain time period, like a goods vehicle loading or unloading, a taxi picking up or dropping off a passenger, a broken down vehicle, road works, etc.*

In a second phase, to simulate the effects of collaborative distribution systems and considering the majority of suppliers park illegally, incidents *n* which would start within a 30 minutes period to supply that area are aggregated. Such condition implies a new incident *v* will be created to replace the respective aggregated incidents *n*. The incident *v* will occur at a random position between the ones in which were occurring the respective *n* incidents. The extent of the incident *v* corresponds to the sum of duration of the respective *n* incidents (sum of the *n* delivery parking times).

6.7.3.1 Scenario 4: Collaborative distribution systems on Unit 1

The strong dominance of the fashion branch representing 32% of the stores located in the area added to the fact that 75% of the freight vehicles supplying Unit 1 have a load factor <50%, lead to the consideration of collaborative delivery systems.

Scenario 4 represents a prediction of the effects of collaborative systems applied in Cedofeita Street and Passos Manuel Street. It assumes that freight vehicles that supply the fashion branch would aggregate their deliveries with an arrival time not superior to 30 minutes. Such condition implies about **30%** of the supply trips would be reduced.

Quantitative effects of scenario 4 are presented on Annex A4.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The consolidation of loads is carried out in a micro-platform located outside the unit. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

Results at street level in Cedofeita are positive and quite significant, with a range of total impacts varying from -16% to 7% (Figure 6.37). Total general delays are reduced by -4% and travel times by -1%. These two indicators together with a higher speed (5%) indicate a better mobility, explained by the reduction of delivery trips and consequent reduction of obstacles to road circulation. The improvement on mobility also leads to an improvement on sustainability through the decrease on the energy consumed (-16%) and on the CO2 emissions (-16%). It is a typical case of output A – better mobility and sustainability.

The implementation of scenario 4 in Passos Manuel Street would lead to similar effects to the ones illustrated on Figure 6.37 to each of the analyzed stakeholders.

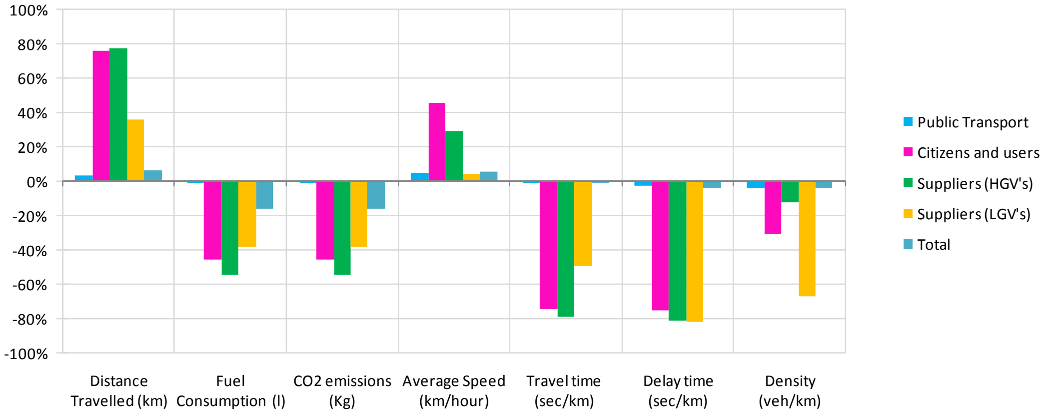

Figure 6.37. Collaborative systems in Cedofeita street in Unit 1

At Downtown area (unit level), results are still positive, indicating a positive direction towards a better mobility and sustainability (Output A), both for public and private stakeholders.

The decrease of the number of delivery trips with the implementation of collaborative distribution systems leads to a decrease on delays (-4%) and on travel times (-20%). Such decrease on congestion, also followed by a slight increase on the average speed (2%) lead to a decrease on fuel consumption (-14%) and CO2 emissions (-14%).

The effects on suppliers on LGV's are significant in most of the indicators: delays (-19%), travel times (-32%), average speed (4%), fuel consumption (-22%), CO2 emissions (-22%), CO (-18%) and NOx (10%). The positive dimension of the effects and its homogeneity to all group of stakeholders indicates collaborative systems as a potential deliver practice to the area.

Results from simulation reveal that the impact of collaborative systems in the overall system is positive, confirming the yielding tendency observed at the micro level. Although the overall relative effects are very low [-10%; + 2%], results are consistent enough to indicate a positive tendency. Decreasing travel times (-10%) and delays (-5%) show an increase on mobility patterns. Such ease of movement leads to a decrease on fuel consumption (-8%) is registered as well as lower CO2 emissions (-8%). CO and NOx also decrease by -23% and -25%, respectively due to an increasing mobility.

These positive effects are homogeneous to all stakeholders towards a better mobility and environmental sustainability (output A).

6.7.3.2 Scenario 5: Collaborative distribution systems on Unit 2

The strong dominance of the fashion branch representing 44% of the stores located in the area added to the fact that 75% of the freight vehicles supplying Unit 2 have a load factor <50%, lead to the consideration of collaborative delivery systems.

Scenario 5 represents a prediction of the effects of collaborative systems applied in Costa Cabral Street. It assumes that freight vehicles that supply the fashion branch would aggregate their deliveries with an arrival time not superior to 60 minutes. Such condition implies about **40%** of the supply trips would be reduced.

Quantitative effects of scenario 5 are presented on Annex A5.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The consolidation of loads is carried out in a micro-platform located outside the unit. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

Results at street level are positive (output A) and quite significant, with a range of total impacts varying from -37% to 10% (Figure 6.38). Total general delays are reduced by -18% and travel times by -11%. These two indicators together with a higher speed (10%) indicate a better mobility, explained by the reduction of delivery trips and consequent reduction of obstacles to road circulation. The improvement on mobility leads also to an improvement on sustainability through the decrease on the energy consumed (-37%) and on the CO2 emissions (-38%). Suppliers on HGV's are the ones who most benefit from collaborative delivery systems, achieving an impressive reduction of -74% on delays, -49% of travel times, -55% on fuel consumed and an increase on average speed by 49%.

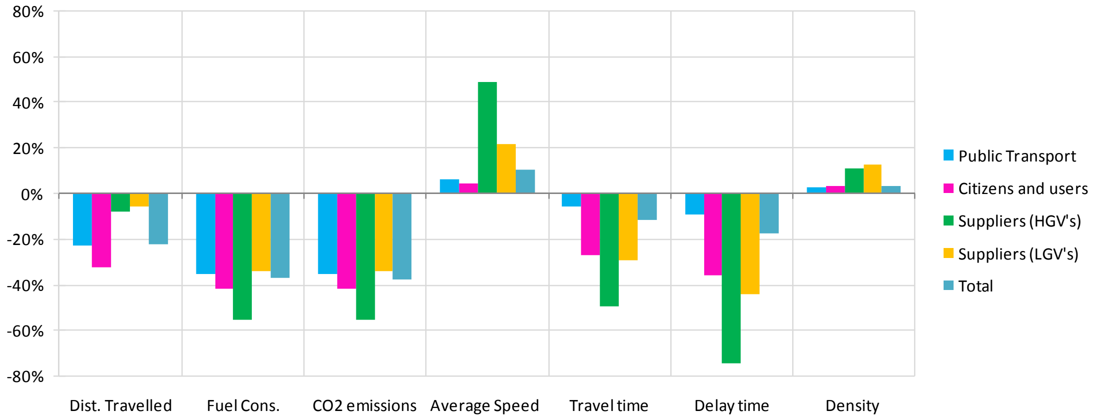

Figure 6.38. Collaborative systems at street level in Unit 2

At Marquês area, results are lower [-5; 11]% but still positive, indicating a positive direction towards increasing mobility and sustainability (output A). Both, public stakeholders and private stakeholders benefit from it.

The decrease of the number of delivery trips with the implementation of collaborative distribution systems leads to a decrease on delays (-5%) and on travel times (-4%). Such decrease on congestion, also followed by a slight increase on the average speed (2%) lead to a very slight decrease on fuel consumption (-5%) and CO2 emissions (-5%). Such improvements on the quality of the urban environment are also visible on the decrease of CO by 3% and NOx by 4%, respectively.

The effects on suppliers on HGV's are significant in most of the indicators: delays (-16%), travel times (-8%), average speed (3%), fuel consumption (-5%), CO2 emissions (-5%), CO (-2%) and NOx (-6%).

Despite the low (but positive) dimension of the effects, the homogeneity of the effects to all groups of stakeholders indicates collaborative systems as a potential good delivery practice to the area.

Results from simulation reveal the impact of collaborative systems in the overall system is negative, contradicting the yielding tendency observed at the micro level (output F). Although the overall relative effects are very low [-3%; + 3%] they are consistent enough to indicate a negative tendency. Increasing travel times (3%), delays (3%) and density (2%) show a decrease on mobility patterns caused by congestion. Such unease of movement leads to a decrease on distance travelled (-3%) by cars inside the study area and because of that time they are idling, lower fuel consumption (-2%) is registered as well as lower CO2 emissions (-2%). CO and NOx also increase by 4% and 3%, respectively due to a decreasing mobility.

These low and negative effects are not homogeneous to all stakeholders. Public stakeholders and one of the private stakeholders (suppliers on LGV's) would feel a negative effect. The other private stakeholders, suppliers on HGV's, would have minor but positive results, achieving a reduction by 1% on delays and by 1% on travel times. Such small variation added to the fact it happens at the overall system, makes this heterogeneity to be considered irrelevant. Collaborative systems are not a good delivery practice to be applied at Unit 2.

6.7.3.3 Scenario 6: Collaborative distribution systems on Unit 3

Scenario 6 represents a prediction of the effects of collaborative systems applied in Avenida da Boavista. It assumes that freight vehicles that supply the retail branch would aggregate their deliveries with an arrival time not superior to 60 minutes. Such condition implies about **20%** of the supply trips would be reduced.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The consolidation of loads is carried out in a micro-platform located outside the unit. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

Quantitative effects of scenario 6 are presented on Annex A6.

The effects of collaborative systems applied in *Avenida da Boavista* would not have a significant effect at street level (figure 6.39). Despite the reduction of 20% of the supply trips to the street, the initiative would not contribute to a better local mobility or sustainability. All indicators would vary within the range of [-2; 0] % on the total. Such low effect is strongly influenced by the layout of the avenue (Figure 6.18), which allows suppliers to illegally park on the deactivated tram lane and thus, not interfere with the normal circulation. This fact has already been observed with scenario 3 (Figure 6.25).

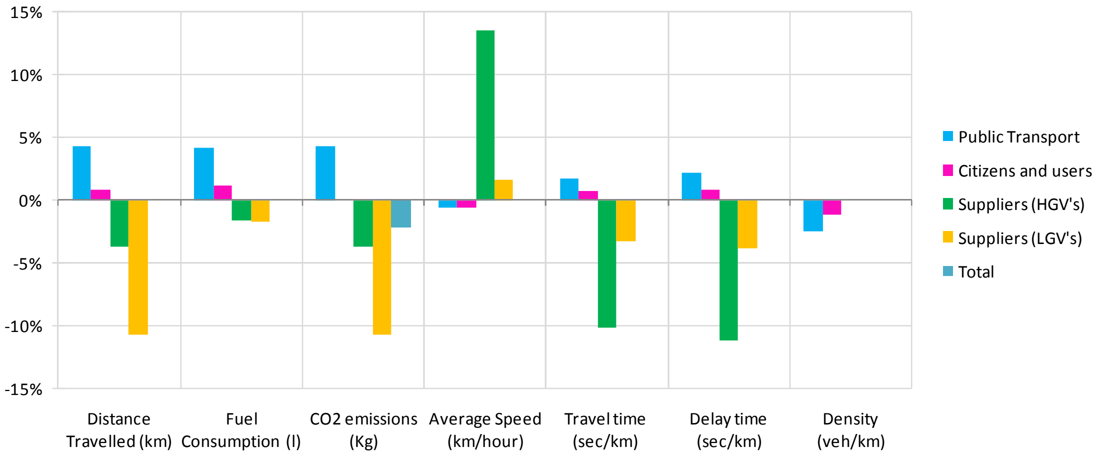

Figure 6.39. Collaborative systems at the street level in Unit 3

In spite of the variation of the total effects on the street are close to 0%, there are some heterogeneities within the stakeholders impacts (Figure 6.39). The negative effects are felt mainly by public stakeholders (output G). Private stakeholders have a positive, although low, impact (Output A). Suppliers on HGV's and LGV's would have a decrease on travel times by -10% and -3%, respectively, and delays would be reduced by -11% and -4%. Such improvement on mobility would lead to an increase on speed. Faster suppliers and a lower distance travelled due to collaborative systems contribute for a reduction on energy consumption and on pollutants emitted by suppliers.

Despite the positive potential to private stakeholders at street level, the low range of effects added to the consideration of public stakeholders interests, shows the initiative cannot be considered a 'good practice' towards mobility and sustainability of the street.

At *Boavista* unit, the effects of the initiative are positive and with a higher range of effects than at the street level [-5; 7]%. Such fact can at first, seem counterintuitive. It would be expected that a measure forcing suppliers to reduce the number of trips to the street, would benefit more the local stakeholders and with a higher range of effects than at the unit and at the system levels. First, the low effect at the street level is explained by the layout of the street (vd figure 6.18). Suppliers park over the deactivated tram lane in a wide street. Thus, all the other users are not significantly affected by this transgression. Second, the consolidation is carried out in a platform located within the unit and therefore, at this level there's more traffic around the platform from suppliers who want to consolidate. Such fact leads to higher effects at the unit level than at the street level.

Private stakeholders would have positive effects at the unit level (output A). Suppliers on HGV's and on LGV's would have lower travel times by -8% and -4%, respectively, and delays would decrease by -10% and -5%. Lower congestion would be followed by a decrease on distance travelled and on energy consumed and pollutants emitted.

The low dimension of the effects of collaborative systems and the need to integrate public and private stakeholders makes it impossible to consider it a good practice to supply the area.

On the overall system the effects are very low [0; 3]% and without a clear and direct explanation of the variation on indicators. All groups of stakeholders present negative effects. Higher travel times, higher delays, lower average speed, higher density, higher energy consumed and pollutants emitted occur both to public and private stakeholders.

In spite of the homogeneity of results by stakeholders group, these effects refer to changes on absolute values that are minimal (for instance, by 0.17 km/h on the average speed). Such small effects at the city coverage do not allow to give a direct explanation of the variation of the indicators.

6.7.3.4 Scenario 7: Collaborative distribution systems in Camoes

Scenario 7 represents a prediction of the effects of collaborative systems applied in Camoes street. It assumes that freight vehicles that supply the automobile spare parts would aggregate their deliveries with an arrival time not superior to 60 minutes. Such condition implies about **8%** of the supply trips would be reduced. This relative reduction is lower than the ones observed on the previous scenarios.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The consolidation of loads is carried out in a micro-platform located close to the street. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

Quantitative effects of scenario 7 are presented on Annex A7.

The effects of collaborative systems applied in *Camoes Street* would not have a significant effect at street level (figure 6.40). All indicators would vary within the range of [-5; 0] % on the total system.

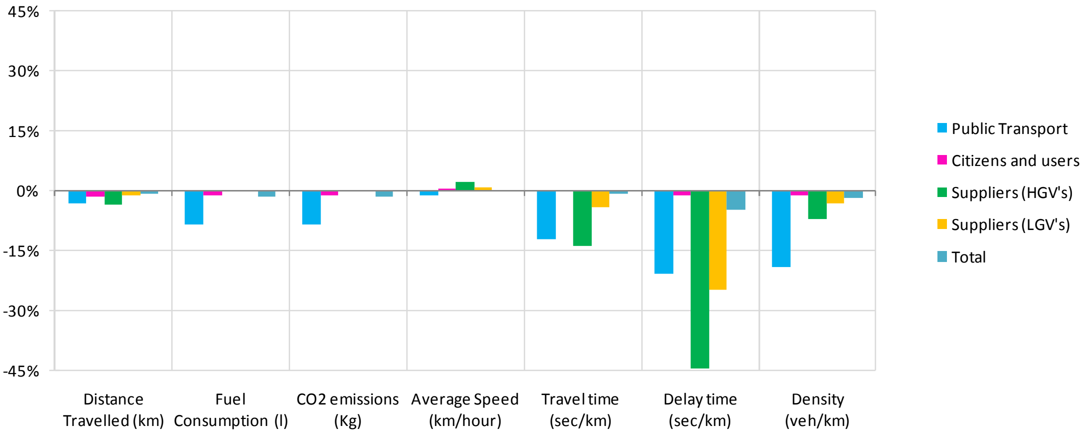

Figure 6.40. Collaborative systems at Camões street

In spite of the variation of the total effects on the street are close to 0%, there are some heterogeneities within the stakeholders impacts (Figure 6.40). Suppliers on HGV's and LGV's would have a decrease on travel times by -4% and -14%, respectively, and delays would be reduced by -45% and -25%. Although this relative variation on delay times seems to be very relevant, it corresponds to a decrease by -15 and -4 sec/km, which in absolute terms is not so impressive.

Despite the positive potential to most of the stakeholders at street level, the low range of effects added to the consideration of the costs of the implementation of such initiative, shows it cannot be considered a ‘best practice’ towards mobility and sustainability of the street.

Table 6.9. Summary of effects of collaborative systems on mobility and sustainability

	Public Transport	Citizens and city users	Suppliers HGV’s	Suppliers LGV’s	Society (Total)
Unit 1					
Cedofeita Street	🟩	🟩	🟩	🟩	🟩
Passos Manuel Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Unit 2					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟥	🟥	🟩	🟥	🟥
Unit 3					
Street	🟥	🟥	🟩	🟩	⬜
Unit	🟥	🟥	🟩	🟩	⬜
System	🟥	🟥	🟥	🟥	🟥
Scenario 7: Camoes					
Street	🟩	🟩	⬜	🟩	⬜

🟥 Unfavorable
⬜ Not conclusive
🟩 Favorable

The analysis of **collaborative delivery systems** revealed the initiative has more potential at the street and unit levels then at the city coverage. It would expectably benefit more private stakeholders, although its implementation would also require more from them than from the other actors. Determinant requirements like the existence of a specific commercial software program to make the deliveries, a particular depot to consolidate or the acceptance of shopkeepers to be included on such scheme make the estimated positive effects to be insignificant to convince public and private stakeholders to implement collaborative systems. In what concerns to costs, a particular focus on the platform feasibility is required. In the present study it was assumed that once the platform already existed, no additional operational costs would occur, which is not true in most of the cases.

The previous facts, together with the small number of carriers that are (expectably) willing to join such system, leads to low benefits on the overall system. Moreover, the simulation of the four scenarios showed theoretical reductions of supply trips by 30%, 40%, 20% and 8% corresponding to modest impacts due to illegal parking. With such numbers, it is raised the question whether decision-makers should be worried with the reduction of the supply trips or with the reduction of the illegal parking.

With such effects, collaborative systems simulated on scenarios 4, 5, 6 and 7, cannot be considered a 'best practice' to supply the area, under mobility and sustainability criteria, and considering public and private objectives.

6.7.4 Regulation of access based on time

The regulation of access based on time is a measure imposed by public authorities, who force suppliers to make their deliveries to a specific area in limited and less sensitive periods. The idea is to define periods in which the distribution activity causes fewer disturbances in the city and on other users of the road infrastructure. It is expected that less interaction with other users, through the separation of different types of traffic, leads to less congestion and to an improvement in safety and environment (Ruesch and Glücker, 2001). On the suppliers side, the regulation of the access based on time can contribute to some changes in the way their trips into the city are organized. In principle (and depending on the characteristics of the distribution activity) suppliers will opt to increase the load factors of their vehicles, which will lead to fewer trips into the city.

Such initiative is reproduced on AIMSUN acting on the traffic incidents feature. In a first phase, following the delivery pattern observed during the survey, which based the modeling exercise, all the incidents were signalized (Figure 6.31). In a second phase, to simulate the effects of the regulation of access based on time, incidents *n* which would start out of the time window, are forced to occur during the legal period with a random distribution.

6.7.4.1 Scenario 8: Regulation of access based on time on Unit 2

Currently freight vehicles access to Costa Cabral Street at any time of the day and park on the direction that allows road circulation for every type of vehicles. Scenario 8 establishes the regulation of the access imposing a time window between 10:00 and 14:00.

The period of access was defined based on opening times of shops located on the area, local habits and traffic counting results and the regulation period was not synchronized with other ones existent in the city.

The simulation exercise assumed the initiative is in force 4 hours per day, 5 days per week, covering the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the area. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. Suppliers access to the area only during the legal time window. Outputs of the simulation exercise refer to the average hour.

Quantitative effects of scenario 8 are presented on Annex A8.

The effects of the regulation of access based on time on Unit 2 at street level follow the output A (better mobility and sustainability). The range of general effects varies from -21% to +25%. Delay times on the total decrease -18%, correspondent to minus 13 seconds along the street and travel times by -12% (minus 14 seconds). Such results, together with an increase of the average speed of 7km/h to 38km/h, confirm a higher mobility along the street. Also in terms of sustainability, results are quite positive with average reductions on fuel consumption levels and CO2 emissions by 21%.

Such positive effects are obtained to all groups of stakeholders as shown in figure 6.41. Citizens and other road users on passenger vehicles are the ones who clearly benefit more with this practice. Once the initiative forces suppliers to avoid the morning peak hour, citizens experiment a huge benefit from the regulation of access based on time. Such positive effects can contribute for this measure to be (at least one of) the most popular practices adopted by decision-makers and city planners.

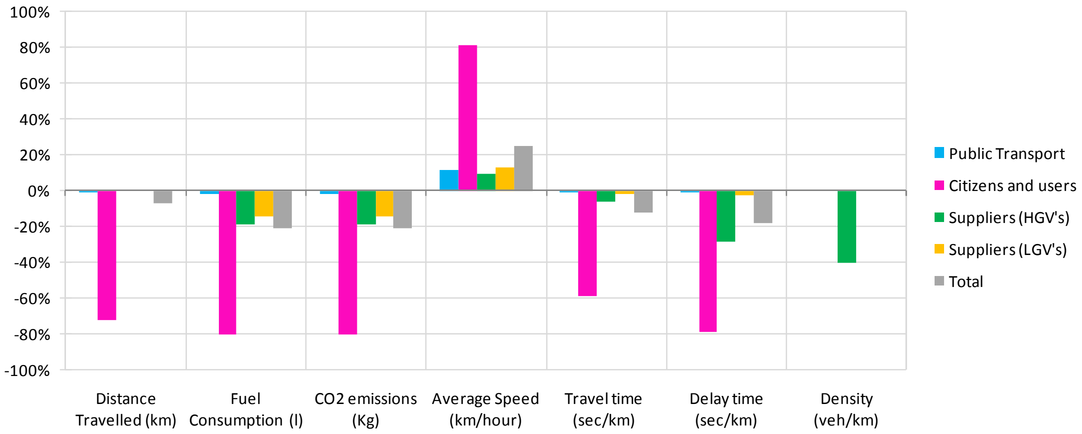

Figure 6.41. Regulation of access based on time in Costa Cabral street in Unit 2

At the unit level, in Marquês area, results are less significant but still indicate a better mobility and sustainability to all stakeholders (output A). The range of effects is lower than at the street level, varying between [-1; 12]% (not considering the CO and NOx variation). The decrease of the delays (-2%) and travel times (-1%) seem to indicate a slightly lower congestion in the unit. The lower congestion added to a higher average speed (1%) reveal an easiness of movement, a measure of mobility. Fuel consumption and CO2 emissions decrease -1%, suggesting an improvement of the sustainability of the unit.

At the overall system, the range of effects is low [-1; 5]% as it has been observed with the previous scenario, but consistent enough to indicate this initiative as a good practice to be implemented on Unit 2.

6.7.4.2 Scenario 9: Regulation of access based on time in Camoes

Currently freight vehicles access to Camões Street at any time of the day and park on double lane. Scenario 9 establishes the regulation of the access imposing a time window between 10:00 and 14:00.
The period of access was defined based on opening times of shops located on the area, local habits and traffic counting results and was not synchronized the regulation periods with other ones existing in the city.

The simulation exercise assumed the initiative is in force 4 hours per day, 5 days per week, covering the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the area. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. Suppliers access to the area only during the legal time window. Outputs of the simulation exercise refer to the average hour.

Quantitative effects of scenario 9 are presented on Annex A9.

The effects of the regulation of access based on time in Camões Street follow the output A (better mobility and sustainability). The range of general effects varies from -5% to +0%, which is not significant. Delay times on the total decrease -5%, correspondent to minus 1 seconds along the street and travel times by -1%. Such results are not relevant enough to support the idea that this initiative leads to a better and relevant mobility on the axle. Also in terms of sustainability, results are positive with average reductions on fuel consumption levels and CO2 emissions by -2%. Such positive effects are obtained to all groups of stakeholders as shown in figure 6.42, as it has been also observed with the previous scenario.

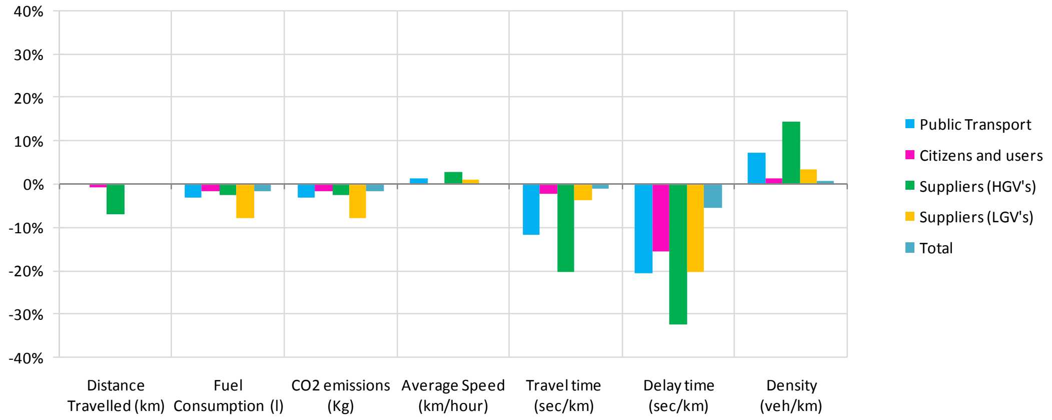

Figure 6.42. Regulation of access based on time in Camões axle

Table 6.10 summarizes the effects of regulation of access based on time.

Table 6.10. Summary of effects of regulation of access based on time towards increasing mobility and sustainability

	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society (Total)
Unit 2					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Camões axle					
Street	🟩	🟩	🟩	🟩	🟩

🟥 Unfavorable
▨ Not conclusive
🟩 Favorable

The analysis of the effects of the **regulation of access based on time** only considers the impacts at the final destination. To accomplish the requirements imposed by the city (regulation of access) and by receivers (reliability), suppliers have to re-organize their supply trips (load factor, routing, scheduling, etc). Such re-organization impacts and costs are not quantified on this analysis and can predictably affect in a negative way the acceptance of this measure, rather than it seems from the results illustrated above. This initiative is usually imposed by local administrators, who aim to achieve a better quality of urban environment and might affect private stakeholders interests (namely suppliers), who aim a better efficiency on their operations with lower operational costs.

Despite it seem reasonable that local administrators should bring to discussion the industry stakeholders to help on the definition of the time windows that would lead to more common benefits, most of the times private interests are overlooked. Local administrators are aware of its power to impose a specific time window and suppliers are not evolved in decision in a determinant and direct way. In Porto (Portugal) as in most of the Portuguese cities, the time window is defined by local administrators, mainly taking in consideration shopkeepers and residents interests. It is still assumed that suppliers will always adapt their operations to the new regulations and conditions imposed by the city. The simulation can be a useful tool to evaluate possible scenarios and choose the ones that will lead to better overall benefits.

Under a perspective focused on mobility and environmental sustainability, the regulation of access based on time is a ‘best practice’ to supply the area. Considering the positive effects obtained in a first analysis, regulation of access based on time will be evaluated under a perspective focused on operational costs.

6.7.5 Alternative fuels with a penetration rate of 10% and 20%

Alternative fuels are a good example of new technologies related with vehicles, which can be helpful in the reduction of the dependence on petroleum-derived fossil fuels used for transport. From the examples of alternative fuels described in chapter 3 (section 3.4.4), it was chosen to simulate the specific impact of the use of electric vehicles in Downtown (Unit 1). Electric vehicles have zero emissions at the local level, (except the plug-in type) and are the alternative fuels which are more probable to increase its market share at the short-medium term.

6.7.5.1 Scenario 10: Alternative fuels in Unit 1 with a penetration rate of 10% and 20%

Scenario 10 estimates the impact of the use of alternative fuels (electric vehicles) with a penetration rate of 10% and 20% of the O/D matrices. The idea is not to estimate the effects of a Low Emission Zone but rather to evaluate the impacts of an increasing market share by electric vehicles.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, covering the daily peak of deliveries in the area. The initiative applies to all vehicles circulating in the area. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. The penetration rate is the same to all types of vehicles (passenger's cars, public transport and suppliers). Outputs of the simulation exercise refer to the average hour.

Quantitative effects of scenario 10 are presented on Annex A10.

The effects of the use of alternative fuels with a penetration rate of 10% and 20% would lead to effects of type A (better mobility and sustainability) on the Unit. The range of general effects is low and the effects on the different groups of stakeholders is homogeneous (Figure 6.43)

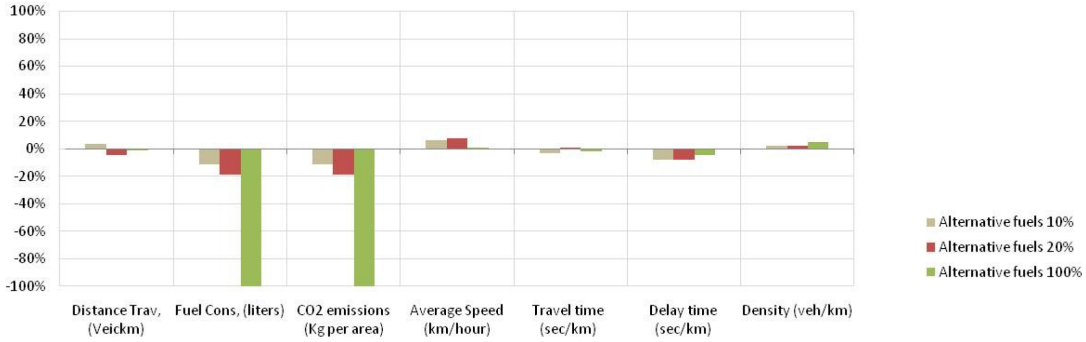

Figure 6.43. Alternative fuels use in Unit 1

On unit 1, the effects on mobility levels would be insignificant but on the environmental sustainability impacts would be significant and close to the values of the penetration rate (as expected). For a penetration rate by electric vehicles by 10%, fuel consumption levels would have a general decrease of -11%, with suppliers on HGV's and LGV's having a decrease by -9% and -11%, respectively. For a penetration rate of 20%, fuel consumption would decrease in general -19%, with suppliers on HGV's and

LGV's having a decrease by -19% and -24%, respectively. The small variations in relative terms of the energy consumption levels compared with the penetration rate is due to the fact that despite a penetration rate of 10% implies that 10% of the demand is constituted by electric vehicles, these ones are randomly assigned to different paths along the network. Different paths imply different levels of congestion and different fuel consumption levels along those routes. Therefore the variation in terms of fuel consumption and CO2 emissions is close to the level of the penetration rate, but still slightly different. At the overall system, the effects are lower but still confirming the (local) positive effects of the use of electric vehicles.

Table 6.11 summarizes the effects of the use of electric vehicles.

Table 6.11. Summary of effects of the use of electric vehicles towards increasing mobility and sustainability

	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society (Total)
Unit 1 – 10% PR					
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Unit 1 – 20% PR					
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩

It must be highlighted that only the effects at the final destination were considered on the previous analysis. If the impacts and costs of generating electricity and producing liquid fuels for vehicles are considered, the evaluation leads to less positive effects to society in general and its goal to attain a more sustainable development.

Moreover, despite the general benefits of electric vehicles under an environmental perspective, its use on urban goods distribution still presents some important obstacles to be overcome. The limited autonomy in terms of distance travelled and the costs of such vehicle and possible changes on suppliers' fleet makes this solution for now a 'best *theoretical* practice'. It has potential to become a 'best practice' but only the market will determine its evolution in the medium-long term.

6.7.6 Pricing Policies

Road pricing is an example of a transport pricing policy, which aims to influence the demand by manipulating transport costs. Road pricing is a (direct) charging fee for the use of road, based on the "user pays principle" and that tries to charge external costs, influence demand or to attain a fair charge of infrastructure cost (Wild, 2002).

Such measure is reproduced on AIMSUN based on the principle that users want to minimize their travel costs and acting on the cost function feature. The generalized cost is the sum of the operating cost of the vehicle and the cost of the travel time.

6.7.6.1 Scenario 11: Implementation of road pricing to the system

Scenario 11 estimates the effects of a single cordon charge, defined by the barrier that the first ring (VCI) imposes in Porto municipality. The potential impact of a road pricing scheme assumes a 2.5 Euros for private cars and of 3.5 Euros for heavy duty vehicles crossing the cordon. Such taxation should reduce individual travel and freight demand for all O/D pairs crossing the ring.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, from 7:00 to 14:00, covering the daily peak of deliveries in the area. The initiative applies to all vehicles crossing or/and circulating in the area inside the ring. The flow unit is vehicles, not passengers or cargo. The income segmentation for individual travel was not taken into account. Outputs of the simulation exercise refer to the average hour.

Quantitative effects of scenario 11 are presented on Annex A11.

The effects of the implementation of road pricing show improvements towards mobility and sustainability at the system level to public transport, private transport and freight transport. It is an output of type A to all groups of stakeholders (Figure 6.44).

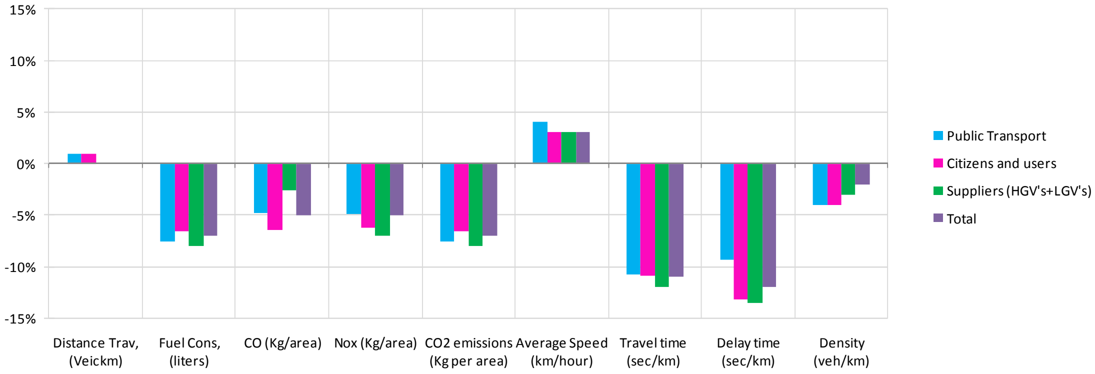

Figure 6.44. Implementation of road pricing in the overall system

The positive results obtained within the system, result from the fact that the implementation of road pricing reduces the number of vehicles crossing the cordon (VCI). Thus, the average speed within the system increases by 3% to an average of 31 km/h, travel times and delays are also reduced considerably by -11% and -12%, respectively and pollutant emissions confirm the positive effects of such solution inside the system.

Despite an increasing acceptance of this kind of solution by society, there are still some problematic issues to the approval of road pricing. The methods used to quantify the costs, the costs measured, the followed approach, the use of the fees charged, and the choice of strategies to be financed are some examples of problematic points. These problems can, however, be minimized through the quantification in advance of the overall results that are expected to be achieved with the initiative. In some cases (as the one described here) this quantification can reveal that the expected results are not significant enough to justify the implementation of the initiative.

Thus, although road pricing simulated on scenario 11 presents benefits towards mobility and sustainability to all group of stakeholders, the inclusion and consideration of other determinant features makes it unfeasible to categorize it as a ‘best practice’, without a more detailed analysis.

6.7.7 Scenario 12: Reserved-capacity Strategies: shared usage of a bus lane by freight vehicles in Unit 2

Scenario 12 estimates the effects of the impact of a reserved-capacity strategy applied to Costa Cabral Street (Figure 6.14). The idea that supports this initiative is that bus lanes occupy a considerable area of road infrastructure and are not used all the time, giving the opportunity to be shared by other type of traffic in non peak periods. The separation of traffic that comes from the usage of bus lane by suppliers leads to less physical interaction of freight vehicles with other users, which leads to less congestion, more safety and to a better quality of urban environment.

Traffic counting revealed that there's an average of 56 vehicles/hour entering the street in the direction of the bus lane, having a peak period between 7:30 and 9:30 a.m.. Along the opposite direction, the value is of 588 vehicle/hour, having a peak use in the end of the afternoon (Figure 6.45).

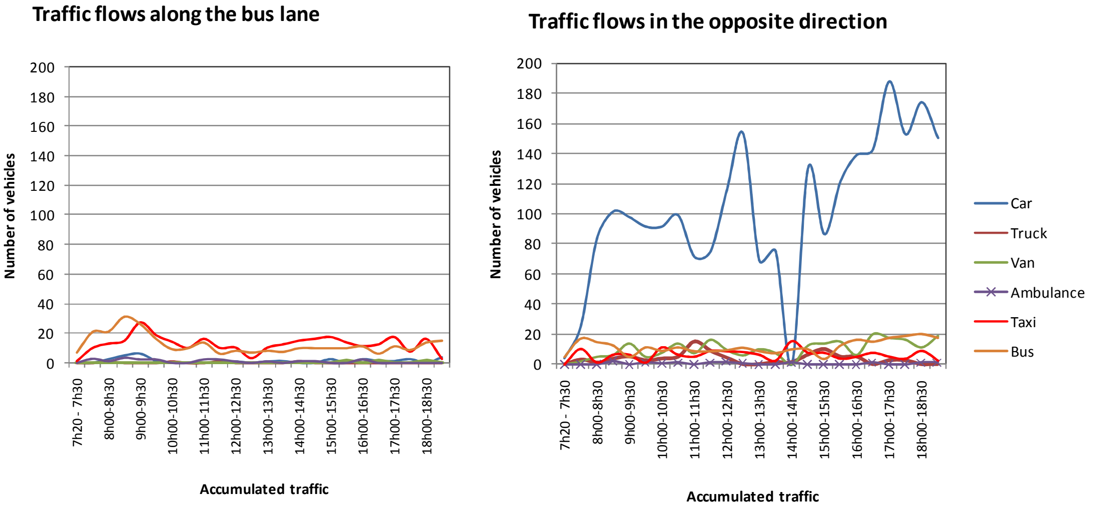

Figure 6.45. Traffic flows in the study area [35]

The average traffic per hour along the bus lane represents 9% of the total average traffic per hour along the entire street, which suggests that the bus lane is not entirely using its capacity.

This situation leads to propose the usage of the bus lane by freight vehicles, as long as the lane wouldn't be significantly affected by congestion and delays on the lane.

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[35] *Bicycle and motorbike represent less than 1% of this value.*

To define the requirements that should be fulfilled by freight vehicles in order to allow them to use the bus lane, four options were simulated:

- **Option 1** - Freight vehicles that take **one minute** or less to deliver are allowed to use the bus lane. According with the delivery pattern of the unit about 30% of the freight vehicles fulfill this criterion.
- **Option 2** - Freight vehicles that registered a parking time not superior to **two minutes** are allowed to use the bus lane. Such condition implies that about 40% of the freight vehicles supplying the area would be allowed to access to the bus lane during the periods defined above.
- **Option 3** - Freight vehicles that take 3 minutes or less to deliver are allowed to use the bus lane. 50% of the freight vehicles that access to the area take **3 minutes** or less to deliver its goods.
- **Option 4** - Freight vehicles that take 4 minutes or less to deliver are allowed to use the bus lane. 80% of the freight vehicles that access to the area take **4 minutes** or less to deliver its goods.

It were not considered options with parking time superior to 4 minutes because a) option 4 was already significantly disturbing for the circulation along the bus lane and b) 80% of freight vehicles could already use the bus lane with option 4.

The four options of Scenario 12 assume that the usage of the bus lane in Costa Cabral Street would be a compensation itself for suppliers. It was assumed that goods vehicles which fulfill the specified delivery time criteria would opt to use the bus lane. Suppliers of the unit (not included on this compensation) would keep its normal delivery and parking patterns (including the transgressions).

Quantitative effects of scenario 12 are presented on Annex A12.

The simulation exercise assumed the initiative is in force 7 hours per day, 5 days per week, during the morning period (7:00 – 14:00). It covers the daily peak of the bus lane and the daily peak of deliveries in the area. The initiative applies to all light and heavy goods vehicles supplying the unit. The flow unit is vehicles, not passengers or cargo. The delivery patterns adopted on the exercise are the ones obtained during the survey. Buses do not pass freight vehicles in the bus lane, which means that each time a freight vehicle is parked on the bus lane, it obstructs the normal circulation of buses and consequently increases the delay times on the lane. And lastly, outputs of the simulation exercise refer to the hourly average of the period.

Figure 6.46 illustrates the impacts of the shared usage at the street level (both directions).

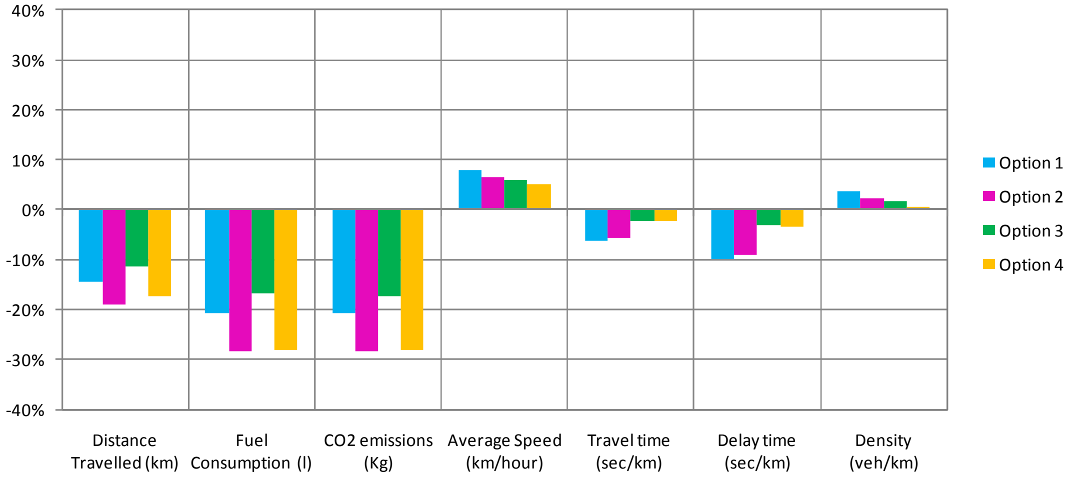

Figure 6.46. Shared usage effects at street level in Unit 2

At this micro scale, results are positive (output A) and with a high range of relative effects [-30, 10]%. At street level, the four options have positive results towards mobility and sustainability. The decrease of travel and delay times and by an increase on the average speed indicates a higher mobility. The decrease of distance travelled, with a consequent decrease on energy intensity and CO2 emissions consolidates what seem to be the signs of an improvement on the sustainability of the area.

Results are more positive for citizens and users. Public transport, which includes taxis, buses and intercity buses on both directions also has a positive performance due to the importance of this street on the route of intercity buses coming to Porto in the morning. This may sound a contradiction because it might not be clear why parking operations on bus lanes decrease bus delay times. There are mainly two reasons that justify this correlation. The first one is that the bus lane is being used bellow its capacity and consequently it allows other vehicles to use it without provoking significant disturbance. The other one is that the measured impacts refer to both directions of the street and not only to the buses driving on the bus lane. Consequently, more freight vehicles using the bus lane capacity relieve the traffic in all the area and consequently decrease the general (and specific buses) delay times, always considering the limitations imposed by bus circulation.

Results at the street level are clearly different according with the direction of the street (vd Figure 6.47 and 6.49).

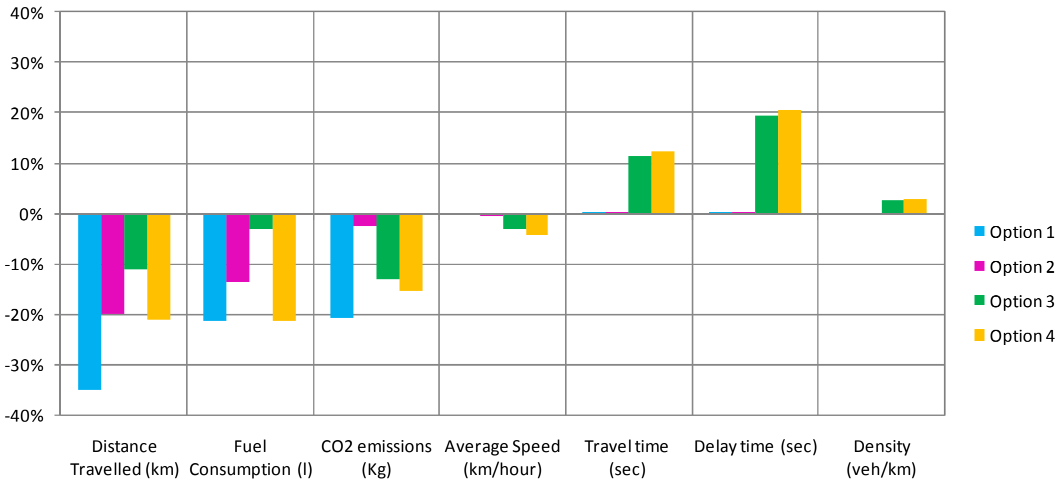

Figure 6.47. Shared usage effects at the bus lane for the four options

Along the bus lane it is visible that the range of effects is high. The effects are (negatively) increasing, particularly for option 3 and 4. In absolute terms, delays and travel times for option 3 increase 6 seconds, which is not significant.

On the particular case of buses along the bus lane, delay times can increase by more than 40%, equivalent to an average of 11 additional seconds per vehicle (to 35.6 seconds) along the street. None of the options would be positive to public transport (buses and taxis) along the bus lane and the difference of effects between options does not explicitly shows one of them as less negative (Figure 6.48).

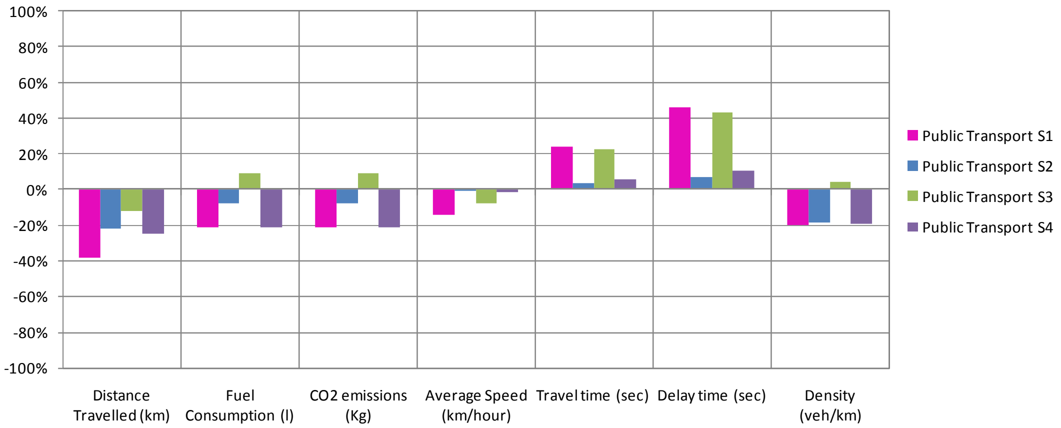

Figure 6.48. Shared usage effects along the bus lane for public transport

Along the opposite direction, results are positive for all options as it is shown in Figure 6.49. Such benefits are a consequence of a decrease in the traffic and disturbance caused by LGV's and HGV's along this direction.

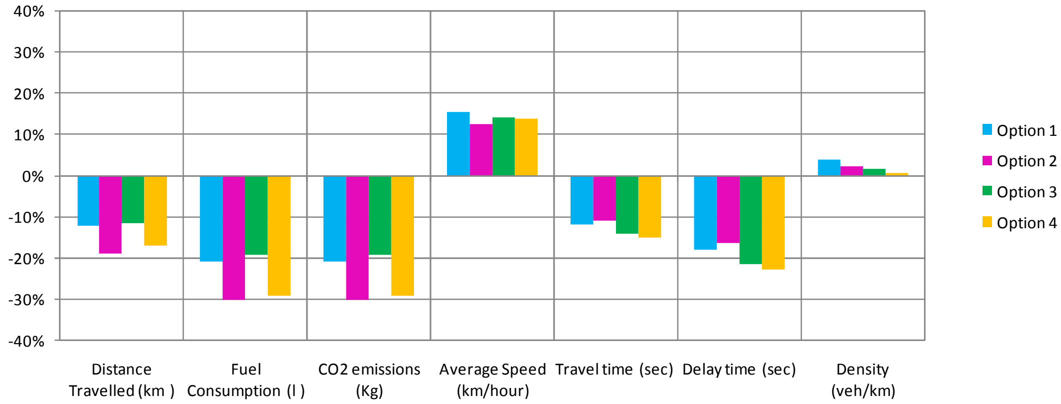

Figure 6.49. Shared usage effects along the opposite direction

As it would be expected, the allowance of circulation and parking by suppliers on the bus lane relieves the traffic flow on the opposite direction. The decrease of the number of transgressions along the street leads to lower travel times, delays and higher average speed. This increase in mobility is followed by an improvement of sustainability, through lower distance travelled, energy consumed and CO2 emitted.

In absolute terms the changes at microlevel are not significant. Option 4, the one with best performance, would lead to a decrease on travel times and delays of 9 seconds and an increase on average speed by 5 km/h to 37 km/h.

Figure 6.50 shows that at a higher geographical layer, the effects of the measure at the **unit level** are on average lower than at the street level.

None of the four options is positive to all stakeholders, although the beneficial effects increase with the increasing number of suppliers allowed circulating on the bus lane.

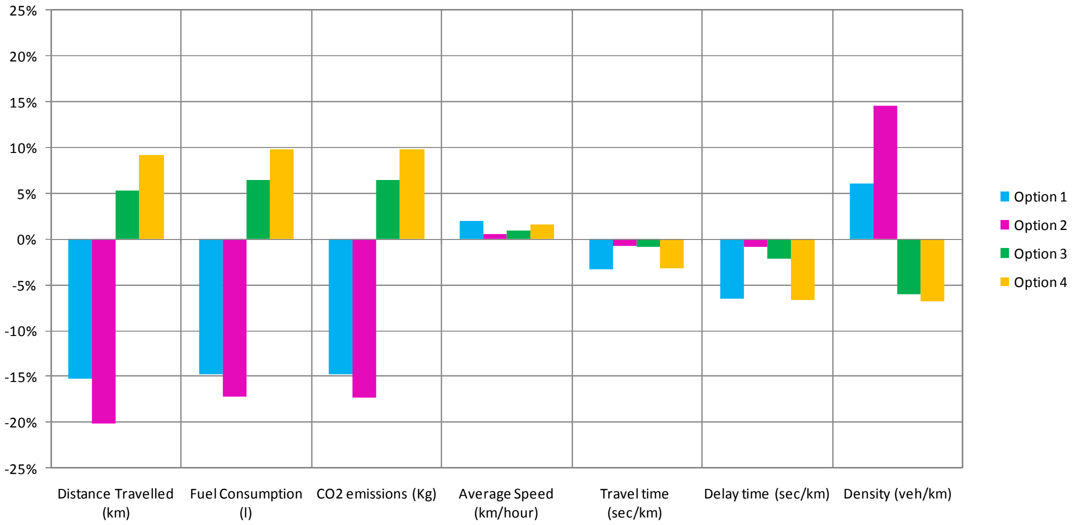

Figure 6.50. Shared usage effects in Unit 2

The dimension in relative terms at the unit level varies between [-20; 15] % and is not consistent enough to suggest any option as a 'best practice' towards mobility and sustainability.

However, it is possible to identify at this level, Option1 and 2 as the best ones to improve mobility and sustainability in the Unit. The decrease on travel time and delays and a higher average speed are the visible signs of a better mobility. Together with a lower fuel consumption and CO2 emitted, both options result also in a more sustainable environment at the Unit.

The simulation of the 4 options, allowing the use of the bus lane by freight vehicles meeting specific delivery time criteria, would not have a significant and conclusive impact in the overall system.

Figure 6.51 illustrates the effects of the four options in the overall system to all the set of indicators.

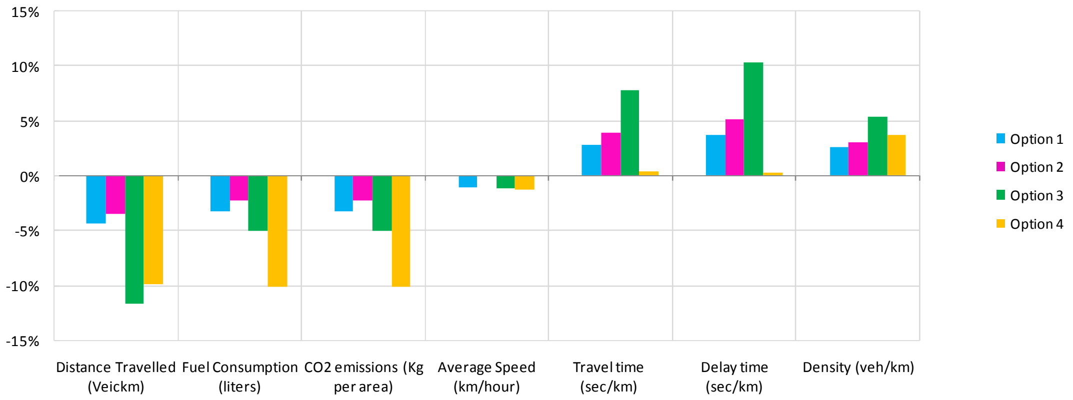

Figure 6.51. Shared usage effects in the overall system

The four options would lead to a very slight decrease of mobility and sustainability, with a range of effects varying approximately between [-10; 10]%.

Option 1 (correspondent to delivery parking time on the bus lane not superior to 1 min) would lead to an increase of congestion in the overall system. Increasing travel times, delays and densities would be followed by a decreasing distance travelled (due to congestion) and consequent reduction of fuel consumption and air pollutants emitted. The travelled distance would also be lower due to congestion. Option 2 and option 3 would follow the same tendency although with even increasing worse results in terms of mobility.

The four options would be negative to the main stakeholders involved. An exception of these effects with a very slight positive impact would be suppliers on LGV's to Option1 and for public transport in Option4.

Such effects on the overall system can be explained by factors like changes on traffic behavior and paths choices, which are difficult to identify and relate in an exclusive and direct way with the allowance of the use of a bus lane by freight vehicles in a particular commercial street of the city. Moreover, the absolute variance of these effects is rather low, making it difficult to support any further explanation.

Table 6.12 summarizes the effects of the shared usage of a bus lane.

Table 6.12. Summary of effects of the shared usage of a bus lane towards increasing mobility and sustainability

Street	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society
Option1	🟥	🟩	🟩	🟩	🟩
Option2	🟩	🟩	🟥	🟩	🟩
Option3	🟩	🟩	🟩	🟩	🟩
Option4	🟩	🟩	🟩	🟩	🟩

Unit	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society
Option1	🟥	🟩	🟩	🟩	🟩
Option2	🟩	🟩	🟩	🟩	🟩
Option3	🟥	🟩	🟩	⬜	🟩
Option4	🟥	🟩	🟩	🟩	🟩

System	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society
Option1	🟥	🟥	🟥	🟥	🟥
Option2	🟩	🟥	🟥	🟥	🟥
Option3	🟥	🟥	🟥	🟥	🟥
Option4	🟩	🟥	🟥	🟥	⬜

🟥 Unfavorable
⬜ Not conclusive
🟩 Favorable

The effects of the **shared usage of a bus lane by freight vehicles** are not significant enough at the micro or meso level within the city, neither in terms of geographical coverage neither in terms of consistent effects to stakeholders, to justify the implementation of any of the 4 options. All of them are negative to the overall system, with very low absolute variations comparing with the current situation. To the street level, most of them are positive, but with considerable discrepancies between the benefits from one direction and the other. With such effects, it raises the question of which stakeholders and priorities should be considered. Would it make sense to benefit stakeholders and street level affecting in a slight negative way the remaining actors of the system? The quantified impacts in terms of mobility and sustainability (at street level) do not seem to be significant enough to justify its acceptance by the groups negatively affected at local level, in particular by STCP and suppliers.

It is also expectable that private interests might be different from the public ones and that they do not speak with only one voice. The private ones, represented by suppliers and bus operators, mainly aim to achieve a better efficiency on their operations. Suppliers who are not allowed to use the bus lane might create some opposition to this initiative. Despite they will benefit indirectly with this initiative, through the decrease of congestion and operational costs (fuel consumption), they might feel excluded or negatively affected and consequently, contest this initiative. Suppliers allowed to use the bus lane are expected to easily accept the initiative, although some will prefer not to use it due to the differences on routes that it might imply the access to the bus lane (direction Southwest-Northeast). Bus operators (who currently use the exclusive lane) also might fear it as an obstacle to their operations, if the boundaries of the initiative are not clearly defined in advance. Bus operators who have buses on that area, but do not use the exclusive lane are expected to easily accept the initiative, once they feel directly its benefits.

Moreover, this first selective analysis does not quantify yet the costs of its implementation (technology) and the operational costs for suppliers. With such non convincing results, the analysis of these options will not be further explored along this study.

6.7.8 Enforcement

The (ineffective) predicted effects of the previous scenarios to the public objectives leads to the consideration of a strict enforcement (although this practice is not described in chapter 3). Parking enforcement significantly improves traffic flows, reduces congestion and contributes to the quality of life in the community. In London, for instance, the implementation of this measure reduced the number of illegally parking by 35% from 2638 vehicles in February 2006 to 1708 in February 2007 (TfL, 2007).

6.7.8.1 Scenario 13: Enforcement on Unit 1

Scenario 13 establishes that freight vehicles are not allowed to park illegally to deliver on the area. All vehicles would be forced to park legally in the closest available and legal parking place in relation to the store to be supplied. According with the delivery pattern of the unit, such scenario would affect **100%** of the freight vehicles supplying the area.

The simulation exercise assumed that the initiative is in force 7 hours per day, 5 days per week, covering the morning peak period of the bus lane and the daily peak of deliveries in the area (7:00 – 14:00). Suppliers park legally and have a civic behavior, which implies not to park in a place creating an obstacle to the normal road circulation. The enforcement is put into practice only with human resources, without the use of additional automated technology. Outputs of the simulation exercise refer to the morning average hour.

Quantitative effects of scenario 13 are presented on Annex A13.

At the street level, the range of effects in Cedofeita street is high. Delay times on the total decrease 71%, correspondent to minus 242 seconds along the street and travel times by -94%. Such impressive results, together with an increase of the average speed of 9 km/h to 52 km/h, confirm a higher mobility along the street[36]. Also in terms of sustainability, results are quite positive with average reductions on fuel consumption levels by 54% and on CO2 emissions by 21%. Only the indicator ‘distance travelled’ does not follow this remarkable positive tendency. The indicator shows an increase of 24%, mainly due to the need to search for an available legal place to park.

Such positive effects are felt by all the analyzed stakeholders as shown in Figure 6.52.

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[36] *This speed value is slightly higher than the maximum value allowed by law.*

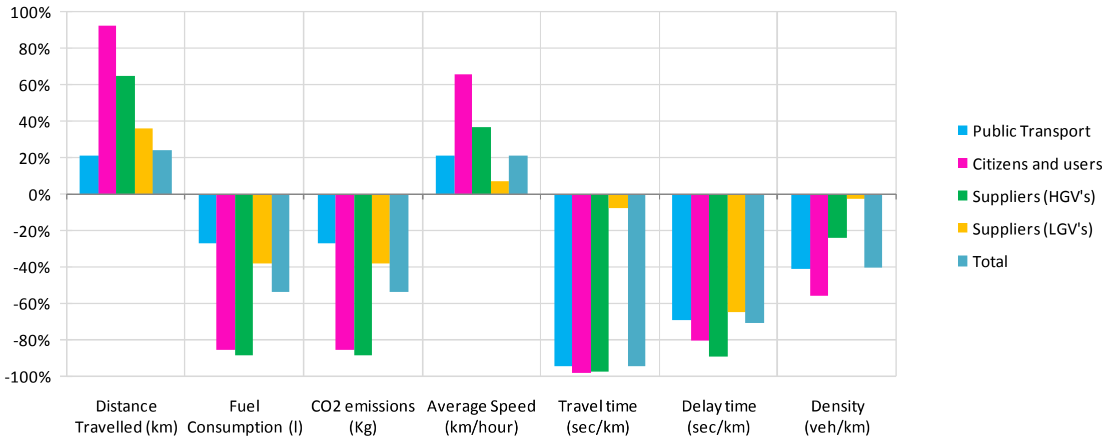

Figure 6.52. Enforcement in Cedofeita street

The implementation of this scenario in Passos Manuel street would lead to a similar effect to each of the analyzed stakeholders.

At the unit level, in Downtown, the results are less positive towards an improvement of mobility and environmental sustainability (output A). The range of effects are lower than at street level, varying between [-37; 9]% (not considering the CO and NOx variation). The decrease of the delays (-29%) and travel times (-37%) indicate a lower congestion in the unit. The lower congestion added to a higher average speed (4%) reveal an easiness of movement, a measure of increasing mobility. Fuel consumption and the CO2 emissions decrease -15%, suggesting an improvement of the environmental sustainability of the unit. CO levels are also reduced to all groups of stakeholders as a consequence of the decrease of congestion levels.

At the overall system, results confirm what was already observed at the other levels of analysis. The effects of enforcement are positive to all group of stakeholders (output A), although with a very low range of effects [-1; 1]%.

6.7.8.2 Scenario 14: Enforcement on Unit 2

Scenario 14 establishes that freight vehicles are not allowed to park illegally to deliver on the area. All vehicles would be forced to park legally in the closest available and legal parking place in relation to the store to be supplied. According with the delivery pattern of the unit, such scenario would affect **100%** of the freight vehicles supplying the area.

The simulation exercise assumed that the initiative is in force 7 hours per day, 5 days per week, covering the morning peak period of the bus lane and the daily peak of deliveries in the area (7:00 – 14:00). Suppliers park legally and have a civic behavior, which implies not to park in a place creating an obstacle to the normal road circulation. The enforcement is put into practice only with human resources, without the use of additional automated technology. Outputs of the simulation exercise refer to the morning average hour.

Quantitative effects of scenario 14 are presented on Annex A14.

At the street level, the range of effects is clearly high [-44; 19]%. Delay times on the total decrease 44%, correspondent to 29 seconds along the street and travel times by 28%, correspondent to 31 seconds. Such impressive results, together with an increase of the average speed of 5 km/h to 36 km/h, confirm a higher mobility along the street. Also in terms of sustainability, results are quite positive with average reductions on fuel consumption levels by 24% and on CO2 emissions by 19%. Only the indicator 'distance travelled' does not follow this remarkable positive tendency. The indicator shows a slight increase of 5%, mainly due to the need to search for an available legal place to park.

Such positive effects are felts by all the analyzed stakeholders (Figure 6.53). Public transport is the one with lower effects, which is explained by the fact that in one of the directions there is an exclusive bus lane, where the effects are negligible. Intercity buses circulating on the other direction feel a low effect. Citizens and users experience the effects of the enforcement in a significant way, because incidents occur on the road direction in which they circulate. Suppliers are the ones that have more benefits in terms of mobility but also the ones which have to make a higher travel (distance travelled) due to enforcement.

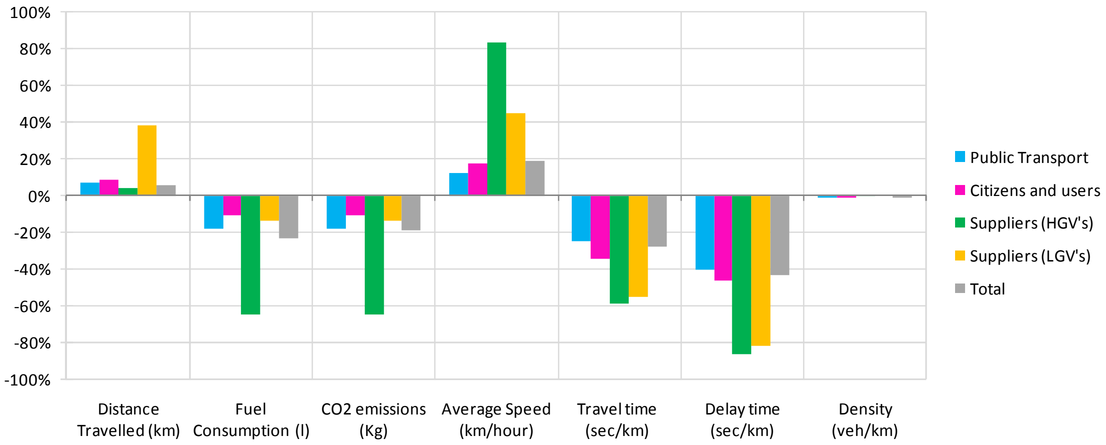

Figure 6.53. Enforcement at street level in Unit 2

In terms of mobility, the positive results observed along the street come mainly from the opposite direction to the bus lane, where the incidents occurred before the implementation of the measure.

The reduction on delays on the opposite direction to the bus lane of about 80% corresponds to 30 seconds along the street, which is considerably high. Also the increase of the speed on 11km/h to 43km/h and the decrease on travel times by 30 seconds confirm the impressive results on this direction.

Along the bus lane, the effects are more legible in terms of sustainability with a reduction of the distance travelled, the energy consumed and the CO2 emitted. The effects along this direction are clearly minor due to the fact the bus lane is not so significantly affected by the disappearance of illegal parking as the other direction.

At the unit level, in Marquês area, results are less positive towards an improvement of mobility. The range of effects is lower than at street level, varying between [-2; 8]% (not considering the CO and NOx variation). The decrease of the delays (-2%) and travel times (-1%) seem to indicate a lower congestion in the unit. The lower congestion added to a higher average speed (1%) reveal an easiness of movement, a measure of mobility. The distance travelled in the area increases 2% (due to the search for legal parking places). Fuel consumption and the CO2 emissions decrease -3%, suggesting an improvement of the sustainability of the unit.

The analysis of results by area of impacts reveals that strict enforcement would not have a significant impact in the overall system. The range of effects at the overall system would be low [-11; 3] % as it was also observed with the previous scenarios. The effects of the enforcement in the overall system would be negative, leading to a decrease in mobility and sustainability (output B). The general effects in terms of density, travel times, delay times and average speed would be lower than 3%. The remaining indicators would be slightly higher in absolute terms, but still not significant. An analysis of results by stakeholders group reveals that at city level, enforcement would be slightly negative for public stakeholders (public transport, citizens and users) but positive for private stakeholders, which is quite a surprising result. Such fact can be explained by the beneficial effects that suppliers of the all system feel from a system with less congestion, although the variation is too low to be easily explained by a direct cause-effect clarification.

6.7.8.3 Scenario 15: Enforcement on Unit 3

Scenario 15 establishes that freight vehicles are not allowed to park illegally to deliver on the area. All vehicles would be forced to park legally in the closest available and legal parking place in relation to the store to be supplied. According with the delivery pattern of the unit, such scenario would affect **100%** of the freight vehicles supplying the area.

The simulation exercise assumed that the initiative is in force 7 hours per day, 5 days per week, covering the morning peak period of the bus lane and the daily peak of deliveries in the area (7:00 – 14:00). Suppliers park legally and have a civic behavior, which implies not to park in a place creating an obstacle to the normal road circulation. The enforcement is put into practice only with human resources, without the use of additional automated technology. Outputs of the simulation exercise refer to the morning average hour.

Quantitative effects of scenario 15 are presented on Annex A15.

At the street level, the effects of enforcement in Unit 3 would be very similar to the ones observed on Unit 2. The range of effects is lower [-2; 0]%, which can be explained with the fact suppliers park on a deactivated tram lane, that other road users avoid to use. Due to the lack of comfort (and safety) that drivers feel when circulate over the metallic tracks, added to the large width of the street, drivers prefer to use the other lanes. Thus, if enforcement is implemented, not allowing suppliers to park on the deactivated tram lane, the traffic effects on the total are irrelevant. On the total traffic, only CO2 emissions show a variance (-2%), mainly due to reductions on public transport and suppliers' emissions. These low effects are felt in a similar and positive way by all groups of stakeholders (Figure 6.54).

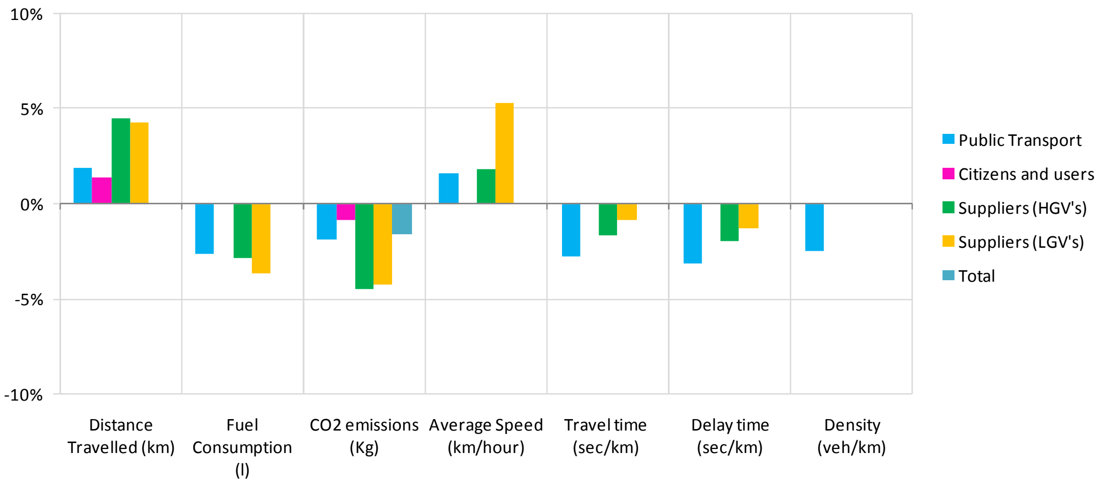

Figure 6.54. Enforcement at street level in Unit 3

Lower delays and travel times, together with higher average speed seem to indicate a higher mobility along the street. The increase on distance travelled, due to the search for legal parking places, is followed by a decrease on the fuel consumption levels as well as on the emitted emissions. This tendency indicates 'enforcement' as a 'good practice' towards increasing mobility and sustainability on Boavista Avenue.

Such positive results at the street-level are also reflected at the respective unit, with a similar range of total effects [-2;2]%. Despite the low range of values, all the stakeholders at the unit level would expectable have positive benefits with enforcement (output D). At this level, citizens and users (passenger traffic) are affected in an irrelevant way. Suppliers are the ones who benefit more from the implementation of enforcement, immediately followed by public transport. Enforcement is also a positive scenario towards mobility and environmental sustainability at the unit level.

When analyzing the effects of a strict enforcement applied in Boavista Avenue, on the city level, effects are still positive on the total. The total effects vary between [-1; 1]%, although the impacts on the different groups of stakeholders is not homogeneous. Despite all of them experience decreasing delays and travel times, followed by a slight increase on speed, 'citizens and users' have an irrelevant increase on the distance travelled reflected on higher levels of fuel consumption while all the other stakeholders travel a lower distance and consume less fuel. Considering the variation of these indicators felt by 'citizens and users' is lower than 1%, such heterogeneity is considered irrelevant for the overall evaluation. Furthermore, the absolute and relative variation at the city coverage is irrelevant to be easily supported by a direct and unequivocal explanation. Thus, the only conclusion possible to extract from it, is that enforcement applied at Boavista Avenue also constitutes a positive tool towards an increasing sustainability and mobility at the city level.

6.7.8.4 Scenario 16: Enforcement on Camoes axle

Scenario 16 establishes that freight vehicles are not allowed to park illegally to deliver on the area. All vehicles would be forced to park legally in the closest available and legal parking place in relation to the store to be supplied. According with the delivery pattern of the unit, such scenario would affect **100%** of the freight vehicles supplying the area.

The simulation exercise assumed that the initiative is in force 7 hours per day, 5 days per week, covering the morning peak period of the bus lane and the daily peak of deliveries in the area (7:00 – 14:00). Suppliers park legally and have a civic behavior, which implies not to park in a place creating an obstacle to the normal road circulation. The enforcement is put into practice only with human resources, without the use of additional automated technology. Outputs of the simulation exercise refer to the morning average hour.

Quantitative effects of scenario 16 are presented on Annex A16.

At the street level, the effects of enforcement in Camões axle would be much more significant than the ones observed on the previous scenarios. The range of effects is higher [-96; 7]%, which can be explained with the short length of the axle and with the fact currently suppliers park on double lane, forcing other road users to use only one lane of circulation. These low effects are felt in a similar and positive way by all groups of stakeholders (Figure 6.55).

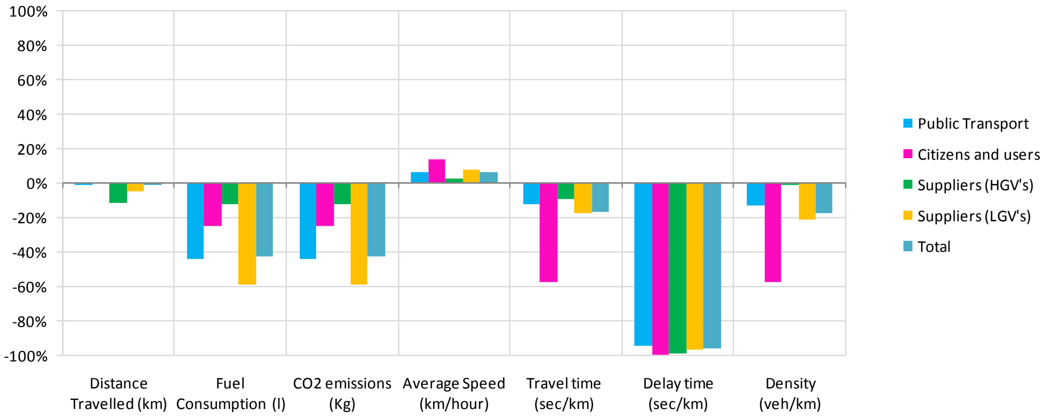

Figure 6.55. Enforcement at Camões street

Lower delays and travel times, together with higher average speed seem to indicate a higher mobility along the street. This tendency indicates 'enforcement' as a 'good practice' towards increasing mobility and sustainability in Camões axle.

Table 6.13 summarizes the effects of the enforcement.

Table 6.13. Summary of effects of enforcement towards increasing mobility and sustainability

	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society (Total)
Unit 1					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Unit 2					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	⬜	⬜	🟩	🟩	⬜
Unit 3					
Street	🟩	⬜	🟩	🟩	⬜
Unit	🟩	⬜	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Camoes axle					
Street	🟩	🟩	🟩	🟩	🟩

🟥 Unfavorable
⬜ Not conclusive
🟩 Favorable

The effects of the enforcement are significant at micro and meso level within the city, both in geographical coverage and in terms of consistent effects to stakeholders. To the unit and street levels, it is positive and clearly more easy and cheap to implement than most of the other measures simulated along this chapter. It is important as well to take into account that a strict enforcement applied in a specific area also can lead to a marginal effect on the surrounding areas, namely larger flows of traffic due to the search for an available parking place. This effect can (in some cases) have worst effects than a do-nothing situation. In the areas analyzed on this case study, enforcement does not create such secondary effects.

These simulated effects of scenarios 13, 14, 15 and 16 confirm enforcement as a 'best practice' to supply goods distribution in Porto towards mobility and sustainability. Considering the positive effects obtained in a first analysis, enforcement will be evaluated under a perspective focused on private objectives and public interests compatibility.

6.7.9 Private Objectives and public interests compatibility

The simulation of effects towards mobility and (environmental) sustainability under public interests perspective revealed that two initiatives can be considered 'best practices' to supply the area: regulation of access based on time and enforcement. Along this section it is presented a quantification of the costs associated with the operational effects and the environmental externalities of each initiative. Such quantification will allow to confirm whether those initiatives are 'best practices' also towards social and economic sustainability under private objective criteria.

6.7.9.1 Scenario 8*: Regulation of access based on time on Unit 2

At the street level the implementation of regulation of access based on time would lead to a benefit on the total operational costs along Costa Cabral Street by 25% (Table 6.14).

Along Costa Cabral Street, this relative variation corresponds to a decrease on total costs by 69 Euros/day for the total road users. Citizens and users would be the ones who would benefit more from it. Suppliers on HGV's and suppliers on LGV's would have relative variations on the operational costs along the street of 12% and 2%, respectively. Such variation in absolute terms is not significant.

The environmental externalities costs would also decrease with the regulation of access based on time (-7%), which can be associated with the eradication of transgressions on the street and respective consequences in terms of congestion, delays, etc.

Table 6.14. Cost effects of regulation of access at street level in Unit 2

	Costa Cabral Street	
	Operational costs/day	Environmental Externalities/day
Total	-25%	-7%
Bus	-11%	0%
Car	-43%	-32%
Taxi	-29%	-14%
Truck	-12%	0%
Van	-2%	0%

A similar analysis to the unit level, would lead to an increase of operational costs by 1% and a reduction of environmental externalities by 3%. At the system level the total effects are not relevant in terms of operational costs (-1%) and in terms of environmental externalities the predicted change is of less than -1%.

Regulation of access based on time has a micro level effect, which is diminished when decreasing the geographical level of analysis.

Regulation of access based on time is a 'best practice' at Unit 2.

6.7.9.2 Scenario 9*: Regulation of access based on time on Camões axle

The implementation of regulation of access based on time would lead to a benefit on operational costs along Camões axle by 2% (Table 6.15). The environmental externalities associated with the implementation of enforcement would have a slight decrease (-1%), which can be associated with the eradication of transgressions and respective consequences in terms of congestion and delays.

Table 6.15. Costs effects of regulation of access at street level Camões axle

	Camões axle	
	Operational costs/day	Environmental Externalities/day
Total	-2%	0%
Bus	-4%	0%
Car	-2%	-1%
Taxi	-5%	-5%
Truck	-10%	-7%
Van	-5%	0%

Although results obtained to this area are lower than the ones observed on the scenario 8*, they confirm the same effect: regulation of access based on time is a 'best practice' also for private objectives criteria and public interests compatibility.

6.7.9.3 Scenario 13*: Enforcement on Unit 1

Towards the positive results of enforcement at a first analysis (stakeholders and geographical coverage), on the criteria of mobility and sustainability – public objectives - a more detailed analysis is followed to confirm it also fulfills one of the most relevant private objective criteria: costs levels.

At the street level the sum of the total operational costs with the implementation of enforcement would lead to a benefit along Passos Manuel street by 26% and along Cedofeita Street by 50% (Table 6.16).

Along Passos Manuel Street, these relative variations correspond to a decrease on total costs by 191 Euros/day for the total road users. This benefit comes from the reduction of travel times, delays and congestion and respective effects on driving and vehicle costs. Suppliers on HGV's and suppliers on LGV's would have an increase on operational costs by 4,3 and 2,1 Euros/day along the street, respectively.

The environmental externalities of enforcement at Passos Manuel Street would increase, which can be associated with the increase of the distance travelled due to the search for legal parking. The higher distance travelled by some stakeholders leads to higher environmental externalities. The sum of operational costs with the external costs shows an average total benefit of 183 Euros/day along the street.

Along Cedofeita Street, the effects are far more positive. Public transport would have a reduction on operational costs of 303 Euros/day, equivalent to a reduction of 42%. The difference in absolute values between both streets is explained by the difference of length and traffic volume and the effects the transgressions have in the normal road circulation in each of them. All stakeholders would experience a reduction in operational costs, which mainly comes from the reduction of delays, travel times and congestion.

These operational benefits would be slight lower if environmental externalities would be added to the calculation. In relative terms, the variations are very high which does not correspond to a considerable absolute variation. On the total for all groups of stakeholders, environmental externalities reduction would correspond to an average of 10 Euros/day, which mainly comes from s higher distance travelled.

Table 6.16. Cost effects of enforcement at street level in Unit 1

	Passos Manuel Street		Cedofeita Street	
	Operational costs/day	Environmental Externalities/day	Operational costs/day	Environmental Externalities/day
Total	-26%	18%	-50%	24%
Bus	0%	20%	-42%	21%
Car	-40%	27%	-83%	92%
Taxi	-29%	20%	-44%	13%
Truck	-42%	4%	-78%	65%
Van	-14%	20%	-40%	36%

A similar analysis to the unit level, enforcement would lead to a reduction of operational costs by 17% and of environmental externalities by 7%, which results both from a slight reduction on the distance travelled and from the reduction of congestion and travel times per vehicle. At the system level the total effects are irrelevant in terms of operational costs (less than 1%) and in terms of environmental externalities the predicted reduction is of -1%.

These values constitutes a first step to seriously consider the implementation of enforcement in the area, once the costs of implementation (human resources costs) can be covered at the street and unit levels by the benefits obtained both to society and industry.

Enforcement is a ‘best practice’ in Unit 1 (downtown).

6.7.9.4 Scenario 14*: Enforcement on Unit 2

At the street level the sum of the total operational costs with the implementation of enforcement would lead to a benefit along Costa Cabral Street by 21% (Table 6.17).

Along Costa Cabral Street, these relative variations correspond to an average decrease on total costs by 58 Euros/day for all road users. Suppliers on LGV’s are the only group with higher operational costs due to enforcement, mostly due to the higher distance travelled (+38%) on the search for legal parking as it can also be confirmed by the much higher variation of environmental externalities to this group (38%).

The general estimated costs would be slight lower if environmental externalities would be added to the calculation, as it was also observed on the previous scenario for Unit 1.

Table 6.17. Cost effects of enforcement at street level in Unit 2

	Costa Cabral Street	
	Operational costs/day	Environmental Externalities/day
Total	-21%	5%
Bus	-19%	7%
Car	-17%	8%
Taxi	-12%	4%
Truck	-37%	4%
Van	23%	38%

At the unit level, enforcement would lead to a general reduction of the distance travelled as well as on travel times and congestion. Therefore, at this level of analysis, enforcement would lead to a reduction of operational costs by 10% and of environmental externalities by 2%. At the system level the total effects are irrelevant in terms of operational costs (less than 1%) and in terms of environmental externalities the predicted reduction is of -2%.

Enforcement is a ‘best practice’ to supply Unit 2.

6.7.9.5 Scenario 15*: Enforcement on Unit 3

At the street level the sum of the total operational costs with the implementation of enforcement would lead to a benefit along the stretch of Avenida da Boavista by 1% (Table 6.18). The same low effect has already been observed on the quantification of the effects on annex A15.

Along Avenida da Boavista, these relative variations correspond to a decrease on total costs by 145 Euros/day for the total road users. The sum of all suppliers on HGV’s and suppliers on LGV’s would have a decrease on operational costs by 2 and 5 Euros/day along the street, respectively. The environmental externalities of enforcement at Avenida da Boavista would have an irrelevant variation, which can be associated with the fact that currently suppliers park illegally but in a deactivated tram lane, not causing a significant disturbance on other road users. Therefore, the implementation of enforcement at the avenue does not have a significant impact on the reduction of operational costs and environmental externalities.

Table 6.18. Cost effects of enforcement at street level in Unit 3

	Avenida da Boavista	
	Operational costs/day	Environmental Externalities/day
Total	-1%	0,0%
Bus	-4%	0,0%
Car	-1%	0,0%
Taxi	-5%	0,3%
Truck	-1%	0,7%
Van	-5%	0,7%

A similar analysis to the unit level, would lead to a reduction of operational costs by 5% and of environmental externalities by 2%. At the system level the total effects are irrelevant in terms of operational costs and in terms of environmental externalities (less than 1%).

Enforcement is also a ‘best practice’ in Unit 3 (Boavista).

6.7.9.6 Scenario 16*: Enforcement on Camões axle

The implementation of enforcement would lead to a benefit on operational costs along Camões axle by 41% (Table 6.19). Considering results previously shown in Annex A16, such reduction on operational costs is mainly due to the considerable reduction of delays and travel times.

The environmental externalities associated with the implementation of enforcement would have a slight decrease (-1%), which can be associated with the eradication of transgressions and respective consequences and with a minor decrease on distance travelled.

Table 6.19. Cost effects of enforcement at street level in Camões axle

	Camões axle	
	Operational costs/day	Environmental Externalities/day
Total	-41%	-1%
Bus	-26%	-1%
Car	-41%	-1%
Taxi	-1%	-9%
Truck	0%	-5%
Van	-39%	-5%

Enforcement is a 'best practice' to supply Camões axle.

6.8 Findings from the case study

Section 6.8 presents findings from the case study and is constituted by two main sub-sections. Sub-section 6.8.1 presents the specific remarks of analysis for each initiative and an overall comparison of all scenarios. Some of those specific remarks were already revealed on the analysis of results towards mobility and sustainability under a public objective perspective. Section 6.8.2 presents the general remarks and raises some questions originated by findings from the case study.

6.8.1 Specific Remarks of Analysis

The estimation of effects carried out along section 6.7 allowed to quantify and predict the impacts of each of the initiatives on the mobility and sustainability of the area, under a perspective based on public good.

Table 6.20 summarizes those results and identifies the favorable and unfavorable effects of each initiative. It also explicitly reveals its estimated impacts both at geographical level and stakeholders effects.

Table 6.20. Comparison of the initiatives towards mobility and sustainability

	Public Transport	Citizens and city users	Suppliers HGV's	Suppliers LGV's	Society (Total)
Coop Sys: Unit 1					
Cedofeita Street	🟥	🟥	🟥	🟥	🟥
Passos Manuel Street	🟥	🟥	🟥	🟥	🟥
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Coop Sys : Unit 2					
Street	🟥	🟥	🟥	🟩	🟥
Unit	🟥	🟥	🟥	🟩	🟥
System	🟥	🟥	🟥	🟥	🟥
Coop Sys : Unit 3					
Street	🟥	🟥	🟩	🟩	⬜
Unit	🟥	🟥	🟥	🟥	🟥
System	🟥	🟥	🟥	🟥	🟥
Coll Sys : Unit 1					
Cedofeita Street	🟩	🟩	🟩	🟩	🟩
Passos Manuel Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Coll Sys : Unit 2					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟥	🟩	🟩	🟥	🟥
Coll Sys : Unit 3					
Street	🟥	🟥	🟩	🟩	⬜
Unit	🟥	🟥	🟩	🟩	🟥
System	🟥	🟥	🟥	🟥	🟥
Coll Sys :: Camoes					
Street	🟩	🟩	⬜	🟩	⬜
Regulation : Unit 2					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	⬜	🟩	🟩	⬜
Regulation : Camões axle					
Street	🟩	🟩	🟩	🟩	🟩
Unit 1 – 10% PR					
System	🟩	🟩	🟩	🟩	🟩
Unit 1 – 20% PR					
System	🟩	🟩	🟩	🟩	🟩
Road Pricing					

System	🟩	🟩	🟩	🟩	🟩
Enforcement: Unit 1					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟩	🟩	🟩	🟩	🟩
Enforcement: Unit 2					
Street	🟩	🟩	🟩	🟩	🟩
Unit	🟩	🟩	🟩	🟩	🟩
System	🟥	🟥	🟩	🟩	⬜
Enforcement: Unit 3					
Street	🟩	⬜	🟩	🟩	⬜
Unit	🟩	⬜	🟩	🟩	⬜
System	🟩	⬜	🟩	🟩	⬜
Enforcement: Camoes axle					
Street	🟩	🟩	🟩	🟩	🟩

🟥 Unfavorable
⬜ Not conclusive
🟩 Favorable

Results illustrated on table 6.20 are complemented by the numerical quantification presented on annexes A1 to A16 and by other practical considerations. The following remarks explicitly refer those considerations in order to justify the thinking behind the final selection of two initiatives to be evaluated also under a perspective based on private interests.

The estimated impacts of **cooperative distribution systems** revealed the initiative could not be considered a 'best practice' at none of the spatial levels considered on the study, neither to any particular group of stakeholders. Moreover, the implementation of this initiative would not minimize the problems of circulation on any of the areas, despite the significant reduction on the number of delivery trips. On the contrary, it would aggravate the existing problems due to longer illegal parking times and to a consolidation infrastructure which would generate new local traffic problems.

The previous facts resultant from the simulation exercise, together with the small number of carriers that are (expectably) willing to join such system, leads to low benefits on the overall system. Furthermore, it was assumed that once the platform already existed, no additional operational costs would occur, which is an optimistic assumption. Moreover, considering the reduction of supply trips achieved with the three scenarios (by 65%, 30% and 60%) and the respective impacts, it is raised the question *whether decision-makers should be worried with the reduction of the supply trips or with the reduction of the illegal parking*.

With such effects, scenarios 1, 2 and 3 could not be considered a best practice, under mobility and sustainability criteria.

The analysis of **collaborative delivery systems** revealed the initiative would expectably benefit more private stakeholders, although its implementation would also require more from them than from the other actors. Determinant requirements like the existence of a specific commercial software program to make the deliveries, a particular depot to consolidate or the acceptance of shopkeepers to be included on such scheme make the estimated positive effects to be insignificant to convince public and private stakeholders to implement collaborative systems. In what concerns to costs, a particular focus on the platform feasibility is required. In the present study it was assumed that once the platform already existed, no additional operational costs would occur, which is not true in most of the cases.

The previous facts, together with the small number of carriers that are (expectably) willing to join such system, leads to low benefits on the overall system. Moreover, the simulation of the four scenarios showed theoretical reductions of supply trips by 30%, 40%, 20% and 8% corresponding to modest impacts due to illegal parking. With such numbers, it is raised the same question mentioned for the cooperative delivery systems.

With such effects, collaborative systems simulated on scenarios 4, 5, 6 and 7, could not be considered a 'best practice' to supply the area, under mobility and sustainability criteria.

The analysis of the effects of the **regulation of access based on time** only considered the impacts at the final destination. To accomplish the requirements imposed by the city (regulation of access) and by receivers (reliability), suppliers have to re-organize their supply trips (load factor, routing, scheduling, etc). Such re-organization impacts and costs are not quantified on this analysis and can predictably affect in a negative way the acceptance of this measure, rather than it seems from the results illustrated above. This initiative is usually imposed by local administrators, who aim to achieve a better quality of urban environment and might affect private stakeholders interests (namely suppliers), who aim a better efficiency on their operations with lower operational costs. Despite it seem reasonable that local administrators should bring to discussion the industry stakeholders to help on the definition of the time windows that would lead to more common benefits, most of the times private interests are overlooked. Local administrators are aware of its power to impose a specific time window and suppliers are not evolved in decisions in a determinant and direct way. In Porto (Portugal) as in most of the Portuguese cities, the time window is defined by local administrators, mainly taking in consideration shopkeepers and residents interests. It is still assumed that suppliers will always adapt their operations to the new regulations and conditions imposed by the city. On this context, the simulation can be a useful tool to evaluate possible scenarios and choose the ones that will lead to better overall benefits.

Under a perspective focused on mobility and environmental sustainability, the regulation of access based on time is a 'best practice'. Considering the positive effects obtained in a first analysis, regulation of access based on time was also evaluated under a perspective focused on operational costs and the results confirmed it as a 'best practice'.

The estimation of the effects of **electric vehicles** with a demand penetration rate of 10% and 20% only considered impacts at the final destination. If the impacts and costs of generating electricity and producing liquid fuels for vehicles would have been considered, the evaluation would have lead to less positive effects to society in general and its goal to attain a more sustainable development.

Moreover, despite the general estimated benefits of electric vehicles under an environmental perspective, its use on urban goods distribution still presents some important obstacles to be overcome. The limited autonomy in terms of distance travelled and the costs of such vehicle and possible changes on suppliers' fleet makes this solution for now a 'best *theoretical* practice'. It has potential to become a 'best practice' but only the market will determine its evolution in the medium-long term.

Despite an increasing acceptance of **road pricing** by society, there are still some problematic issues to the approval of this pricing strategy. The methods used to quantify the costs, the costs measured, the followed approach, the use of the fees charged, and the choice of strategies to be financed are some examples of problematic points. These problems can, however, be minimized through the quantification in advance of the overall results that are expected to be achieved with the initiative. In some cases (as the one described here) this quantification can reveal that the expected results are not significant enough to justify the implementation of the initiative. Moreover, Porto currently faces problems of decline in its inner centre. Implementing road pricing would predictably being more harm than good to the city and its users. Small retailers in the inner centre could become even less competitive compared to large retail outlets in the vicinity of Porto; the ongoing tendency of citizens to move and to live outside the city centre would be strengthened; the attractiveness for external shopping visitors would decrease and affect the economy of the city.

Thus, although road pricing simulated on scenario 11 presents theoretical benefits towards mobility and sustainability to all group of stakeholders, the inclusion and consideration of other determinant features makes it unfeasible to categorize it as a ‘best practice’, without a more detailed analysis.

The effects of the **shared usage of a bus lane by freight vehicles** are not significant enough at the micro or meso level within the city, neither in terms of geographical coverage neither in terms of consistent effects to stakeholders, to justify the implementation of any of the 4 options. All of them are negative to the overall system, with very low absolute variations comparing with the current situation. To the street level, most of them are positive, but with considerable discrepancies between the benefits from one direction and the other. It is also expectable that private interests might be different from the public ones and that they do not speak with only one voice. The private ones, represented by suppliers and bus operators, mainly aim to achieve a better efficiency on their operations. Suppliers who are not allowed to use the bus lane might create some opposition to this initiative. Despite they will benefit indirectly with this initiative, through the decrease of congestion and operational costs (fuel consumption), they might feel excluded or negatively affected and consequently, contest this initiative. Suppliers allowed to use the bus lane are expected to easily accept the initiative, although some will prefer not to use it due to the differences on routes that it might imply the access to the bus lane. Bus operators (who currently use the exclusive lane) also might fear it as an obstacle to their operations, if the boundaries of the initiative are not clearly defined in advance. Bus operators who have buses on that area, but do not use the exclusive lane are expected to easily accept the initiative, once they feel directly its benefits. The quantified impacts in terms of mobility and sustainability (at street level) do not seem to be significant enough to justify its acceptance by the groups negatively affected at local level. With such heterogeneous

effects, it is raised the question of *which stakeholders and priorities should be considered*. Would it make sense to *benefit stakeholders and street level* affecting in a slight negative way the remaining actors of the system?
Moreover, this first selective analysis did not quantify the costs of its implementation (technology) and the operational costs for suppliers. With such non convincing results, the analysis of these options was not be further explored along this study.

The effects of the **enforcement** are significant at micro and meso level within the city, both in geographical coverage and in terms of compatible effects to stakeholders. To the unit and street levels, it is positive and clearly more easy and cheap to implement than most of the other measures simulated along this chapter.

The significant benefits that are probable to happen with a strict enforcement might be influenced by the fact that currently in all units, one of the lanes of circulation is often occupied by suppliers illegally parked.

The simulated effects of scenarios 13, 14, 15 and 16 confirm enforcement as a 'best practice' to supply goods distribution in Porto towards mobility and sustainability. Considering the positive effects obtained in a first analysis, enforcement was also evaluated under a perspective focused on private objectives and public interests compatibility. The second analysis also confirmed enforcement as a 'best practice'.

Added to the individual analysis of each solution, a comparative evaluation is briefly described. The comparison is summarized in Annex B1, which complement the information from Table 6.20. The annex derives from the Annexes A1 to A16 and should be interpreted following the scheme illustrated in Figure 6.56.

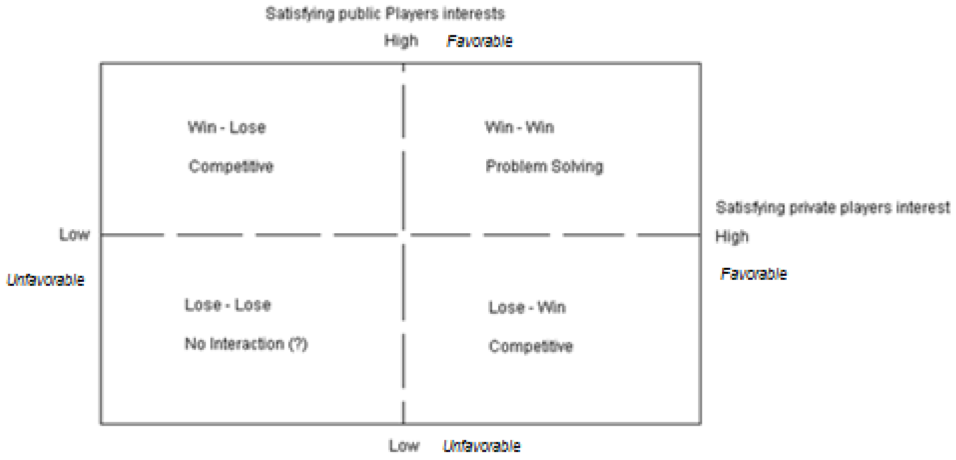

Figure 6.56. Integration of public and private objectives towards a better mobility and sustainability.

Figure 6.56 explicitly shows that in win-win/lose-lose strategies, both public and private players experience better/worst mobility and sustainability levels, respectively. Win-win strategies are then those which solve problems, replying to public and private concerns and interests. In lose-lose strategies there is not a significant interaction between stakeholders and consequently, results can be unsuccessful. Win-lose and lose-win strategies correspond to initiatives in which only one (public or private) group of stakeholders, get benefits with the initiative. On these strategies, labeled here as competitive, each group of players tries to solve its own problem not cooperating with the other.

Following the schematic representation illustrated on Figure 6.56, Annex B1 presents the contribution of each initiative towards mobility and sustainability at different geographical levels, considering public and private stakeholders. The chosen indicator to be illustrated on Annex B1 was ‘delay time’ because it always follows the same direction of mobility and (environmental) sustainability on the simulated scenarios.

On the specific case study carried out along chapter 6 (Annex B1), cooperative delivery systems clearly fall on lose-lose strategies both for public and private stakeholders. The introduction of an added consolidation infrastructure does not improve the efficiency of the distribution system neither decreases its impacts in terms of mobility and sustainability. Collaborative systems correspond to a win strategy for private stakeholders and public stakeholders can either win or lose with it. The implementation of this kind of initiative requires a specific context to assure their success and a strong will and acceptance of some private stakeholders. Public stakeholders indeed are not a key element neither a determinant partner for its success on its promotion and thus, can benefit or lose with it. Shared usage of a bus lane has heterogeneous effects, being difficult to assign it only to one type of solution or strategy. Regulation of access based on time, alternative fuels, road pricing and enforcement are problem solving strategies, in which both public and private players win, under a public good perspective. When comparing enforcement and regulation of access based on time with others which also present positive theoretical effects (electric vehicles and road pricing), the regulation and the enforcement would clearly constitute easier and more consensual solutions to be implemented. Added to these conditions, the benefits that both solutions would predictably achieve on the reduction of operational costs and environmental externalities contribute for a simple consensus both from public and private stakeholders (Figure 6.57).

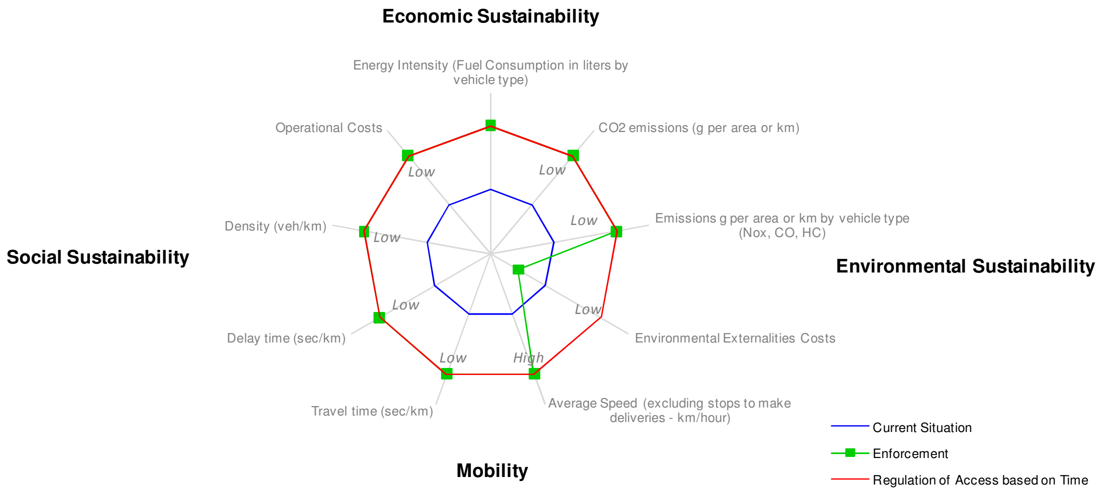

Figure 6.57. Representation of the enforcement and regulation of access based on time (illustrative example). The more towards the outside the values of the individual indicators lie, the higher is the mobility and sustainability of the area

6.8.2. Overall Remarks

The evaluation of 16 scenarios[37] simulated to areas with specific characteristics and commercial patterns correspond to seven initiatives, recently labeled as 'best practices' by the scientific community in diverse geographical, economical and cultural contexts. The areas selected to be studied (4 streets, 3 units, one axle, one system) have similarities and discrepancies between them. The noticeable similarities are the problems all of them have related with urban goods distribution: a) the layout restrictions to change the infrastructure, b) the inexistence of proper unloading facilities to accommodate delivery operations, c) the common cultural context that justifies a flexible attitude from other road users towards suppliers and d) the disturbance suppliers cause on the normal road circulation. The discrepancies are mostly a) the commercial activities pattern of location, b) the supply patterns, directly dependent of the first, c) the land use pattern d) the infrastructure layout and e) the low rotation of parking places on surface promoting illegal parking.

The results demonstrate the types of initiatives, which are likely to give positive results and therefore merit further study. However, theoretical, methodological and data limitations mean that some care is required in their interpretation and dissemination. Despite these reservations, the fact that most of the results point out the same direction to each initiative, not depending of the differences between the 4 areas, are understandable and confirms the **validity of the underlying theoretical considerations**. Also the fact that most of the effects reveal such homogeneity validates the adequacy of those specific initiatives to areas with common problems to the ones observed on the streets, units, axle and system of this case study.

1. One of the common points revealed on the case study is that the benefits of each measure are rather visible at street level and decrease at a meso and macro level (Table 6.20; Annex B1). Results at the street level are quite significant and easily readable and understandable. Results at the overall system are rather low and the relation cause-effect is not obvious to explain. Such fact seems to indicate the scope at which urban goods distribution should be considered: **local level**. The implications of this fact are that local administrators, supported by planners and consulting the mains

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[37] *This selection could be more extent, but that would not necessarily imply a significant added value to the case study.*

stakeholders involved, can significantly contribute for the achievement of good practices on urban goods distribution. Such factor does not imply it should merely become a municipal issue. Urban goods distribution measures taken at city level should be integrated as much as possible with neighbor municipalities. The inter-municipality integration and cooperation can contribute for the creation of the needed economies of scale, determinant for the success of the implementation of some measures. Initiatives requiring the use of adequate logistics infrastructures are good examples of which feasibility can be more easily assured in a context of **inter-municipal cooperation**. Furthermore, collaboration between neighbor municipalities can promote the establishment of integrated strategies, like the regulation of access based on time. This integration, and in some situations, homogeneity can also contribute for a better acceptance by suppliers.

2. The evaluation at a disaggregated level by stakeholder interest group (Table 6.20, Annexes A1 to A16) revealed that **stakeholders** having more benefits towards mobility and sustainability are the suppliers, followed (in general) by citizens and users. Public transport (buses and taxis) are usually affected in a less positive way. Such conclusion can be due to the fact that the 16 scenarios refer to initiatives which were labeled as ‘best practices’. This label comes from the ability to solve a specific problem on urban goods distribution, affecting suppliers or citizens (society in general). Thus, public transport was likely not considered when promoting such reactive policies and thus, it is not positively affected by its implementation.

To get all actors involved, (including public transport) some changes to the approach that has being followed must be done. Suppliers, and other stakeholders, have been given limited opportunity in the past to influence the drafting of mobility and sustainability strategies. To this situation it has contributed the fact that administrators haven’t tried to involve them at these discussions and freight industry and public transport sector do not speak with one voice. However, there are some policy issues on which there is consensus and also some policies that appear to be commonly negatively perceived by certain sectors. The challenge is to find that common level of acceptance by all stakeholders involved in the negotiation. That level will not be the best level each group would individually aspire but it is the one which maximizes the consideration of all the interests involved.

3. Towards some possible contestation that might arise, **microscopic traffic simulation** might be a useful tool to predict the effects of a specific initiative to all the interested parties. If the effects are estimated and the stakeholders are aware of the benefits they can have with a specific measure, the negotiation process is more transparent and can easily lead to an integrate strategy. Therefore, the simulation can be determinant to a better acceptance by the interested stakeholders.

4. Mobility and sustainability were established to be the main targets to be achieved under a public good perspective. Operational costs were established as the main target under private interests' perspective. Towards such different targets, some difficulties might arise in attaining a flexible attitude from such different and almost **conflicting perspectives**.

It is recognized that suppliers will not by themselves be able to achieve adequate systemwide improvements in urban freight efficiency. In some instances possibly there would exist a lack of concern about distribution costs since these costs may be only a small proportion of total service cost. In some cases may be a reluctant acceptance by the suppliers to reduce current levels of congestion, since there is no competitive advantage to any one supplier as a result of a lower congestion level. On this context it might be needed to consider offering some compensation to suppliers who accept to be part of a solution promoting public good.

5. The most surprising facts revealed by the case study, considering mobility and sustainability targets seem to contradict what would appear to be accepted propositions.

First, initiatives that imply significant reductions of supply trips to the city do not have a relevant (or necessarily positive) effect towards mobility and sustainability. Such condition raises the question whether urban planners want to promote the reduction of the number of movements to the city or the regulation of the periods in which those movements could preferably occur. Results of the case study indicate the choice for the second option, with obvious advantages.

Second, recent initiatives labeled as 'best practices' do not necessarily promote both mobility and sustainability and are simultaneously economically feasible. Such condition raises the doubt whether goods distribution in Porto really needs to implement the so called innovative 'best practices' or just to implement common solutions like strict enforcement and regulation. Moreover, these results highlight the power of the context and the fallacy of the concept of ‘best practices’ pointing in a direction of ‘tailor-made’ solutions.

With such effects, it raises the question of which stakeholders and priorities should be considered.

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7 Conclusions

7.1 Introduction

Chapter 7 presents the main contributions to research and the limitations and recommendations for further research.

7.2 Main scientific contributions

Very few comparable studies on urban goods distribution have been conducted and therefore, this study is an attempt to contribute to the research carried out on the topic. Moreover, its singular approach represents an original input to the research, through the fulfillment of some recognized gaps.

The following findings reflect the six main contributions taken out of the study:

1. There are no clear definitions of **mobility and sustainability** applied to urban freight transport and distribution. The thesis presents, based on few existent information on the issue, its own definition and interpretation of both concepts (chapter 2). The definition by itself has a subjective value, because the concepts of mobility and sustainability have the ability to adapt to different contexts and perspectives. However, it becomes particularly significant due to the fact these definitions of mobility and sustainability were established to be the main targets to be achieved under a *public and private perspective* complemented with a specific *set of (quantitative) indicators*. The

value of this first contribution relies on the ability of the adopted definitions and respective indicators to serve as an initial example to support researchers and policy makers to establish their own interpretations adapted to the scope of their perspectives.

2. Second, and following the previous input, there is not an established framework to make an evaluation towards mobility and sustainability on urban goods distribution. Each ‘good practice’ (chapter 3) presents its own methodology of evaluation and respective outputs, making it impossible to take lessons out of it. The thesis fills this gap, developing a **set of indicators** (chapter 4). The set is valuable because it is the first one in the literature established specifically to measure mobility and sustainability (on its 3 dimensions) of *urban goods distribution* and to consider *public and private stakeholders* perspectives. This set of indicators, which was validated through a survey, was one of the scientific contributions of the thesis. The value of this second contribution relies on its ability to constitute a tool to actually operationalize and quantify mobility and sustainability of urban goods distribution and thus, provide an objective tool of evaluation for all stakeholders to be involved.

3. On the analysis of urban goods distribution, results are highly dependent on the framework conditions and thus, selected initiatives identified as the better potential practices are defined looking at a specific transport chain, considering spatial constraints and commercial activities located at the respective area. This disable the transferability of results that is usually associated with the term ‘Best Practices’. Along this work, **‘Best Practices’** was a concept interpreted as “the customers” satisfaction with the lowest loss and the society satisfaction with the highest benefit in terms of mobility and sustainability. On this context, it was possible to conclude there is not one-size-fits-all- solutions for problems related to urban freight (not even within the same city). This does not mean that existing practices, which have been designed to one particular context, cannot serve as sources of inspiration in the design of another local’s response to its own challenges. Nevertheless, depending on the city, not all of the tools may be equally suitable, nor may they be applicable uniformly; moreover, they might be implemented for the whole city, or only to a specific part of it, like an unit or a street where mobility and sustainability problems related to urban goods distribution are especially relevant. On this sense, the literature review made along Chapter 3 and the simulation of scenarios along Chapter 6 is not only a selection of the most successful

initiatives, but also an organized list of initiatives which can be used to design the foundations of a general **good practice project and process approach.** The list can be useful for local administrators to more rapidly and more effectively find the 'best practice' and the 'not so good practice' examples in which to look for ideas in the design of their own solution. In terms of research the value of this third contribution relies a) on the updated literature review (chapter 3) which can be the basis for other studies and b) on the simulated scenarios for a medium size city (chapter 6) which can serve as a comparison (and inspiration) example with other cities.

4. Understanding why a given solution was a success/failure at a certain time, in a certain place is as important as knowing whether or not it was a success/failure. Nevertheless, there are no validated (scientific) contributions about pitfalls and success factors and which stakeholders should be involved to implement an initiative. The thesis also tries to give a contribution to this gap.

Good practices are described in detail in chapter 3 and a strong emphasis is given to the identification of stakeholders involved and indicators adopted or measured. With the development of a specific set of indicators (chapter 4) which takes into consideration the ones identified in chapter 3, the success or failure of initiatives is evaluated towards mobility and sustainability under a stakeholder-based analysis. Stakeholders are analyzed separately in order to add to the analysis of public good, the effects on operational costs and on environmental externalities. This task is carried out with microsimulation tools and enables to understand what the pitfalls and success factors may be and which stakeholders should be involved (chapter 6). The thesis fills in a fourth gap, because it takes both **public and private perspectives** into consideration in an attempt to identify pitfalls and success factors of each initiative.

5. By providing a detailed analysis of 'best practices' in chapter 3 and analysing those initiatives under a perspective focused on the main public stakeholders perspective (public good – mobility and sustainability) and complemented by private stakeholders concerns (operational costs), the thesis seems to have been demonstrated that there is a lack of interaction between both players. Currently there are only some few successful examples of initiatives promoted and implemented (simultaneously) by both private and public stakeholders. The current **lack of cooperation between private and public stakeholders** can be due to the lack of willing from both to make faster developments:

local administrators (public stakeholders) expect industry (private stakeholders) to fit to the rising needs of customers, considering the overall concern with the environment; private stakeholders wait public ones to initiate and subsidize practices which can prove to be poorly profitable and highly risky (Dablanc, 2006). This absence of contact and cooperation can also be the reason why the improvements that are assumed by public stakeholders to occur in operational costs are sometimes not achieved in practice. Therefore, it seems that one potential direction to promote 'best practices' towards mobility and sustainability is to improve the **knowledge within stakeholders** about the other's concerns and perspectives. The more each partner knows about other's expectations, the easier it will be to achieve win-win solutions. The thesis tries to contribute to reduce this lack of interaction, suggesting the use of microsimulation tools to predict stakeholders' effects.

6. The six contribution, closely related with the previous one, is the issue of the lack of interaction which seems to exist between research and practice on the topic of urban goods distribution. The number of successful 'best practices' in urban goods distribution is limited and only few of them have been in practice for a longer period than the experimental one. Moreover, most of the contributions to define 'best practices' appear in scientific literature and do not include an analysis of stakeholders effects. Such gap might lead to a lag between the effects predicted by researchers and the ones actually achieved in practice.

To overcome this gap and to predict what can actually constitute a 'best practice', it is suggested the use of microsimulation tools.

Towards some possible contestation that might arise, microscopic traffic simulation might be a useful tool to predict the effects of a specific initiative to all the interested parties. The challenge in urban goods distribution is often to find a sustainable collective optimum of drawbacks and benefits for all actors. If the short-term effects are estimated (but the interest in long term is also there) and the stakeholders are aware of the benefits they can have with a specific measure, the negotiation process is more transparent and can easily lead to an integrate strategy.

For instance, if a public stakeholder is planning to implement a certain initiative, aiming at solving a problem caused by urban goods distribution, it can be helpful to know which stakeholder group is affected in a negative way and which one in a positive way. When this information is available, the initiative envisaged and/or its implementation plan can be adapted so as to compensate the stakeholders negatively impacted.

Therefore, the thesis provides a sixth contribution suggesting an useful tool of evaluation and of support to negotiation: microsimulation.

Traditionally, researchers have developed theory by combining observations from previous literature, common sense and experience (Eisenhardt, 1989). It is the close link with empirical reality that allows the development of a testable, relevant and valid contribution to theory.

Combining observations from literature, common sense and experience on the topic of urban goods distribution, it becomes clear the existence of a) heterogeneous theoretical and empirical methodologies of evaluation, and b) a lack of integration and representation of stakeholder's perspectives on such assessments. Moreover, it is also evident a strong dependency between the performances of most of the labeled 'best practices' and the specific contexts and variables in which they were applied.

Altogether these facts underline the need for the development of an integrated agent based approach for the evaluation of the performance of initiatives on urban goods distribution. By attaining the sixth findings presented above and confirming the hypothesis launched at the beginning of the study, the thesis developed a testable and valid contribution to the theory existent on the topic.

7.3 Limitations and recommendations for further research

1. The literature review on good and best practices on urban goods distribution, presented on Chapter 3, tries to be as complete as possible. However, other initiatives with positive effects, particularly the ones implemented by the **private sector** may exist. Once they were not documented, the magnitude of their impact has also not been published and so it were not included on the review. However, if those initiatives exist it would be useful to include them in future work. Once they are actually implemented in practice and not in an experimental phase, they can indicate what and who were the determinants for its success and can provide more knowledge to other stakeholders who are not aware of its existence.

2. The transfer of an initiative that is successful in one city is by no means a guarantee for success elsewhere. The success of a given initiative depends to a large extent on the overall project and process implementation and not only on the procedures of the initiative. For instance, even when an initiative reveals to have a positive evaluation for all or most stakeholders, the transitory process to be followed until its full implementation requires particular attention from the local administrators and planners. The final scenario might be a feasible one and supposedly better than the existing one, but the intermediary scenario that occurs during the **implementation process** and that might last for several months or years, might not be adequate. In that case, the best approach might be for the local administration to leave things the way they are, which is always one of the available options for a policy maker. In future work (when there are more practical examples) it would be interesting to analyze the impacts of the implementation process.

3. When seeking for a methodology that makes explicit suppliers interests, it is important to be aware that such vision does not reflect entirely “freight industry” perspective. Other stakeholders involved in retail/wholesale/distribution complement that perspective. Due to the scope of the thesis, focused on the last step of the supply chain, it was highlighted the most relevant group: suppliers. Findings from this study suggest that those formulating urban goods distribution strategies, need to investigate the interests of the various stakeholders in depth. Explaining and understanding individual stakeholders responses should lead to policy development that better reflect the complex and diverse needs of goods distribution towards mobility and sustainability. Further investigation should be carried out on the several stakeholders from freight industry. Such approach would overcome an observed tendency in which **freight industry** has been largely ignored for planning purposes and have also been referred to in passing as the “freight industry” with a presumed homogeneity of interests. This analysis would allow policy makers to identify first the policy issues on which there is consensus and also identify those policies that appear to be negatively perceived by most or all stakeholders of the ‘freight industry’.

4. Results from modeling can be a useful indication to forecast mobility and sustainability at a short-medium term. However, most of the modeling exercises are

based on past behavior and are not able to take into account changes escaping from continuous trends. Factors like the closing of stores or specific conjunctures are lacking and jeopardize the possibility of the **long term quantification**. Although to the present work such limitation is not determinant, analysis such as the construction of logistics facilities are more sensitive to long term quantification. Further investigation is needed to give a precise analysis of these weaknesses and their relevance at urban scope.

5. The research was carried out at **retail stores level** because these ones represent better the issue of the effects urban goods distribution generated in urban areas. It would be useful as well to analyze other commercial areas like outlets and shopping centres to give a whole picture of the distribution sector and of the interactions between retailers, wholesalers and the city. In Porto metropolitan area, most of the wholesalers are located in less central municipalities and thus, the chosen approach does not significantly affects the final results. However, in other contexts, such analysis can be determinant to analyze and support decisions like the shift of outlets to less congested areas, considering the impacts on remaining shops and therefore, respective turnover to stakeholders of the area, etc.

6. The focus of the thesis was at the local level (city) and despite the robustness of results, it would be useful to compare it with other Portuguese cities or in an ambitious attempt, with sufficient cities to consider it a national level analysis. The comparison could allow to take lessons out of it and hopefully identify patterns of what can be ‘good practices’ to the Portuguese context.

7. The deliveries were analyzed based on a survey carried out at the final destination. It was not obtained information about the number of movements which were **direct and round trips**. Considering the variability of the delivery patterns, depending strongly on the type of commercial store (size) and respective activity branch, that information would not add a significant value to this work. Nevertheless, in future research with a specific focus on suppliers activity, it is essential (although difficult) to gather that data (or at least, to predict it).

8. One growing (but still not significant) share of urban goods distribution is generated by **e-commerce**. Along the thesis, e-commerce was not particularly differentiated because a) the analysis is mostly focused at the *final* destination which

within the city of Porto corresponds mainly[38] to retail activities, b) the process of acquiring a product through e-commerce is not universally identified as a good practice towards mobility and sustainability, (high number of no answer at destination) c) it is not possible to obtain reliable data on effects of e-commerce to each group of stakeholders and by geographical area of influence disabling the opportunity to apply the approach adopted on the thesis. Nonetheless, if e-commerce share becomes representative in terms of its impacts within urban areas, it would be interesting to include it in future works.

9. Once receivers are included on the group of stakeholders whose interests are defended by local administrators, they were not focused in detail. However, their role must be emphasized as a very important partner, once most of the times suppliers can ignore all the rules and regulations benefiting the time agreed with the receiver to make the deliveries. On this sense, receivers can be a strong partner to involve and consequently, to analyze separately in further research.

Besides the main limitations of the study referred above, the development of this work also leaves several questions to be answered in future research:

- What is the contribution technologies can give to the improvement of sustainability and mobility?
- Are there other indicators of sustainability and mobility that need to be addressed?
- How determinant for the success of an initiative to reach consensus of a vision of mobility and sustainability between stakeholders?
- What are the roles, responsibilities, and relationships of each of these stakeholders in the planning and policy setting processes?
- What methods would best be used to forecast impacts of alternative initiatives?
- What is the role of land use patterns in urban goods distribution and how can it influence the achievement of a better mobility and sustainability?
- For which items is more information required so that good decisions can be taken?
- What will be the best way of influencing suppliers behavior?
- What will be the best way of changing society behavior?
- How can e-commerce contribute to the achievement of a better mobility and sustainability?

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[38] *The survey did not register home delivery operations occurring in any of the areas.*

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Annex 4.1. Questionnaire adopted for the validation of an indicator framework

Selecting Indicators to evaluate mobility and sustainability performance

The definition of indicators to evaluate the performance of initiatives in terms of sustainability and mobility targets can be a complex and subjective task. In order to get a perception of how adequate the following indicators are under a perspective of a researcher, retailer, administrator of a public company, consultant, etc, I would kindly ask you to reply to this short survey.

Job

Institution

Gender Female Male

Age (optional)

23-30
31-35
36-40
41-45
46-50
+ 50

1) For how long do you work on the transports, environment or logistics field?

less than 5 years
5 to 10 years
10-15 years
16 years or more

2) How would you describe your knowledge on mobility and sustainability concepts?

No knowledge at all
I know the concepts
I have worked in projects, studies, etc closely related to these topics
I consider myself an expert on these topics
Other (Please Specify):

3) How would you describe your knowledge on the selection of indicators to evaluate a initiative in terms of mobility and sustainability?

No experience
I have experience(participation in studies/projects, knowledge about the topic)
Other (Please Specify):

4) Please select the quality criteria that you consider that best fits to the use of the selected indicator to measure the dimension in ().

	Scientific validity	Representativeness	Relevance	Easy to understand	Evidence of links and effect	Responsiveness	Transferability	Accuracy	Other (Please Specify):
Fuel Consumption (Environmental Sustainability)									
CO2 emissions (Environmental Sustainability)									
Emissions NOx, VOCs, PM (Environmental Sustainability)									
Average Speed km/h (Mobility and Social Sustainability)									
Average journey time (Mobility and Social Sustainability)									
Travel time (Mobility and Social Sustainability)									
Delay time (Mobility and Social Sustainability)									
Distance travelled (Mobility and Social Sustainability)									
Mean flow (Mobility and Social Sustainability)									
Density veh/km (Mobility and Social Sustainability)									

5) Please evaluate the use of the indicators to measure the dimension in (). (*For instance: how would you evaluate the accuracy of measuring environmental sustainability with fuel consumption from 0 to 4?) 0 - is a very bad indicator and 4 is a very good indicator.*

	0	1	2	3	4
Fuel consumption (Environmental Sustainability)					
CO2 emissions (Environmental Sustainability)					
Emissions NOx, VOCs, PM (Environmental Sustainability)					
Average speed (Mobility and Social Sustainability)					
Average journey time (Mobility and Social Sustainability)					
Travel time sec/km (Mobility and Social Sustainability)					
Delay time sec/km (Mobility and Social Sustainability)					
Distance travelled (Mobility and Social Sustainability)					
Mean flow (Mobility and Social Sustainability)					
Density (Mobility and Social Sustainability)					

6) The selection of indicators should always reflect stakeholders interests and objectives in order to better evaluate an initiative. Considering a simple distinction of **public interests** (administrators, residents, workers), concerned with the quality of life, economic vitality and mobility on the area, versus **private interests** (industry), concerned with customer levels, costs levels, service levels and competition, of whose interests would you consider the following indicators are a good tool of evaluation? *(for Instance, is fuel consumption a good indicator to measure private interests, public interests or both?)*

	Private Interests	Public Interests	Both	None
Fuel consumption (Environmental Sustainability)				
CO2 emissions (Environmental Sustainability)				
Emissions NOx, VOCs, PM (Environmental Sustainability)				
Average speed (Mobility and Social Sustainability)				
Average journey time (Mobility and Social Sustainability)				
Travel time sec/km (Mobility and Social Sustainability)				
Delay time sec/km (Mobility and Social Sustainability)				
Distance travelled (Mobility and Social Sustainability)				
Mean flow (Mobility and Social Sustainability)				
Density (Mobility and Social Sustainability)				

7) The indicators mentioned above are effective and proper to measure mobility and sustainability on transports activities? (0 - I do not agree at all and 4 - I fully agree)

8) The use of indicators to evaluate the mobility and sustainability performance is relevant to support policy statements and actions on urban transport systems? (0 - I do not agree at all and 4 - I fully agree)

9) Would you add some indicator to the previous list to measure mobility and sustainability?

Yes
No
I don't know
If yes, please specify

10) Would you remove some indicator from the previous list to measure mobility and sustainability?

Yes
No
I don't know
If yes, please specify
Other:

11) Email

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Annex 5.1. Use of the input and output indicators in AIMSUN

Input Indicators	Meaning	Measurement	AIMSUN
Delivery time	Delivery time extends from the point at which the supplier parks to the moment when he leaves	Data collection *in loco*	Incidents representing delivery operations have an extent equal to the respective delivery time
Deliveries/day	Number of deliveries per day per activity located in the area of study	Data collection *in loco*	Incidents representing delivery operations have a frequency per activity equal to the respective 'delivery/day' indicator
Use of load capacity	Load factor of the vehicle categorized as: less than 50%; 50-75% and full (100%)	Data collection *in loco*	Assignments of loads to vehicles on the simulation of alternative initiatives can vary according with this parameter. On the case study (existent situation), one unit load corresponds to one vehicle
Proportion of goods vehicles in total traffic	Proportion of freight vehicles (trucks, vans, in total traffic of the demand data	Existent traffic counting and data collection *in loco*	Demand data distinguishes traffic demand matrices and states by vehicle types. Goods vehicles are trucks and vans

Output Indicators	Meaning	Measurement	AIMSUN
Energy Intensity (Fuel Consumption in liters by vehicle type)	Fuel Consumed: total liters of fuel consumed by vehicle types that have crossed the network or stream of sections	The AIMSUN Fuel Consumption Model assumes that each vehicle is either idling, or cruising at a constant speed, or accelerating or decelerating. The state of each vehicle is determined and the model uses the appropriate formula to calculate the fuel consumed for this state. Formulas are available at the software users' manual (TSS, 2007)	The Fuel Consumption parameters are edited for each vehicle type, specifying a) fuel consumption rates (ml/s) for idling, decelerating and accelerating vehicles, b) fuel consumption rates (liters per 100 km) for vehicles travelling at a constant speed of 90 km/h and of 120 km/h and c) the speed at which the fuel consumption rate (ml/s) is at a minimum for a vehicle cruising at constant speed
Emissions g per area or km by vehicle type	For each pollutant, total weight of pollution emitted by vehicle types that have crossed the network or stream of sections	Formulas are available at the software users' manual (TSS, 2007)	The vehicle state (idling, cruising, accelerating or decelerating) and the vehicle speed / acceleration is used to evaluate the emission from each vehicle for each simulation step. This is done by referencing look-up tables for each pollutant, which give emissions (in g/s) for every relevant combination of vehicle behavior, speed / acceleration. There are different sets of look-up tables for each vehicle type and for each pollutant

Output Indicators	Meaning	Measurement	AIMSUN
CO2 emissions (g per area or km)	Total weight of CO2 emitted by vehicle types that have crossed the network or stream of sections	CO2 emission was calculated through a function dependent of all types of fuel shares and the respective levels of fuel consumed	CO2=f (Fuel consumption)
Average Speed (excluding stops to make deliveries – km/hour)	Average speed for all vehicles that have left the system. This is calculated using the mean journey speed for each vehicle	Formulas are available at the software users' manual (TSS, 2007)	Obtained as an output after car-following and lane-changing rules and behavior parameters are defined, namely maximum desired speed of the vehicle, speed acceptance of the vehicle and speed limit of the sections or turning s
Travel time (sec/km)	Average time a vehicle needs to travel one kilometer (or one section) inside the network.	Formulas are available at the software users' manual (TSS, 2007)	This is the average of all the single travel times (exit time - entrance time) for every vehicle that has crossed the network, converted into time per kilometer. Obtained as an output (sec/km or sec/section)
Delay time (sec/km)	Average delay time per vehicle per kilometer or per section	Formulas are available at the software users' manual (TSS, 2007)	This is the difference between the expected travel time (the time it would take to traverse the system under ideal conditions) and the travel time. It is calculated as the average of all vehicles and then converted into time per kilometer or per section.
Distance Travelled by HGV, LGV, car, bus and taxi (km)	Total number of kilometers travelled by all the vehicles that have crossed the network, stream or section	Formulas are available at the software users' manual (TSS, 2007)	Obtained as an output (km)
Density (veh/km)	Density: average number of vehicles per kilometer for the whole network or in the section	Formulas are available at the software users' manual (TSS, 2007)	Obtained as an output (vehkm)

Annex A1. Cooperative distribution systems effects in Unit 1

Cooperative distribution systems – Street level - Cedofeita

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-4%	-3%			-3%	-7%	22%	24%	-5%
Public transport	-7%	-5%			-5%	-7%	31%	32%	-5%
Citizens and users	-32%	-12%			-12%	-19%	48%	49%	-4%
Suppliers (HGV's)	-24%	-15%			-15%	-11%	25%	47%	-20%
Suppliers (LGV's)	-16%	-51%			-51%	-3%	3%	44%	-41%

Cooperative distribution systems – Street level - Passos Manuel

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-4%	-1%			-1%	-9%	5%	7%	-2%
Public transport	-30%	-5%			-5%	-5%	2%	1%	-8%
Citizens and users	0%	-2%			-2%	-8%	9%	19%	-3%
Suppliers (HGV's)	-38%	-22%			-22%	-13%	1%	4%	-16%
Suppliers (LGV's)	-23%	-10%			-10%	-4%	25%	26%	-23%

Cooperative distribution systems – Unit level – U1

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	-5%	-2%	8%	-5%	4%	-11%	-12%	1%
Public transport	-1%	-7%	-27%	32%	-7%	3%	-12%	-10%	1%
Citizens and users	0%	-4%	-1%	1%	-4%	4%	-11%	-12%	1%
Suppliers (HGV's)	1%	-7%	-27%	26%	-7%	4%	-14%	-12%	-5%
Suppliers (LGV's)	2%	-10%	-17%	15%	-10%	7%	-14%	-19%	-8%

Cooperative distribution systems – Overall System

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-2%	-5%	-16%	-17%	-5%	2%	-9%	-8%	0%
Public transport	1%	-2%	-22%	-22%	-2%	2%	-4%	-6%	1%
Citizens and users	-2%	-5%	-16%	-17%	-5%	2%	-10%	-9%	0%
Suppliers (HGV's)	1%	0%	-7%	-5%	0%	2%	-2%	-4%	1%
Suppliers (LGV's)	-2%	-7%	-28%	-32%	-7%	2%	-8%	-6%	-2%

Annex A2. Cooperative distribution systems effects in Unit 2

	Cooperative distribution systems – Street level – Costa Cabral								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-16%	-7%			-8%	-10%	36%	56%	-10%
Public transport	-16%	-6%			-6%	-11%	46%	76%	-11%
Citizens and users	-10%	-4%			-4%	-13%	17%	24%	-7%
Suppliers (HGV's)	-4%	-31%			-31%	-9%	65%	94%	-53%
Suppliers (LGV's)	-44%	-38%			-38%	-10%	-25%	-37%	-6%

	Cooperative distribution systems – Unit level – U2								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	-3%	14%	-13%	-3%	-2%	2%	5%	-10%
Public transport	-5%	0%	8%	-10%	0%	-2%	10%	17%	-32%
Citizens and users	1%	-4%	15%	-13%	-4%	-2%	2%	6%	-8%
Suppliers (HGV's)	-4%	0%	13%	-19%	0%	0%	6%	13%	-67%
Suppliers (LGV's)	-3%	-1%	9%	-14%	-1%	4%	-7%	-14%	4%

	Cooperative distribution systems – Overall System								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-6%	-4%	4%	3%	-4%	0%	5%	7%	4%
Public transport	-10%	-10%	-10%	-15%	-10%	-4%	1%	2%	9%
Citizens and users	-6%	-3%	6%	4%	-3%	-2%	6%	8%	4%
Suppliers (HGV's)	-5%	-10%	-3%	-17%	-10%	-4%	3%	3%	32%
Suppliers (LGV's)	-3%	0%	2%	2%	0%	-1%	0%	0%	40%

Annex A3. Cooperative distribution systems effects in Unit 3

Cooperative distribution systems – Street level – Avenida da Boavista

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	0%			-1%	-1%	1%	1%	0%
Public transport	2%	3%			2%	-1%	5%	6%	-3%
Citizens and users	1%	1%			1%	-1%	1%	1%	-1%
Suppliers (HGV's)	-15%	-14%			-15%	0%	0%	0%	14%
Suppliers (LGV's)	-9%	-10%			-9%	7%	-7%	-8%	0%

Cooperative distribution systems – Unit level

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	5%	4%	4%	-1%	5%	0%	2%	2%	-5%
Public transport	6%	1%	20%	-20%	6%	-1%	7%	8%	-7%
Citizens and users	5%	5%	5%	-5%	4%	0%	2%	2%	-5%
Suppliers (HGV's)	2%	4%	14%	-14%	2%	-2%	3%	4%	-3%
Suppliers (LGV's)	9%	9%	8%	-10%	9%	-2%	4%	5%	-2%

Cooperative distribution systems – Overall system

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	0%	-27%	-31%	1%	0%	1%	1%	-3%
Public transport	2%	5%	-38%	-39%	2%	-1%	3%	3%	-1%
Citizens and users	1%	1%	-26%	-27%	0%	0%	0%	1%	-3%
Suppliers (HGV's)	0%	1%	-34%	-30%	0%	-1%	1%	1%	-9%
Suppliers (LGV's)	3%	6%	-35%	-40%	3%	-2%	7%	10%	-6%

Annex A4. Collaborative distribution systems effects in Unit 1

Collaborative distribution systems – Cedofeita Street

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	7%	-16%			-16%	5%	-1%	-4%	-4%
Public transport	3%	-1%			-1%	5%	-1%	-2%	-4%
Citizens and users	76%	-46%			-46%	46%	-74%	-75%	-31%
Suppliers (HGV's)	77%	-54%			-54%	29%	-79%	-81%	-12%
Suppliers (LGV's)	36%	-38%			-38%	4%	-49%	-82%	-67%

Collaborative distribution systems – Passos Manuel Street

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	4%	-8%			-8%	15%	-40%	-45%	-7%
Public transport	5%	-5%			-5%	15%	-45%	-50%	-5%
Citizens and users	18%	-10%			-10%	2%	-4%	-6%	-5%
Suppliers (HGV's)	24%	-7%			-7%	19%	-25%	-23%	-24%
Suppliers (LGV's)	32%	-3%			-3%	4%	-33%	-31%	-23%

Collaborative distribution systems – Unit level

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-11%	-14%	-26%	23%	-14%	2%	-20%	-4%	5%
Public transport	-8%	-14%	-35%	32%	-14%	3%	-20%	-11%	5%
Citizens and users	-11%	-13%	-27%	26%	-13%	2%	-20%	-3%	5%
Suppliers (HGV's)	-10%	-19%	-10%	8%	-19%	3%	-28%	-11%	2%
Suppliers (LGV's)	-14%	-22%	-18%	10%	-22%	4%	-32%	-19%	4%

Collaborative distribution systems – Overall System

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-7%	-8%	-23%	-25%	-8%	1%	-10%	-5%	2%
Public transport	-5%	-9%	-29%	-29%	-9%	2%	-11%	-7%	5%
Citizens and users	-7%	-8%	-23%	-25%	-8%	1%	-11%	-5%	2%
Suppliers (HGV's)	-4%	-7%	-16%	-14%	-7%	2%	-9%	-6%	2%
Suppliers (LGV's)	-8%	-11%	-35%	-39%	-11%	1%	-11%	-5%	2%

Annex A5. Collaborative distribution systems effects in Unit 2

Collaborative distribution systems – Costa Cabral Street

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-22%	-37%			-38%	10%	-11%	-18%	3%
Public transport	-23%	-35%			-35%	6%	-6%	-9%	3%
Citizens and users	-32%	-42%			-42%	4%	-27%	-36%	3%
Suppliers (HGV's)	-8%	-55%			-55%	49%	-49%	-74%	11%
Suppliers (LGV's)	-6%	-34%			-34%	21%	-29%	-44%	13%

Collaborative distribution systems – Unit level

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-5%	-5%	-3%	-4%	-5%	2%	-4%	-5%	11%
Public transport	-7%	-7%	-2%	-4%	-7%	1%	-2%	-4%	26%
Citizens and users	-5%	-5%	-3%	-3%	-5%	2%	-2%	-5%	11%
Suppliers (HGV's)	-6%	-5%	-2%	-6%	-5%	3%	-8%	-16%	20%
Suppliers (LGV's)	-9%	-9%	-16%	-29%	-9%	5%	-5%	-11%	14%

Collaborative distribution systems – Overall System

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-3%	-2%	4%	3%	-2%	-2%	3%	3%	2%
Public transport	-5%	-6%	-10%	-15%	-6%	-2%	0%	0%	-10%
Citizens and users	-2%	-1%	6%	4%	-1%	0%	3%	5%	2%
Suppliers (HGV's)	-6%	-9%	-3%	-17%	-9%	-2%	-1%	-1%	16%
Suppliers (LGV's)	-1%	-5%	2%	2%	-5%	0%	1%	1%	13%

Annex A6. Collaborative distribution systems effects in Unit 3

	Collaborative distribution systems – Avenida da Boavista								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	0%			-2%	0%	0%	0%	0%
Public transport	4%	4%			4%	-1%	2%	2%	-3%
Citizens and users	1%	1%			0%	-1%	1%	1%	-1%
Suppliers (HGV's)	-4%	-2%			-4%	13%	-10%	-11%	0%
Suppliers (LGV's)	-11%	-2%			-11%	2%	-3%	-4%	0%

	Collaborative distribution systems – Unit level								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-5%	7%	41%	42%	6%	0%	5%	7%	2%
Public transport	5%	13%	34%	35%	5%	-2%	11%	13%	0%
Citizens and users	4%	6%	40%	41%	7%	0%	5%	6%	-2%
Suppliers (HGV's)	-10%	-11%	-61%	-58%	-10%	1%	-8%	-10%	2%
Suppliers (LGV's)	-3%	-8%	-56%	-61%	-3%	1%	-4%	-5%	3%

	Collaborative distribution systems – Overall System								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	2%	2%	-32%	-36%	3%	0%	0%	1%	-1%
Public transport	5%	6%	-48%	-48%	5%	-1%	3%	4%	0%
Citizens and users	2%	1%	-31%	-32%	2%	0%	1%	1%	-1%
Suppliers (HGV's)	0%	0%	-39%	-34%	0%	-1%	1%	1%	-5%
Suppliers (LGV's)	6%	6%	-34%	-39%	6%	-1%	2%	2%	-3%

Annex A7. Collaborative distribution systems effects in Camões

	Collaborative distribution systems – Camões Street								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-1%	-1%			-1%	0%	-1%	-5%	-2%
Public transport	-3%	-8%			-8%	-1%	-12%	-21%	-19%
Citizens and users	-1%	-1%			-1%	0%	0%	-1%	-1%
Suppliers (HGV's)	-4%	0%			0%	2%	-14%	-45%	-7%
Suppliers (LGV's)	-1%	0%			0%	1%	-4%	-25%	-3%

Annex A8. Regulation of access based on time in Unit 2

	Regulation of access based on time – Costa Cabral Street								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-7%	-21%			-21%	25%	-12%	-18%	0%
Public transport	0%	-2%			-2%	12%	-1%	-1%	0%
Citizens and users	-72%	-80%			-80%	81%	-59%	-79%	0%
Suppliers (HGV's)	0%	-19%			-19%	9%	-7%	-29%	4%
Suppliers (LGV's)	0%	-14%			-14%	13%	-2%	-2%	0%

	Regulation of access based on time – Unit level								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-3%	-1%			-1%	1%	-1%	-2%	12%
Public transport	-5%	-4%			-4%	3%	-4%	-7%	19%
Citizens and users	-3%	0%			0%	1%	-1%	-2%	12%
Suppliers (HGV's)	-6%	-4%			-4%	1%	-6%	-11%	20%
Suppliers (LGV's)	-5%	-1%			-1%	1%	-1%	-1%	16%

	Regulation of access based on time – Overall System								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	-1%			-1%	5%	0%	0%	1%
Public transport	-5%	-8%			-8%	4%	-5%	-6%	0%
Citizens and users	0%	0%			0%	3%	0%	0%	1%
Suppliers (HGV's)	-1%	-7%			-7%	0%	0%	-1%	0%
Suppliers (LGV's)	-2%	-1%			-1%	0%	-2%	-3%	0%

Annex A9. Regulation of access based on time in Camoes

	Regulation of access based on time – Camoes axle								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	-2%			-2%	0%	-1%	-5%	1%
Public transport	0%	-3%			-3%	1%	-12%	-21%	7%
Citizens and users	-1%	-1%			-1%	0%	-2%	-16%	1%
Suppliers (HGV's)	-7%	-2%			-2%	3%	-20%	-33%	14%
Suppliers (LGV's)	0%	-8%			-8%	1%	-4%	-20%	3%

Annex A10. Alternative fuels in Unit 1

Alternative fuels in Unit 1 with a penetration rate of 10%

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	4%	-11%			-11%	6%	-3%	-8%	2%
Public transport	4%	-9%			-9%	6%	-8%	-5%	4%
Citizens and users	4%	-12%			-12%	6%	-5%	-8%	5%
Suppliers (HGV's)	4%	-9%			-9%	6%	-6%	-8%	4%
Suppliers (LGV's)	4%	-11%			-11%	5%	-7%	-7%	5%

Alternative fuels in Unit 1 with a penetration rate of 20%

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-5%	-19%			-19%	7%	0%	0	2%
Public transport	-5%	-19%			-19%	6%	-3%	-5%	4%
Citizens and users	-6%	-25%			-25%	7%	-2%	-8%	5%
Suppliers (HGV's)	-5%	-19%			-19%	6%	-3%	-8%	4%
Suppliers (LGV's)	-6%	-24%			-24%	5%	-3%	-7%	5%

Annex A11. Implementation of road pricing to the system

Implementation of road pricing to the system

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	-7%	-5%	-5%	-7%	3%	-11%	-12%	-2%
Public transport	1%	-7%	-6%	-6%	-7%	3%	-11%	-13%	-4%
Citizens and users	1%	-8%	-5%	-5%	-8%	4%	-11%	-9%	-4%
Suppliers	0%	-8%	-3%	-7%	-8%	3%	-12%	-14%	-3%

Annex A12. Reserved – capacity strategies

Shared usage of a bus lane by freight vehicles – Street level (Option 1)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-14%	-21%			-21%	8%	-6%	-10%	4%
Public transport	-15%	-24%			-24%	0%	4%	8%	-6%
Citizens and users	-10%	-8%			-8%	14%	-11%	-15%	3%
Suppliers (HGV's)	-8%	-45%			-45%	49%	-14%	-20%	1%
Suppliers (LGV's)	-24%	-36%			-35%	34%	-25%	-13%	29%

Shared usage of a bus lane by freight vehicles – Street level (Option 2)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-19%	-28%			-28%	6%	-6%	-9%	2%
Public transport	-20%	-28%			-28%	5%	-2%	-3%	-6%
Citizens and users	-31%	-35%			-35%	1%	-20%	-26%	16%
Suppliers (HGV's)	16%	-26%			-26%	84%	93%	99%	7%
Suppliers (LGV's)	-18%	-42%			-41%	93%	-11%	-31%	34%

Shared usage of a bus lane by freight vehicles – Street level (Option 3)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-11%	-17%			-17%	6%	-2%	-3%	2%
Public transport	-11%	-16%			-16%	3%	-3%	-6%	-5%
Citizens and users	-6%	-10%			-10%	93%	-12%	-16%	15%
Suppliers (HGV's)	-32%	-58%			-58%	96%	-32%	-2%	-5%
Suppliers (LGV's)	-35%	-39%			-39%	96%	-72%	-61%	29%

Shared usage of a bus lane by freight vehicles – Street level (Option 4)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-17%	-28%			-28%	5%	-2%	-3%	0%
Public transport	-18%	-27%			-27%	5%	-4%	-6%	0%
Citizens and users	-18%	-30%			-30%	92%	-23%	-31%	0%
Suppliers (HGV's)	-12%	-40%			-40%	98%	-45%	-22%	0%
Suppliers (LGV's)	3%	-27%			-26%	98%	-18%	-23%	0%

Annex A12. Reserved – capacity strategies (cont.)

Shared usage of a bus lane by freight vehicles – Unit level (Option 1)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-15%	-15%			-15%	2%	-3%	-6%	6%
Public transport	-15%	-16%			-16%	0%	3%	6%	29%
Citizens and users	-15%	-14%			-14%	2%	-3%	-7%	6%
Suppliers (HGV's)	-18%	-18%			-18%	3%	-10%	-19%	38%
Suppliers (LGV's)	-14%	-14%			-14%	4%	-3%	-7%	-20%

Shared usage of a bus lane by freight vehicles – Unit level (Option 2)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-20%	-17%			-17%	1%	-1%	-1%	15%
Public transport	-19%	-18%			-18%	-1%	-3%	-5%	31%
Citizens and users	-20%	-17%			-17%	1%	-1%	-1%	14%
Suppliers (HGV's)	-25%	-23%			-23%	1%	-7%	-14%	37%
Suppliers (LGV's)	-27%	-22%			-22%	2%	-1%	-2%	-15%

Shared usage of a bus lane by freight vehicles – Unit level (Option 3)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	5%	6%			6%	1%	-1%	-2%	-6%
Public transport	6%	9%			9%	0%	4%	7%	20%
Citizens and users	6%	7%			7%	1%	-1%	-2%	6%
Suppliers (HGV's)	6%	7%			7%	1%	-7%	-13%	34%
Suppliers (LGV's)	1%	5%			5%	2%	0%	0%	-12%

Shared usage of a bus lane by freight vehicles – Unit level (Option 4)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	9%	10%			10%	2%	-3%	-7%	-7%
Public transport	9%	11%			11%	-2%	4%	7%	28%
Citizens and users	10%	10%			10%	2%	-3%	-7%	6%
Suppliers (HGV's)	10%	11%			11%	1%	-8%	-16%	39%
Suppliers (LGV's)	6%	8%			8%	4%	-5%	-10%	-17%

Annex A12. Reserved – capacity strategies (cont.)

Shared usage of a bus lane by freight vehicles – System level (Option 1)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-4%	-3%	-14%	-16%	-3%	-1%	3%	4%	3%
Public transport	-8%	-9%	-21%	-26%	-9%	-4%	0%	1%	9%
Citizens and users	-4%	-2%	-13%	-15%	-2%	-1%	3%	5%	3%
Suppliers (HGV's)	-13%	-9%	-28%	-36%	-9%	-4%	3%	4%	3%
Suppliers (LGV's)	-4%	-1%	-18%	-21%	-1%	1%	-1%	-2%	-4%

Shared usage of a bus lane by freight vehicles – System level (Option 2)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-3%	-2%	-14%	-14%	-2%	0%	4%	5%	3%
Public transport	-8%	-10%	-2%	-7%	-10%	2%	-2%	-3%	-7%
Citizens and users	-3%	0%	-16%	-16%	0%	-2%	5%	7%	2%
Suppliers (HGV's)	-10%	-11%	-5%	-8%	-11%	-4%	1%	1%	4%
Suppliers (LGV's)	0%	-2%	10%	10%	2%	0%	1%	2%	3%

Shared usage of a bus lane by freight vehicles – System level (Option 3)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-12%	-5%	-6%	-8%	-5%	-1%	8%	10%	5%
Public transport	-15%	-4%	3%	-3%	-4%	-5%	5%	6%	8%
Citizens and users	-11%	-5%	7%	8%	-5%	-3%	8%	11%	6%
Suppliers (HGV's)	-13%	-2%	1%	-15%	-2%	-5%	7%	9%	26%
Suppliers (LGV's)	-13%	-2%	-3%	2%	-2%	-3%	5%	7%	29%

Shared usage of a bus lane by freight vehicles – System level (Option 4)

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-10%	-10%	-7%	-10%	-10%	-1%	0%	0%	4%
Public transport	-16%	-25%	-34%	-40%	-25%	-1%	-9%	-11%	-11%
Citizens and users	-9%	-8%	-6%	-7%	-8%	-1%	1%	2%	4%
Suppliers (HGV's)	-	-17%	-23%	-36%	-17%	-5%	1%	1%	29%
Suppliers (LGV's)	-6%	-5%	-14%	-13%	-5%	1%	2%	3%	28%

Annex A13. Enforcement effects in Unit 1

Enforcement – Cedofeita Street

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	24%	-54%			-54%	21%	-94%	-71%	-41%
Public transport	21%	-27%			-27%	21%	-94%	-69%	-41%
Citizens and users	92%	-86%			-86%	66%	-98%	-80%	-56%
Suppliers (HGV's)	65%	-89%			-89%	37%	-97%	-89%	-24%
Suppliers (LGV's)	36%	-38%			-38%	7%	-8%	-65%	-3%

Enforcement – Passos Manuel Street

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	18%	-41%			-37%	12%	-42%	-47%	-4%
Public transport	20%	-31%			-31%	13%	-49%	-54%	-1%
Citizens and users	27%	-80%			-80%	1%	-60%	-61%	-32%
Suppliers (HGV's)	4%	-65%			-65%	16%	-71%	-55%	-24%
Suppliers (LGV's)	20%	-23%			-23%	16%	-76%	-78%	-23%

Enforcement – Unit level

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-7%	-15%	-28%	-31%	-15%	4%	-37%	-29%	9%
Public transport	0%	-14%	-16%	-20%	-14%	2%	-26%	-25%	5%
Citizens and users	-8%	-14%	-27%	-30%	-14%	4%	-38%	-30%	9%
Suppliers (HGV's)	0%	-20%	-47%	-48%	-20%	4%	-37%	-28%	1%
Suppliers (LGV's)	-7%	-25%	-39%	-50%	-25%	7%	-40%	-34%	5%

Enforcement – Overall System

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-1%	-5%	-14%	-15%	-5%	1%	-13%	-12%	3%
Public transport	0%	-8%	-18%	-19%	-8%	2%	-13%	-14%	4%
Citizens and users	-2%	-5%	-15%	-16%	-5%	1%	-13%	-12%	2%
Suppliers (HGV's)	2%	-3%	-4%	-5%	-3%	2%	-6%	-10%	0%
Suppliers (LGV's)	0%	-7%	5%	5%	-7%	2%	-10%	-12%	5%

Annex A14. Enforcement effects in Unit 2

Enforcement – Costa Cabral Street

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	5%	-24%			-19%	19%	-28%	-44%	0%
Public transport	7%	-18%			-18%	12%	-25%	-40%	0%
Citizens and users	8%	-11%			-11%	17%	-34%	-47%	0%
Suppliers (HGV's)	4%	-65%			-65%	84%	-59%	-87%	0%
Suppliers (LGV's)	38%	-14%			-14%	45%	-55%	-82%	0%

Enforcement – Unit level

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-2%	-3%	-17%	21%	-3%	1%	-1%	-2%	4%
Public transport	-3%	-4%	-34%	25%	-4%	2%	-3%	-4%	19%
Citizens and users	-2%	-3%	-16%	17%	-3%	1%	-1%	-2%	4%
Suppliers (HGV's)	-2%	-2%	-42%	31%	-2%	1%	-6%	-13%	0%
Suppliers (LGV's)	-3%	-3%	-22%	29%	-3%	2%	-3%	-7%	7%

Enforcement – Overall System

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-11%	-8%			-8%	0%	2%	2%	3%
Public transport	-13%	-13%			-13%	-3%	4%	5%	-4%
Citizens and users	-10%	-7%			-7%	-2%	2%	2%	-3%
Suppliers (HGV's)	-14%	-11%			-11%	-6%	0%	-1%	18%
Suppliers (LGV's)	-10%	-7%			-7%	0%	-3%	-3%	7%

Annex A15. Enforcement effects in Unit 3

	Enforcement – Avenida da Boavista								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	0%			-2%	0%	0%	0%	0%
Public transport	2%	-3%			-2%	2%	-3%	-3%	-3%
Citizens and users	1%	0%			-1%	0%	0%	0%	0%
Suppliers (HGV’s)	4%	-3%			-4%	2%	-2%	-2%	0%
Suppliers (LGV’s)	4%	-4%			-4%	5%	-1%	-1%	0%

	Enforcement – Unit level								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	2%	-2%	-1%	-1%	-1%	2%	0%	-1%	0%
Public transport	1%	-3%	-9%	-10%	-1%	1%	-4%	-4%	2%
Citizens and users	2%	-2%	-1%	-2%	-2%	2%	0%	0%	1%
Suppliers (HGV’s)	4%	-5%	11%	4%	-4%	0%	-3%	-4%	2%
Suppliers (LGV’s)	3%	-3%	-17%	-20%	0%	1%	-5%	-6%	5%

	Enforcement – Overall System								
	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	0%	0%	3%	3%	0%	1%	-1%	-1%	0%
Public transport	-2%	-4%	0%	1%	-4%	1%	0%	0%	1%
Citizens and users	1%	0%	3%	3%	0%	1%	-1%	-1%	0%
Suppliers (HGV’s)	-2%	-2%	-3%	-3%	-2%	0%	-1%	-1%	4%
Suppliers (LGV’s)	-1%	-1%	0%	1%	-1%	2%	-3%	-4%	3%

Annex A16. Enforcement effects in Camões axle

Enforcement – Camoes axle

	Distance Trav.	Fuel Cons.	CO	NOx	CO2 emissions	Average Speed	Travel time	Delay time	Density
Total Motorized Society	-1%	-43%			-43%	7%	-17%	-96%	-17%
Public transport	-1%	-44%			-44%	6%	-13%	-94%	-13%
Citizens and users	1%	-25%			-25%	13%	-57%	-99%	-57%
Suppliers (HGV’s)	-12%	-13%			-13%	2%	-9%	-99%	0%
Suppliers (LGV’s)	-5%	-59%			-59%	8%	-17%	-97%	-21%

Annex B 1. Comparison of delay times

1, 2, 3	Cooperative Delivery Systems
4, 5, 6, 7	Collaborative Systems
8, 9	Regulation of access based on time
10	Alternative fuels
11	Implementation of Road Pricing
12	Shared usage of a bus lane
13, 14, 15, 16	Enforcement