TÉCNICO LISBOA

# OPTIMAL LOCATION FOR AN URBAN DISTRIBUTION CENTRE

GLASGOW CASE STUDY

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Thesis to obtain the Master of Science Degree in

## Civil Engineering

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# RESUMO

O trabalho desenvolvido e apresentado neste documento insere-se no contexto da Logística Urbana, tratando-se de um caso de estudo referente à implementação de um Centro de Distribuição Urbana que sirva o centro da cidade de Glasgow, do ponto de vista de entidades públicas. O objetivo é a construção de uma metodologia que permita cruzar os padrões de distribuição de mercadorias no centro da cidade, avaliados através da elaboração de inquéritos aos retalhistas, com a possibilidade de implementar um centro de distribuição urbano que satisfaça esses padrões e, simultaneamente, possibilite a mitigação da atividade logística no centro.

Mais do que a simulação do funcionamento de um centro de distribuição, pretende avaliar-se se este representa uma solução válida para mitigar a atividade logística em meio urbano e em que medida é que a aceitabilidade desta solução por parte dos principais *stakeholders* envolvidos no processo é decisiva no sucesso da sua implementação, no centro da cidade de Glasgow. Relativamente a este último tópico, é também objetivo analisar que políticas públicas melhor acompanhariam a implementação de um centro de distribuição urbana de forma a aliciar os *stakeholders* a transferirem o seu esquema de entregas para o centro.

A metodologia utilizada pretende tirar partido do trabalho já realizado por Munõz-Villamizar et al. 2014, juntamente com outras características necessárias para tratar o problema identificado. Com a utilização dessa formulação pretende-se compreender a melhor localização para o centro de distribuição assim como o melhor esquema de entregas para servir o centro da cidade com máxima eficiência e sustentabilidade. Além disso, pretende ter-se em conta as preferências dos retalhistas assim como o ambiente já construído em termos de legislação vigente referente à circulação rodoviária na cidade.

**Palavras-Chave**: Logística Urbana, Centros de Distribuição Urbana, Políticas Públicas, Optimização, Location Routing Problem, Glasgow

# ABSTRACT

The work carried out and presented in this report is inserted in the context of City Logistics, being a case study of the implementation of an Urban Distribution Centre serving Glasgow City Centre, from public entities point of view. The goal is to build a methodology that allows to cross present freight patterns in the city centre, evaluated through a survey process to retailers, with the possibility of implementing an urban distribution centre that satisfies those patterns and, simultaneously, allows the mitigation of the logistics activity in the centre.

More than to simulate the functioning of an urban distribution centre, it is intended to evaluate whether it presents a valid solution to mitigate city logistics activity and how stakeholders' acceptability is a deal-breaker for the success of its implementation, in Glasgow City Centre. On that last note, is it also a goal of this work to analyse what public policies would best accompany the implementation of a UDC in order to draw retailers' into taking part in a UDC scheme.

The methodology will take advantage of the work already carried out by Munõz-Villamizar et al. 2014, alongside other characteristics needed to solve the identified problem. The intent of this formulation is to understand the best location for an urban distribution centre as well as the best delivery scheme that serves the city centre with maximum efficiency and sustainability. Also, retailers' preferences and already imposed legislation for road traffic are to be taken into account.

**Keywords**: City Logistics, Urban Distribution Centres, Public Policies, Optimization, Location Routing Problem, Glasgow

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# 1 INTRODUCTION

## 1.1 PROBLEM DEFINITION

Freight transportation is a vital element in the economic prosperity of any country. Everyday, a wide variety of products has to be efficiently transported within the consumer markets, industry sectors and international trade networks, at the same time adverse impacts on congestion, environment and safety have to be addressed.

As soon as freight crosses the city borderline it is considered as urban freight, even if the transport flow has its origin outside the urban area or within other urban areas. Despite it being a relevant support of the economic life in these areas, it is often found that urban freight operations play a secondary role in city planning priorities, while much more attention is paid to freight transport at an interurban level.

However, urban freight flows occupy about one fourth of the street traffic of a typical city (Comendador, et al., 2012) and require loading and unloading operations, storage/conditioning and packaging, demanding an even greater use of urban space, then suggesting the need to adjust the priority given to urban freight transport.

All these movements and dynamics are a result of logistics decisions, i.e. of the processes required to organize the movement of goods in an efficient manner within the goods production system. These decisions are based on the demands of the production and distribution sectors, while dependent on economic agents' behaviours. It is these interactions that give a complex structure to urban mobility of goods and turn the development of an efficient and sustainable urban freight system a challenging task.

This difficulty in managing the urban goods system, the lack of attention given to this component of the transport system plus the expansion of urban areas and accompanying growth of their populations create, in the transport network, a set of issues associated with freight like congestion, $CO^2$ emissions and local pollution as well as societal issues. For the above reasons, cities' supply systems have to be reorganized. It is this interest in restructuring goods flows within urban areas that is commonly referred to as City Logistics.

Despite the vast set of solutions to mitigate city logistics problems, the main issue relates to the need to alleviate those while ensuring that the efficiency of deliveries is maintained. Therefore, the ultimate solutions should, at the same time, be able to ally efficiency with sustainability, crossing the interests of all stakeholders involved in the process. While private entities (such as transport companies) aim at maximising the efficiency of freight transport, with little regard for a sustainable operation, public entities aim at ensuring that the operation respects environmental standards and minimizes conflicts with the already built environment (whether it is traffic, conflicts between pedestrians and vehicles or illegal parking).

Transferability of city logistics mitigation strategies from city to city is hardly attainable. Here, the development of each strategy has to be done with consideration for:

- Current established freight dynamics (delivery patterns and existing legislation and stakeholders);

- The degree of involvement of public entities (past, current and future studies) as well as decision power;
- Stakeholders preferences and willingness to cooperate in reorganization plans for freight;
- Stakeholders' viewpoint on different logistics activity mitigation strategies.

The need for that amount of information suggests that the study of mitigation solutions for urban logistics has then to be done at city level, in a case study type framework where, ultimately, the success of a freight strategy will depend on how smoothly it can integrate itself in the built environment.

## 1.2 OBJECTIVES

Framed in the field of city logistics, the main goal of this work is to evaluate the degree of implementation and adequacy of a specific solution to the City Centre of Glasgow, through public entities standpoint, and its capability to alleviate city logistics associated issues in the study area.

To that end, the study will firstly attempt to bespeak the presence of public entities in the field of city logistics and acknowledge their importance in the development of any strategy that aims at mitigating freight activity (and transport in general) in urban centres. By recognizing their importance, and through an exhaustive review of literature, this work also aims at gathering current practices in the field, applicable through public entities standpoint.

Furthermore, the work will aim at making an informed selection of a specific logistics activity mitigation strategy for Glasgow City Centre. To support that decision, a review of past projects developed at European level as well as best practices regarding the solution will be made and an understanding of freight dynamics featured in the study area will be performed through fieldwork with stakeholders' consultation.

Crossing the information collected from the city with the review of literature on the solution to be implemented, the development of a mathematical model will aim at checking the feasibility of the selected solution within the study area.

Finally, this work intends to allow a comparison between the current solutions available for the city centre in terms of deliveries and the model output for the suggested mitigation solution as well as provide an input on work that still needs to be carried out in order to best accomplish the main stated goal.

The checklist below resumes the goals to be met throughout the development of this work.

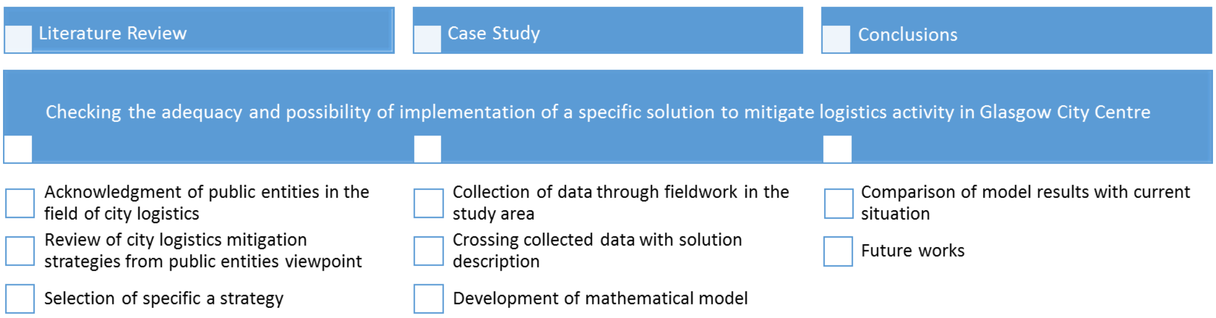


*Figure 1.1 – Objectives checklist*

## 1.3 METHODOLOGY

The methodology used throughout the present work had, on its basis, the following structure:

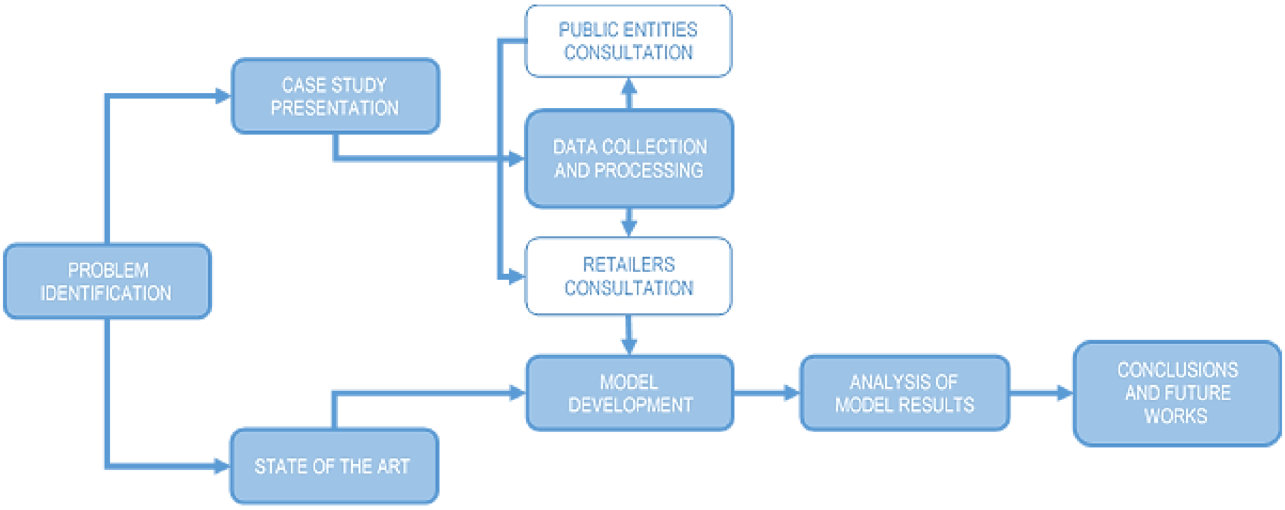


*Figure 1.2 - Structure of dissertation works*

(1) Identifying the problem at hand and the necessary knowledge and tools to solve it;
(2) Review and analysis of literature on concepts and models applied to city logistics mitigation strategies and modelling for that effect through the vision of public entities;
(3) Presentation of the case study and acknowledgement of the identified problems' existence in the study area;
(4) Data collection based on retailers consultation by surveying those stakeholders in the case study city and public entities consultation mainly based on research of projects and already implemented measures by these entities in the study area;
(5) Development of a model, making use of Xpress software by FICO, in order to test the validity of the thesis as a solver for the initially identified problem with reproduction of the study area's dynamics;
(6) Analysis of the model results, testing the thesis validity, the model's handicaps and the needed accompanying solutions to support an eventual thesis validation;
(7) Conclusions and guidelines for future studies.

## 1.4 WORK STRUCTURE

The present work is divided in seven chapters.  The first and present chapter contains the introduction to the dissertation in course with a justification for theme choice, problem definition, the objectives of the work being carried out and the methodology to be adopted in order to achieve them.

The second and the third chapters result from literature review where the theoretical principles that support the dissertation are presented in all the topics to be covered in order to perform the envisaged work. Chapter 2 covers city logistics definitions and domains, its current state and existing mitigation strategies for its activity while chapter 3 focuses on a review of modelling techniques for city logistics until model choice.

The fourth, fifth and sixth chapters are entirely dedicated to the case study. Chapter 4 introduces the case study and delivers a geographic, economic, transport-wise characterization of the study area. It also provides a framework of the city in the topic being developed. Chapter 5 includes the procedure for information gathering and analysis (survey assembly and results processing and analysis) as well as the review of a specific study made for Glasgow in 2010 regarding the solution to be implemented. Chapter 6 is devoted to model presentation and analysis.

Finally, chapter 7 presents the conclusions made throughout the work course and makes reference to future works needed if wanting to continue to explore the theme.

# 2 STATE OF THE ART: CITY LOGISTICS

## 2.1 CITY LOGISTICS DEFINITIONS AND DOMAINS

Logistics can be defined as the part of the supply chain that relates to planning, implementing and controlling the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption, in order to meet customers' requirements (CSCMP, 2014).

Similarly, City Logistics can be described as the process for totally optimising the logistics and transport activities by private companies with the support of advanced information systems in urban areas while considering traffic environment, its congestion, safety and energy savings within the framework of a market economy (Witkowski & Kiba-Janiak, 2014)

According to (Muñuzuri, et al., 2005), City Logistics can also be described as a term used to designate the specific logistics concepts and practices involved in deliveries in congested urban areas and the "last mile" transport, with specific problems such as delays caused by congestion, lack of parking spaces, close interaction with other road users, etc.

Dablanc, 2007 stated that City Logistics can be defined as the attempt to reorganize goods flows within urban areas in the interest of sustainability by restructuring cities' supply systems, justifying this need with the negative effects that come with urban goods transport due to the expansion of urban areas and growth of their populations.

This way, when considering City Logistics, not only as to be taken into account the means over which freight distribution can be arranged in urban areas but also the strategies that can be put into action in order to improve its overall efficiency while mitigating congestion and environmental externalities that come with this activity.

Hence, City Logistics should ideally conciliate the efficient distribution of goods with the promotion of innovative schemes for the reduction of the operations' total cost, including economic, social and environmental costs, with the ultimate objective of reducing the clash between the interests of logistics companies and those of other stakeholder groups involved in urban mobility. It can then be stated that City Logistics deals, mainly, with three different domains: supply chain, transportation network and traffic (and their interactions) where urban goods is common entity in all three domains (Quak & van Duin, 2007)

## 2.2 STAKEHOLDERS INVOLVED IN CITY LOGISTICS

As a mainly private activity, City Logistics tends towards focusing on the interests of both the final consumer and the logistic provider, action that creates externalities that normally have to be regulated by local authorities. This way, City Logistics represents a complex activity, involving the interests of more than one actor, connecting a group of stakeholders with very different interests.

The social system created by different stakeholders acts under several forces which, often, not only reactively but proactively and with vigorous goal orientation, end up conflicting. To be simultaneously satisfied, this multiplicity of interests produces one of the biggest challenges in logistics activity in urban areas where analysis and selection of implementable measures has to consider such interests and find an optimal compromise between them.

### 2.2.1 STAKEHOLDERS: TASKS, GOALS AND INTERACTIONS

Each stakeholder in City Logistics is then an agent in a multi-agent system where each of them has certain goals to achieve and certain rules to follow. On this note, several actors (i.e. agents) can be directly or indirectly considered in the transportation of urban goods (Russo & Comi, 2010)

- **Shippers** (or Wholesalers), who send goods to other entities and receive goods from them, tending to maximize their levels of service in terms of cost and reliability of transport. Their main interest consists of picking-up and delivering goods at the lowest possible cost while meeting customers' needs;
- **Freight Carriers/Logistics Providers**, who are in charge of delivering goods to customers and whose main interest is a low-cost but high-quality transport operation, satisfying both the interests of the shipper and the receiver. These players also have to contend with waste management;
- **Receivers** (Shop Owners if considering retail activity), whose main interest relates to having products delivered at a shot lead-time, ensuring their reliable availability to end-consumers;
- **End-Consumers**, who are the people that live, work and shop in the city and, by suffering from nuisances resulting from urban freight movements near residential and retail areas have, as main interest, to minimise the counter productivity caused by goods transport while benefiting from efficient and reliable delivery;
- **Public Entities/City Administrators**, who attempt to enhance the economic development of the city while putting effort into reducing congestion and environmental nuisances and increasing safety of road traffic. In order to do so, they are in charge of resolving the conflicts between the other stakeholders, having to consider the urban transportation system as a whole.

The course of logistics activity in a certain urban depends on the interaction between the stakeholders presented above. On the one hand, city administrators affect planning procedures by applying legislation to the establishment of delivery patterns. On the other hand, they are in charge of collecting mass data on traffic dynamics, which are a valuable source for more efficient and reliable planning of pick-up and delivery tours.

By assuming that the main goal of logistic providers is a constant growth in profit, a desire for reduction in transportation costs is implicit as well as an increase in the amount of sales, while keeping in mind that retailers (and subsequently residents) and shippers correspond to customers of their service, who expect it to be economic and reliable. Similarly, the prime objective of shippers can also be mentioned as a growth in profit, implying a reduction of the total cost of their operations. These costs consist of opportunity, manufacturing or purchasing and logistics costs (which encompass inventory, transportation and information processing costs) (Ehmke, 2012). As for residents, with the prime goal of providing them a good living environment, it is necessary to reduce the negative impact that comes with traffic, which mainly relates to vehicle emissions.

In order to fully understand the dynamics of logistics in urban areas, it is then necessary to understand how these stakeholders interact, their degrees of understanding and their dependence upon each other. Shortly, if freight carriers deliver late for time windows, shippers charge delay penalty and increase the delay penalty for the subsequent delivery. Simultaneously, trucks performing deliveries release emissions which, when brought to a limit, generate complaints from residents to city administrators who intervene through the introduction of access restrictions, time frames, noise and emissions related regulations, etc. These regulations go back to affecting freight carriers who are forced to revisit their delivery schedule.

As seen to this point, the state of logistics in a certain urban area is the result of the made stands and initiatives from both private and public entities, along with their interactions and coexistence of interests. Since private entities have their main goals on optimization of deliveries and reduction of costs, the assurance of social, economic and environmental standards regarding the field of city logistics falls under the attention of public entities who are then in charge of safeguarding those interests.

It is this task that blends the field of city logistics with urban planning, implying the need to look at freight activity in cities from a larger perspective, one that does not stick to supply chain management but, instead, inserts it in a more complex context, bringing together the diversity of aspects with need for consideration and making a study from public entities' point of view a challenging task, one that will be carried throughout this study.

### 2.2.2 PUBLIC ENTITIES: ROLES AND STRUGGLES

Looking at the concept associated with City Logistics, local authority can then be seen as the player with the most important role in the city logistics system. They are the ones striving to ensure high living standards in the city in the social, economic and environmental fields. They should then be the initiators, motivators and coordinators of logistics solutions in order to improve the movement of people and goods within the city (Witkowski & Kiba-Janiak, 2014).

The following table presents the main goals of local governments for social, economic and environmental high-quality insurance, categorized in their fields of intervention regarding City Logistics.

*Table 2.1 - Local authorities' decisions categorization in the field of city logistics*

| | **Goals of local governments in the field of City Logistics** | | |
|---|---|---|---|
| | *Social (Quality of Life)* | *Economics* | *Environment* |
| **Goods flow (including waste)** | Citizens' safety; citizens' education about waste segregation | Cost reduction | Reduction of $CO_2$, NOx emissions, noise reduction, waste segregation |
| **People flow** | Citizens' education in order to improve their movement within the city by collective transport | Cost reduction of collective transport | Changing citizens' transportation behaviour into the use of collective transport instead of a car |
| **Information flow** | Current information about congestion, Closed roads in the city, etc. | Long term cost reduction of data gathering and analysis | Current information about $CO_2$ emissions |

However, the little influence of local governments on the basic drivers of freight flows can be seen as the main problem these entities deal with regarding their intervention on the field of City Logistics, while local communities have to bear many of the externalities related to this activity.

It happens that local authority' policies have, in general, limited effect on local impacts since supply chains are a difficult target for local policy efforts and due to the fact that these policies do not affect the underlying demand for freight movements (an example of this are producers who, being often located far away from city centres, have freight travelling long distances through multiple jurisdictions. Local authorities can impose parking regulations but the regulation of demand is out of their reach, making the implemented policies ultimately not as effective as intended).

Because of the interdependencies within a chain, policies to address a problem created by one part of the chain affect other links. Control delivery hours, for example, affect the upstream operations of warehouses and the downstream operations of receivers. Essentially, "the complexity and flexibility of supply chains make the outcomes of policy interventions uncertain" (Giuliano & Dablanc, 2013)

Also, local authorities are vulnerable to the fragmentation of local governance, especially in large metropolitan areas where freight problems are more severe and, at the same time, where these areas are under the jurisdiction of multiple government units (sometimes from multiple cities) such as public transit operators, port authorities and planning agencies.

Nonetheless, Local Government intervention is essential in order to regulate freight activity within urban areas, where environmental and operating standards and goals are set and have to be met and guidelines and rules are needed. Congestion, air pollution, noise, safety and intrusion are taken as the most important negative impacts of freight traffic within these areas and are seen as the key drivers of policy necessity.

For most cities, the current freight policies seem to struggle to measure up to the important changes constantly taking place in the production, distribution and consumption sectors. Space dedicated to logistic activities is disappearing from cities (mainly due to the fact that there are other activities that provide bigger profitability to urban space and are then considered as prioritary for choosing a city centre location), and few municipalities are promoting the development of new modern logistic areas (Ville, et al., 2013). It happens that the large majority of cities have not yet found proper solutions to potentiate the optimization of the urban movement of goods, since it seems that all entities involved are expecting initiatives to come from the other side. On the one hand, city governments expect businesses to set up new logistic services fit to emerging needs of the customers and retailers. On the other hand, logistic providers keep expecting city administrations to initiate and subsidize new services before starting a business, which could end up being poorly profitable and high risk.

## 2.3 CITY LOGISTICS CURRENT STATE

### 2.3.1 THE URBAN FREIGHT PROBLEM

It has to be taken into account that the concept of City Logistics emerges from the need to solve the growing problem of freight transport densification in urban areas. Due, on its majority, to the expansion of these areas and the growth of their populations, urban goods transport has a significant contribution to negative effects like congestion, $CO_2$ emissions and local pollution (including noise). Also, globalization has increased freight flows due to the growing distribution of production across multiple locations around the world, rather than remaining local. This, combined with customers' increasing demand for a wide variety of products and retailers' inclination to stock less inventory, leads to the need for more frequent deliveries for replenishment of inventory. Moreover, the decentralization of logistics facilities, resulting on storage and distribution centres being moved to the periphery in response to high land costs within the city, produces the need for freight to be moved into the city to reach its end consumers. Finally, with the growing popularity of e-commerce, substantial amounts of freight movements can be allocated to direct trips to individual homes rather than in bulk to store locations. (Transportation Research Board, 2013)

Taken together, this increase in freight movements has led to congestion, parking and circulation problems in cities as well as a range of other externalities, as referred above. As an example, goods transport is responsible for about 30% of NOx emissions and almost half of particulate emissions resulting from urban transport (Ville, et al., 2013). Also, several European countries are threatened by a significant increase in the level of congestion in the next few decades whose forecasts show that freight transport activity will have increased by 40% by 2030 and just over 80% by 2050, at a considerably higher rate than passenger traffic, according to the European Commission.

Ultimately, the high density of freight flows, frequent deliveries, inefficient use of trucks, poor routing, improper/unauthorized (un)loading and high emission vehicles are a primary reason for poor accessibility, congestion and air and noise pollution in cities, being handled with difficulty by public authorities (Dablanc, 2007).

Also, road capacity within cities is limited, as are the number of parking spaces and loading facilities where each of these resources have, on top of its limitations, to compete with passenger flows.

Therefore, City Logistics plays an increasingly important role in many of these cities where, despite increasing difficulties associated with the movement of goods and people, efforts towards urban logistics remain insufficient. There then is a constant need to restructure cities' supply systems in the interest of sustainability, reorganizing goods flows in urban areas.

Nonetheless, the freight sector is a major source of jobs and freight transport represents an essential link between goods supply and demand. Therefore, it is worth reminding that solutions envisioning the mitigation of freight transport in urban areas have to respect and prioritize its efficiency as much as solving the impacts of its activity in cities. According to Hicks,1997, the problem lies on the difficulty in discovering and effectively implementing measures which will reduce the total social cost of goods movement to the lowest possible, remaining adequate with the freight requirements and objectives of society. The challenge is then to find the best way to accommodate freight and other critical urban functions.

To that intent, it becomes important to recognize the multiplicity of urban freight relatable problems, which fall in a diversity of categories, described in Table 2.2. It is this variety that adds complexity to the problem-solving strategies that can be implemented by local authorities in urban areas and creates the need to fully identify the visible problems in each city.

The table below then identifies the general problems associated with freight transport activity and bespeaks the array of domains where these problems appear in (Muñuzuri, et al., 2005).

*Table 2.2 – Problems associated with freight transport in urban areas*

<table>
<tr><th colspan="5">Problem Domain</th></tr>
<tr><th>Efficiency</th><th>Relational</th><th>Road Safety</th><th>Environment</th><th>Urban Structure</th></tr>
<tr><td rowspan="3">Poorly loaded vehicles leading to excessive trips and thus, congestion</td><td>Lack of influence of local authorities on freight flows</td><td rowspan="7">Passenger/freight conflicts – accidents involving freight vehicles</td><td rowspan="2">Growing demand for reverse logistics flows (waste and recycling)</td><td>Capacity of urban freight systems (leading to congestion)</td></tr>
<tr><td>Improper/unauthorized loading</td><td>Distribution sprawl leading to space consumption</td></tr>
<tr><td>Complexity of supply chains makes policy implementation difficult</td><td rowspan="2">$CO^2$ emissions from freight vehicles</td><td>Contribution of intense freight activity for devitalisation of city centres</td></tr>
<tr><td rowspan="2">Lack of know-how on sustainable freight movements organization</td><td>Fragmentation of local governance: freight activity under the jurisdiction of multiple government units</td><td>Degradation of levels of service due to high volumes of freight traffic</td></tr>
<tr><td>Lack of awareness of the impacts of urban freight transport from private entities – focus on efficiency and profit</td><td rowspan="2">Traffic noise</td><td>Lack of space dedicated to logistic activities inside city centres (Decentralization of logistics facilities)</td></tr>
<tr><td rowspan="2">Scarce and outdated freight activity mitigation policies</td><td rowspan="2">Dichotomy between the efficiency of freight transport and the sustainability of urban areas</td><td>Road capacity limitations within cities</td></tr>
<tr><td>Use of high-emission vehicles for freight distribution</td><td>Limited loading facilities and parking spaces within cities</td></tr>
</table>

This categorization allows the identification of different fields of intervention and, therefore, the possibility of recognizing accountable entities for each problem and group them for strategy formulation.

**Efficiency** issues are generally associated with private entities, namely transport companies and their delivery schemes' organization (poor routing and poorly loaded vehicles). However, their lack of efficiency can also come associated with lack of intervention and know-how from public entities, making it difficult to adapt delivery schemes to unhelpful and outdated regulation.

As for **relational** issues, problems mainly appear from lack of communication and consensus between the public and the private sector: regulation is not respected due to lack of associated penalties and supply chain activities and freight demands are, on the one hand, difficult to control by city administration and, on the other hand, difficult to be transmitted by transport companies. The existent individuality in logistics related decisions makes it difficult to implement a strategy that respects the interests of all involved stakeholders where finding a compromise is key for solving these issues.

**Road safety** issues involving freight vehicles can never be fully mitigated but naturally tend to increase with superior densities of freight flows within urban centres. They can thus be reduced via mitigation of logistics activity, either from implementation of regulation by public entities or better coordination/optimization of deliveries by private entities (through loading optimization of vehicles and reduction of freight trips).

As seen before, **environmental** issues account for a considerable part of freight related problems due to the use of high-emissions vehicles associated with the growing demand for various flows involving freight (e-commerce, reverse logistics and decentralization of logistics platforms). Public entities are then responsible for setting up legislation to incentive (or even oblige) the use of more environmentally-friendly solutions and restrict access to certain zones by high emission vehicles.

Finally, **urban structure** issues relate to problems that come with the processing of freight dynamics within a built environment (streets, location of facilities, disposition of locations to serve, traffic, parking, etc.). Both public and private entities are accountable for these issues; public entities intervene through regulation and traffic restrictions whereas private entities can do so through the development of schemes that allow them to perform delivery tours with less vehicles.

### 2.3.2 REVIEW OF CITY LOGISTICS MITIGATION STRATEGIES

With the intent of solving the mentioned issues and as referred before, local government plays the main role in ensuring that the sustainability of urban functions also takes freight into account, subject that only recently has been identified as an essential element in urban transport planning and policy and, therefore, still lacks a solid strategy for mitigating the impacts that come with this activity for most cities.

The identification of freight mitigation strategies is an essential step when attempting to build an effective and efficient strategy for mitigating logistics activity in urban areas and highly variable from city to city, limiting the ability to develop a fully transferable strategy, applicable to every urban area.

However, a background consultation and analysis of best practices has to be undertaken in order to understand to what extent the current practices under the City Logistics' domain can be applicable to solve the conflicts identified in a certain city.

On this note, and as seen in (Russo & Comi, 2010), according to (BESTUFS, 2006), measures to improve the flows of products in urban areas can be divided in three main classes: *Goods vehicle access and loading approaches* (efficient usage of infrastructure, guidance on measures for goods vehicles access and loading in urban areas, technology in urban freight, etc.), *issues involved in last mile solutions* and *issues associated with urban consolidation centres.* On different approaches, measures can be classified according to a temporal scale, into *strategic*, *tactical* and *operative* measures (Russo & Rindone, 2007) or even as *restrictive, pricing* or *permissive measures* (City Ports, 2005).

Differently, the City Ports project, conducted at a European level, also proposes a classification of urban freight related measures, dividing them in *material infrastructure* (which includes measures that relate to alterations in links of the transport network or to areas that can be dedicated to freight operations), *immaterial infrastructure* (Intelligent Transport Systems: for traffic information, freight capacity exchange, route optimisation, vehicle maintenance management, etc.), *equipment* (measures on loading units or transport units) and *governance* (traffic regulations like access times, heavy vehicle networks, road-pricing, parking times, etc.).

Closer to this last classification, urban freight policies can be divided into *freight traffic regulation* (access, parking, loading and unloading regulations), *physical infrastructure* (links or nodes of the urban transport network), *Intelligent Transport Systems* and *loading units and vehicles* (standards for loading units and environmentally friendly transport solutions).

After analysing some of the classifications on measures for city logistics activity mitigation proposed on the reviewed literature, it was decided to formulate a new classification that could allow to differentiate policies into the ones that express physical and direct changes to the transport network (to facilitate the circulation of vehicles, reduce its impacts and control its intensity inside urban areas), the ones that relate to technology innovation (in order to improve the efficiency of deliveries and to provide the transport system with more environmentally friendly transport solutions) and the ones that, through regulation, can shape delivery approaches into more sustainable solutions (implying the need to rethink delivery strategies).

This proposed classification was made to highlight the involvement of public entities in the range of available freight activity mitigation policies for urban areas, evincing the need for their presence in the development of a broader strategy, especially involving network related solutions and enforcement solutions.

Network related solutions are, in general, initiated by public entities, envisioning not the direct mitigation of freight activity, but the facilitation of more efficient delivery schemes (thus with positive impacts on the transport network), by providing infrastructure for freight activity: building of logistics platforms closer to final destinations, enabling the use of public transport dedicated infrastructure and providing conditions for more efficient loading and unloading operations.

Differently, with enforcement policies, logistics companies are required to shape their delivery schemes to the imposed legislation, with direct impacts on sustainability indicators like traffic, air pollution, noise and conflict levels.

The table below shows the already referred categories as well as the range of practices belonging to each of them (Muñuzuri, et al., 2005).

*Table 2.3 – Overview of policies applicable to urban freight transport mitigation*

| **Overview of policies applicable to urban freight transport mitigation** | | |
|---|---|---|
| ***Network*** | ***Technology*** | ***Enforcement*** |
| Route bans for freight vehicles | Low-emission vehicles (or electric) | Establishment of maximum parking times |
| Dedicated zones for loading and unloading operations | Traffic information systems | Incentives for policy adoption |
| Heavy vehicles' dedicated sub-network | Route Optimisation systems | Time windows for deliveries |
| | Electronic Toll Collection (ETC) | Low Emission Zones (LEZ) |

| | | |
|---|---|---|
| Logistics facilities close to/inside urban areas | Logistic information system (in-company or between companies) | Vehicle regulations (according to sizes or emissions) |
| - | Freight Capacity Exchange Systems | Road pricing |

This group of measures sums up what has already been done for improving urban logistics activity across Europe. The implementation of a set of these policies has proven to require taking into account all the involved stakeholders' point of view (Rooijen & Quak, 2014). This need justifies the existence of Freight Quality Partnerships, FQP, which promote constructive local solutions that bring together the need for access to goods and services and local economic, environmental and social concerns, aiming to develop an understanding of freight, delivery and servicing issues (Filippi, et al., 2010). An FQP is typically composed by a set of transport operators and local authorities coming together to deal with freight related matters, being regarded as a best practice by the UK's Department of Transport.

It is important to reinforce that the application of policies on the transport network, as well as enforcement policies, are under the control of public entities, whereas technology improvement, as well as design and implementation of information can come from both public and private initiatives. Due to the nature of this work, special focus on public policies for mitigating logistics activity in urban areas is then given at this point.

On that note, it is relevant to tell apart public from private initiatives. As seen before, private companies (retail, wholesale or transport companies) are the ones carrying out urban freight transport whereas public entities are responsible for the regulation and facilitation of this activity. Private measures are the ones carried out by the private sector. This type of measures can be part of an urban freight transport policy, especially when public measures are taken to support them (like voluntary-cooperation).

(Oliveira, et al., 2012) highlighted that the increased congestion due to the growing circulation of goods in urban areas relates to the current production and distribution model, based on low inventories and just-in-time deliveries, as well as explosive growth of e-commerce, which generates significant volumes of home deliveries. Because governments treat urban freight distribution as a mainly private activity, public authorities promote few policies on this matter, variously involving regulation of parking, road access and time windows for loading and unloading, among others.

Many of these local authorities consider job creation and regional competitiveness to be more important than logistics concerns, so that improving the efficiency of transport systems is sometimes seen as less important in the decision of public officials, who definitely have to be the ones behind its mostly needed regulation (Oliveira, et al., 2012).

It thus becomes important to single-handedly explore the solutions that are within the reach of local authorities and understand the extent to which they can be conciliated with the simultaneously wanted efficiency of deliveries and local competitiveness of the freight sector.

### 2.3.3 PUBLIC POLICIES FOR CITY LOGISTICS

The set of solutions applicable by public entities to solve urban freight transport related problems can also have different fields of intervention. Firstly, it is important to distinct them between specific and combined solutions (Muñuzuri, et al., 2005) where the first ones are addressed to specific problems or requisites whereas the others are generated by the combination of several specific solutions, composing a strategic policy for logistics in the city.

Furthermore, specific solutions can then be parted in different categories, according to their field of intervention (Muñuzuri, et al., 2005), as can be seen on the following table:

*Table 2.4 – Classification of urban freight solutions for application by local authorities*

| Land Use Management | Public Infrastructure | Access Conditions | Vehicles | Traffic Management |
|---|---|---|---|---|
| Load zone provision | Urban distribution centres | Access according to weight and volume | Emission standards (through Low Emission Zones) | Differentiated parking charges |
| | | Access to pedestrian zones | | |
| Parking space planning | Outskirts logistic centres | Road pricing | Fuel taxes | Street classification |
| | | Night deliveries | | Carrier classification |
| Load/unload interfaces | Use of the tram/underground system | Rotation in load zones | Subsidies for low-emission trucks | Freight zone classification |
| | | Loading time | | |
| Hub areas | Use of rail/ship terminals | Access time windows | Minimal load-factors | Subsidizing intermodal transport |

Linking the above table with Table 2.3. land use management and public infrastructure can fit the broader category of *network* related policies, the same way access conditions, vehicles and traffic management related solutions can fit in the *enforcement* category, with the help of *technology* related interventions as a means to implement them (in road pricing, for example).

The utilization of kerbside parking spaces for **load zone provision** (zones dedicated to serve delivery vehicles for loading and unloading goods in dense urban areas) is nowadays a widespread policy, present in most cities around the world. However, the constant finding for spaces to serve this purpose is always useful due to the growing intensity of freight activity in urban areas. Building regulations can be used to reorganize parking spaces, and have therefore a direct effect upon urban freight delivery operations.

As for **parking space planning**, it seeks the reduction of the number of existing parking spaces in a certain urban area, by eliminating kerbside parking places without compensating with new parking lots. Although apparently contrary to economic development, this solution is suitable for very congested areas, where pollution and double parking constitute a severe problem. It is oriented to improving general traffic conditions rather than logistics itself, but its reorganization implies a reduction in the congestion levels in the area, which improves the freight delivery scenario.

**Load and unload interfaces** are one of the main causes behind the problems in city logistics due to the lack of specific infrastructure that facilitates the access and parking of freight vehicles as well as the loading, unloading and delivery of goods. An access for goods' deliveries different from the one used by customers allows the carrier to unload goods more efficiently and without disturbing shop activity.

As for **hub areas**, it proposes the introduction of areas with reserved parking spaces for vans and trucks, where the vehicles would stay parked while all the deliveries for the area are made on foot or by using a handcart or some alternative vehicle.

**Urban distribution centres** are small freight transport centres meant to be located inside the urban area or on its periphery and are normally based on road transport, serving the purpose of improving load factors in delivery vehicles, through the transference, inside the terminal, from larger trucks to smaller vans (with or without consolidation of cargo), which then cover last mile transport. On the other hand, **outskirts logistic centres** play a role in interurban transport but can, at the same time, be considered as part of the urban logistics chain, aiming to minimize costs or maximize levels of service.

The **use of the tram or underground system** consists of using dedicated trains or cars included in passenger trains, to carry goods. This system would be especially interesting when applied to goods that required urgent movements or that would have a sufficiently continuous flow as to benefit by these high capacity modes. However, the implementation of this measure presupposes the achievement of economies of scale in order to pay for the extra transhipments. The **use of rail or ship terminals** implies the adaptation of these infrastructures to city terminals, independently of the goods having arrived on a train or boat or not, or the possibility of receiving or sending goods on trains from intermodal freight terminals.

**Access** to some streets/areas can be constrained by **weight and volume**, establishing a criteria that determines the type of vehicles that are allowed to access each zone of the city according to their weight, size or load factor. This type of policy is initially aimed at avoiding traffic problems by allowing access only to vehicles with an adequate size for the streets of the city.

The **access to pedestrian zones** is necessary, within the scenario of city logistics, to allow, under certain conditions, the access of freight vehicles to pedestrian areas. These conditions include free access during the night, access according to time windows and use of special vehicles (silent, electric, for example) for access to these areas during commercial hours or the determination of certain types of goods whose vehicles are allowed in the pedestrian area.

Furthermore, and still regarding solutions related to access conditions, **road pricing** intends to internalize the external costs generated by traffic congestion by charging vehicles for entering certain areas of the city, typically on those where road and parking space are scarce, ideally generating the reallocation of mobility towards public transport.

**Night deliveries** avoid the interference with peak hour congestion, taking freight deliveries out of a time window where passenger traffic is strongly instituted. However, this solution generates some opposition from residents due to noise and pollution issues and from retailers since night deliveries present a higher costs of staff that have to be paid for after-hours shifts.

Furthermore, providing adequate **rotation in load zones** by limiting time of stay, seeks to improve the efficient use of load zones by freight carriers, avoiding excessively long stays in the zone, guaranteeing its use as close to optimal as possible.

**Loading time** regulations restrict the time at which vehicles can stop at the kerbside for loading and unloading activities, having to balance the needs to the use of space for loading and unloading and for other activities such as parking (Timms, 2010).

**Access time windows** is one of the most recurrent city logistics public policies and consists of establishing time intervals exclusively during which freight delivery vehicles are allowed entrance in certain parts of the city.

There is also a set of public policies like setting **emission standards** (typically through the implementation of **low emission zones, LEZ**), applying **fuel taxes** and providing private companies with **subsidies for low-emission trucks** that can be implemented in order to incentivize logistic providers to alter their vehicle fleets or at least incorporate more sustainable solutions for last mile transport. Also, by setting **minimum load factors** for freight vehicles, public entities force logistic providers to rethink their deliveries' scheme in order to attain higher load factors and thus reduce the number of vehicles needed, ideally through cooperation with other logistic providers, performing joint deliveries.

Finally, traffic management policies are also within the reach of local administrators. By setting **differentiated parking charges**, public entities can somehow orientate freight flows in certain directions and, by either **street**, **carrier** or **freight zone classification**, charge different values to freight vehicles for its loading/unloading operations, internalizing some of the external costs from this activity while controlling affluence to certain zones. Streets are normally classified based on criteria like width, traffic conditions, proximity to commercial or business areas, parking availability, etc., ending up with classifications like: access, restricted access, load/unload, non-freight and pedestrian streets. Similarly, different types of carriers normally present different delivery times, number of deliveries, etc., suggesting classifications such as: full truckload carriers, one delivery per vehicle, high/low-weight items and deliveries to small premises. Moreover, the division of freight zones into classes is normally applied to the whole city, typically according to economic patterns and transport needs (that related to these economic patterns), while the affectation of different types of problems should still allow having homogenous regulations as a permanent objective.

Finally, the **subsidization of intermodal transport** envisions the reduction of freight traffic on road networks, exporting part of this activity to other modes of transport. By providing efficient nodes (as port or rail terminals or even logistic centres on the periphery of the urban area) or improving transport networks in a way that freight transport is possible through tram or underground could mitigate some of the impacts on road traffic due to freight.

Nearly all these policies have generated both successful and failed implementation cases due to diversified factors that cannot be standardized per reason, location or funding. Every urban area presents itself as a single case study and as to be approached as so.

One of the policies that has been explored for the past years, attempting to make a still very conceptual comeback for solving city logistics' problems are urban distribution centres. As a concept that attempts the relocation of logistics platforms to the inside (or periphery) of the urban area with the goal of improving load factors in freight vehicles and performing deliveries with smaller and more environmentally friendly vehicles, this is a solution that, when rightly explored, can come to solve many of the problems associated with city logistics.

Simultaneously, it represents an interesting solution since it has to conciliate the efforts of both private and public entities, working together to present a solution that is both sustainable and effective: private entities make the compromise of adjusting their delivery schemes while public authority facilitates regulation for freight movements associated with the distribution centre, implying the need for accompanying measures and incentives coming from local authority for successful (as thus profitable) implementation of the centre. More than that, it demands a commitment from all the involved stakeholders, where retailers have to be on board with having their goods come through the logistics platform prior to delivery to their establishments.

For all the above reasons, the implementation of urban distribution centres as a core solution for freight activity mitigation in a certain urban area represents a complex strategy to be adopted, posing as an interesting approach in a study of this nature by allowing to explore, based on a central concept, the universality of policies fitting local authorities' range of action for city logistics as well as the broad group of constraints brought up by all involved stakeholders, only natural in a scheme of this magnitude.

Therefore, and still within the range of solutions applicable by public entities for city logistics, the present study, developed for Glasgow City Centre, will focus on the viability study of the implementation of an urban distribution centre serving that area, interesting not only for the already mentioned reasons but also due to the pioneering attitude of the UK Government towards this concept.

### 2.3.4 URBAN DISTRIBUTION CENTRES

An Urban Distribution Centre is a logistics facility located inside or relatively close to the urban area, intended to serve a city centre, an entire town or a specific site such as a shopping centre, airport, hospital or major construction site, where the goods destined to these locations are dropped off at the centre. Subsequently, centre operators sort and may or may not consolidate the goods (hence the difference between urban consolidation and distribution centres), making deliveries to the final destinations, often using environmentally-friendly vehicles (electric or gas-powered). (Browne, et al., 2011)

The cargo incorporation of different shippers and carriers in the same vehicles, associated with operational coordination in cities is nowadays seen as one of the main ways to mitigate the externalities caused by freight transportation in urban areas (Olsson & Woxenius, 2012) and, therefore, the concept of Urban Distribution Centres is seen as an important instrument among urban logistics initiatives.

This concept involves the separation of logistics activities inside and outside the city where consolidation is not always the best solution from the perspective of the city since supply chain operators optimize their deliveries at the flow of origin while, for the sake of the city as a whole, the optimization considering the destination should come first.

However, the distribution centre concept may have different meanings to different people, where one single definition for the concept under discussion is not provided. It is then perhaps appropriate to view this concept as a range of potential applications along a spectrum that depends upon the share of involvement (or control) between the public and private sector, with a range of terms that includes: *public distribution depot, central goods sorting point, urban transhipment centre, shared-user urban transhipment depot, freight platform, cooperative delivery system, consolidation centre, urban distribution centre, city logistics scheme, logistics centre, pick-up drop-off location or offsite logistics support concept*. (Browne, et al., 2005)

By improving the load factors of goods vehicles for last mile transport, urban distribution centres reduce the total distance travelled by freight vehicles inside urban areas, thus reducing greenhouse gas emissions and local air quality pollutants. Other social and environmental advantages can include noise reductions through the use of quitter vehicles, reduction of conflicts between freight vehicles and other road users and increased pedestrian safety (Browne, et al., 2011).

The goals of a specific distribution centre can vary, being either based on economic efficiency, social factors or both, based on achieving supply chain improvements or even aiming to bring greater consolidation of cargo destined for the urban area or to tranship these goods onto smaller, lighter, cleaner vehicles for final delivery (or both) (Browne, et al., 2005).

Generally speaking, an urban distribution centre can reduce the delivery time in congested areas as well as total fuel consumption and the number of vehicles for urban distribution operations and optimize retailers' stocks. However, and as referred by (van Duin, et al., 2010), retailers and carriers compliance is a crucial factor for a logistics initiative of this nature, since their participation will maximize its benefits and decrease many of the involved costs. BESTUFS (2008) pointed out that a synergistic network of urban distribution of goods is a key factor for the implementation of a successful urban distribution centre.

The following table describes the key advantages and disadvantages of the implementation of a distribution centre serving urban areas (Browne, et al., 2005).

*Table 2.5 – Key advantages and disadvantages of Urban Distribution Centres*

| Key Advantages | Key Disadvantages |
|---|---|
| Environmental and social benefits from efficient and less intrusive transport operations | Potentially high set up and operating costs |
| Better planning and implementation of logistics operations | Much urban freight is already consolidated, limiting the benefits of such a scheme and thus its potential scope |
| Better inventory control, product availability and customer service | Potentially difficult handling when there are different handling and storage requirements and when faced with wide ranges of goods moving in an out of an urban area |
| Facilitation of a switch from push to pull logistics through better control and visibility of the supply chain | The addition of an extra stage in the supply chain imposes cost and time penalties, increasing delivery costs, though depending on how well the centre is integrated in the supply chain |
| Potential to link with wider policy and regulatory initiatives | A single distribution centre for an urban area is unlikely to be attractive for many suppliers' flows due to the degree of diversion required from normal route |
| Conjectural cost benefits from contracting out "last mile" | Lack of enforcement of regulations for vehicles not included in the scheme |
| Public relations benefits for participants in the scheme | Organisational and contractual problems often limit effectiveness |
| Potential to make better use of resources at delivery locations | Potential for creation of monopolistic situations |
| Specific transport advantages | Loss of direct interface between suppliers and customers |
| Opportunity for carrying out value-added logistics | |

The logistics companies dropping off their load at the UDC benefit from not needing to enter a congested urban area, saving time and money. Similarly, those receiving goods from the UDC can benefit in terms of delivery reliability. In addition to potential consolidation and final delivery, a range of other value-added logistics and retail services can also be provided at the centre including off-site stockholding, consignment unpacking, preparation of products for display and price labelling, benefiting receivers by reducing their on-site space requirements, saving time on on-sit tasks and thus enhancing productivity and sales in core activities (Browne, et al., 2011).

For a successful approach to the implementation of an Urban Distribution Centre is it important to recognize the existence of past projects and practices in this domain, understanding similar patterns of freight, urban planning and potential application of similar processes, measuring the degree of transferability of these practices.

A considerable amount of Urban Consolidation Centre schemes can then be identified, where there is evidence of detailed research into the establishment of such schemes, or where trials or operations have taken place, mainly in European countries.

Especially in the United Kingdom, most of the early research and feasibility work was undertaken by local authorities in the 1970s while, since then and until 2000, a decrease of interest in the UCC concept was observed. Since 2000, there has been another period of interest in this concept, both from policy makers thinking about the role they could play in more sustainable urban distribution practices and also in terms of UCCs trials and operational schemes that have been established (Browne, et al., 2005).

A report on Urban Consolidation Centres (Browne, et al., 2005), developed at the University of Westminster for the Department of Transport, summed up the significant European interventions regarding this concept where surveys and data collection activities were undertaken in several countries and cities and a significant amount of research created the possibility of identifying success and failure factors regarding the implementation of city distribution centres, using both literature, reference projects and consultation of experts., where the major findings of that study are described below for multiple locations across Europe.

In *Leiden*, the implementation of an Urban Consolidation Centre failed due to lack of profitability resulting from a disappointing number of parcels handled in the distribution centre, explained by the shortage of participants, strong opposition of transport companies claiming an attempt of monopoly creation as well as retailers' lack of proneness. As for *Nijmegen*, the UCC scheme is still in test phase where local subsidies pay for the service and a courier bike and a van deliver the goods to the shops, from a UCC located at the business area near the city centre. In this case, the provision of subsidies and the offering of value-added services are important elements for success as is the provision of ways to cope with different goals and views through continuous monitoring of attitude of the involved parties, potentiating the increase of participating shopkeepers (Browne, et al., 2005).

In *Bristol*, the UCC is operated by a logistic provider, DHL, selected by the municipality based on local procurement. Here, suppliers can deliver their goods 24/7 to the UCC and DHL bundles these goods and delivers them to the shops with 100% on-time deliveries. No accompanying policies have been implemented by the municipality. As for *Kassel*, the implementation of a UCC was a private transport companies' initiative, where ten of these decided to cooperate, mainly in order to improve their environmentally friendly image. During the first years, the scheme was subsidized by the municipality and pedestrian only zones were introduced in the city centre as an incentive for cooperation (Browne, et al., 2005).

In *La Rochelle*, around 30% of deliveries to the city centre are handled by the UCC, with distribution via electric vehicles. Subsidies are provided by the local government for the infrastructure and a fixed amount per package. Also, the existence of time-window management encourages companies to drop off their goods at the UCC as well as the eradication of high loading-capacity vehicles, expect for reduced time windows early in the morning. The success of this scheme is, firstly, due to shared awareness of freight activity impacts among stakeholders and their involvement at a very early stage of the process, plus encouraging provision of municipal funds (Browne, et al., 2005).

The UCC in *Malaga* is a building from cross-docking in the outskirts of the historical centre, where the municipality promoted the initiative and a private urban transport organisation manages the activities based on distributors' participation. As an accompanying measure, the municipality established a pedestrian zone that only vehicles coming from the UCC can access (Browne, et al., 2005).

It then seems that the number of users is a crucial factor in all success and failure cases, very much dependent on how the organisation of the UDC is setup. The fact that a UDC is privately organised can possibly explain success as does the provision of public subsidies. The selection of the right type of distribution vehicle should meet the unique requirements for the situation and therefore be determined for every scheme individually.

The location of the UDC is also a determinant factor for its success, as emphasised by (Browne, et al., 2005). Well-chosen accompanying measures (such as limited access conditions, both physical and time related) can, to a certain extent, potentiate users' attraction to the UDC scheme.

From public entities point of view, the most attractive attributes of the implementation of an urban distribution centre relate to financial subsidies, decrease of congestion, GHG emissions, noise and visual pollution, recognizing the UDC concept as a solution to reduce the number of cargo vehicles in cities. Therefore, the support of these entities is essential for implementation of such scheme.

As for retailers, participation in a UDC can provide them with an interesting trade-off between unavoidable increases in operating costs and improvements in profitability from increases in display space and decreases in costs from a more reliable and faster service. It is indeed the net analysis of this trade-off that culminates in compliance (or not) to this system.

For transport companies, the literature suggests that the use of a UDC can potentially result in substantial transport benefits, including reductions in the number of vehicle trips and kilometres, potential reduction of the number of drop-off locations, better vehicle and driver utilisation for suppliers (due to quicker turnarounds), improvements in volume/weight utilisation and fewer vehicles required in the urban area to be served by the UDC.

However, organisational and contractual problems seem to arise as major supply chain barriers, as does the desire for companies to maintain competitive advantage rather than sharing expertise and systems. Also, problems related to loss of control sensed by shippers are highlighted (Lindholm, 2012). As a result, more "commercial" schemes have started to be thought and developed, paying more attention to potential supply chain benefits, as a result of greater effort being devoted to integrating the centres into the supply chain. Nevertheless, the impacts are generally only identified towards the end of the supply chain, with little attention being paid to what happens further upstream.

It then seems that there is a considerable lack of awareness of the potential opportunities of a UDC if they were to be established in the right manner and in the right situations, which appears to result from the pre-conceived idea that this system means additional costs and little else. In addition, there is the commonly misconception that there is only one model for a UDC, which is untrue. UDCs need to be customised to the requirements of the locality and the clients they serve.

On a case study framework like this, the study of the possibility of implementation of a scheme of this nature to a specific location becomes interesting. By going beyond traffic regulation measures, this is a policy that involves more than compliance with public authority, involving all stakeholders in a broader sense by taking its individual goals into a strategy that ideally accommodates efficiency and sustainability, demanding the challenging task of guaranteeing the successful integration of an extra step in the supply chain.

# 3 STATE OF THE ART: MODELLING FOR CITY LOGISTICS

## 3.1 THE NEED TO MODEL FOR POLICY IMPLEMENTATION

Passenger transport has been investigated quite thoroughly inside urban areas but a gap in knowledge is perceived in what concerns freight transport in those same areas (van Duin, et al., 2012).

Before the 1990s, modelling of urban goods movements was typically based on both transport and facility costs but a later shift towards policy-oriented modelling took place (van Duin, et al., 2012). In City Logistics models, the general approach is to first estimate commodities or trucks' origins and destinations, followed by vehicle routing calculations for establishing optimal routes for the required goods and destinations. Finally, the influences of traffic conditions are considered in traffic calculation and a final output of parameters is generated.

Differently, policy-oriented modelling tries to understand urban truck movement under the influence of various government policies and adds the policy instruments to the city logistics models, introducing a component of respect for social impacts. A recent generation of models extends this kind of modelling approach with dynamic interactions or negotiation between agents, allowing the study of the dynamic behaviour of actors, reacting on policies, to observe and analyse the effects on sustainability and economic/social impacts (van Duin, et al., 2012)

To this end, it is important to understand that urban goods movement is a means in itself and not an end. On the one hand, goods movements are affected by different parameters like infrastructure conditions and industry structure while, on the other hand, it also affects parameters (i.e. congestion, accessibility, pollution, etc.). This cause-effect dynamic is also interdependent, meaning that more congestion leads to a less efficient movement of goods and vice versa.

While city administrators are not the central decision-making authority for the city logistics domain, they do affect stakeholders' decision-making by applying policy measures (Anand, et al., 2012). Therefore, and in contrast with private stakeholders, public entities are interested in achieving the overall objective of reducing the total social cost (Ogden, 1992). It is this interest that clarifies why most urban freight modelling efforts are directed from an administrative point of view and mostly without considering behaviour or attributes of other stakeholders.

This heterogeneity of stakeholders involved in City Logistics and their diversity of interests and distribution of decision-making processes adds complexity and unpredictability to this domain. It is this complexity that demands a well-designed approach for policy analysis which is impossible to be achieved with traditional modelling techniques due to their restrictive hypothesis. This way, multi-agent modelling for city logistics policy analysis has to focus on understanding the structures under which urban freight movements play out and how to measure their effects in order to determine effective policy measures for City Logistics (Anand, et al., 2012) so as to explore its potential to accurately replicate the urban freight movement by mapping complexity of domain, time and discipline all together.

## 3.2 REVIEW OF EXISTING MODELLING TECHNIQUES

Recent modelling efforts come to understand the importance of including other stakeholders in that process. According to (Anand, et al., 2012), a model by Holguín-Veras (2000) suggests a framework for "integrative market simulation" that considers producer, carrier, customer and government for urban freight analysis. Crainic et al. (2004) presents a model for efficient planning of urban freight distribution while reducing its impact on environment. Models by Visser *et al*. (1997), Kanaroglou *et al*. (2008) and Muñuzuri *et al*. (2010) emphasise the reduction of environmental externalities caused by urban freight transportation. A model by Young *et al*. (1983) focuses on efficient planning of infrastructure for efficiently dividing traffic between rail and road. Similarly, Crainic *et al.*, (2004) discusses the location problem for city distribution centres.

Ogden (1992) suggests that many of the modelling approaches consider traffic and commodity flows as descriptors of the activities and interactions among stakeholders due to the widespread use of the "four step model" as a modelling strategy. Land use and location are also important descriptors as interest in developing better freight facilities grow and more freight related traffic is generated (Anand, et al., 2012).

Another important aspect when considering a modelling approach to a specific urban freight system is having a certain modelling perspective i.e. a meticulous way to represent pre-selected aspects of a system. On this note, urban freight systems can be viewed from different perspectives, depending on the user, the purpose of modelling and the means available to achieve those goals, being essential to understand what different strategic viewpoints are available and how effective they are to achieve the objective at hand. Four widely used perspectives in urban freight modelling can be found: planner, technology, behaviour and policy. Some of the most recent research efforts enable the consideration of a fifth perspective: multiple actors' perspective (Anand, et al., 2012). From a **planner's perspective**, due to limited space and the high costs of infrastructure expansion, proper planning becomes essential, dealing with the organization of freight flows by efficient use of current and proposed infrastructure and services. On a **technology's perspective**, GIS based dynamic information systems allow users to choose the least congested path, saving travel time. This perspective mainly focuses on the application of these technologies to optimize urban freight operations. From a **behavioural perspective**, there is an attempt to understand, describe and predict the behaviour under different situations. These models consider the complexity of attributes and the decision-making ability of the involved stakeholders (which cannot be captured in a traditional four-step approach). From a **policy perspective**, urban freight movement can be improved to more sustainable practices in several ways, either through company-driven changes where companies take measures to reduce the environmental and social impacts of their freight activities or through the implementation of measures by governing bodies (Anand, et al., 2012). Finally, a **multi-actors perspective** considers the multiplicity of stakeholders and their conflicting objectives in the urban freight system. This perspective considers the analysis of the interactions of autonomous stakeholders with a view to assessing their effects on the system as a whole.

In logistics, dominant objectives are, most of the times, costs and service level (e.g. transport time or product availability). Recently, literature and discussion orientate this activity beyond these economic purposes, where sustainability dimensions like 'social' and 'environmental' are becoming more important (Anand, et al., 2012), as referred before.

Taking into account the interest of this study in policy-related interventions for city logistics, it is noticeable that a variety of methodical approaches are identified as a solution for similar challenges due to different levels of importance (i.e. congestion, pollution, safety, etc.) appropriate to different countries. Additionally, these modelling efforts mostly focus on infrastructure optimization and traffic improvement rather than the actual movement of goods, making them poor predictors of city logistics scenarios. Thus, city logistics policy mostly follows a “learning by doing” approach with very limited or no use of modelling or scientific approach (Anand, et al., 2012).

As introduced above, a growing approach is to consider a system consisting of many different agents, known as multi-agent systems. It can be defined as a loosely coupled network of problem solvers that interact to solve problems that are beyond the individual capabilities or knowledge of each problem solver (Anand, et al., n.d.).These multiple agents interact to reach a common goal of goods' delivery from production unit to retailer shop. Interactions among different agents contain different mechanisms like negotiation, adaptive learning, cooperation and coordination. With different settings, scenarios and regulations, different business cases can be created and simulated for better representation of the city logistics evaluation process of urban freight policy (Anand, et al., 2012)

However, a multi-agent model for an urban area provides different information about decision processes even though characteristics of agents are the same. Thus, it is important to define the scope of the model which highly depends upon its goals and objectives (Anand, et al., n.d.). The model should then be an abstraction of reality to achieve the understanding of the different factors that affect it. Reporting to city logistics, it is important to define limits regarding the number and types of stakeholders involved, physical boundary to be modelled, time representation, negotiation, etc. Moreover, the urban freight domain involves stakeholders with potential irrational behaviour, subjective choices and complex psychology, which become difficult to quantify, calibrate and justify. This complicates the implementation and development of the model, as well as the interpretation of the simulation output.

Ultimately, this methodology intends to provide an approximation to the process that takes place in real life through different agents and high consideration for their individual behaviour and behavioural interaction.

As referred before, it is a goal of this study to explore Urban Distribution Centres as a solution for City Logistics related problems for a specific city. Therefore, it becomes essential to find an approach that enables the modelling of real life circumstances among the City Logistics dynamics in Glasgow City Centre, allowing to perform a viability study of a UDC's implementation as well as the creation of possible scenarios.

On that note, when considering modelling for Urban Distribution Centres, five types of agents can be considered in a multi-agent model (van Duin, et al., 2012): **freight carriers**, the **logistics platform (UDC)**, **trucks**, **retailers** and **roads**. The municipality is considered an agent through specification of its policies and collection of feedback information from the road network. There are also two types of *dummy agents*: the **streets** and **nodes**, which are needed for calculations at the model scale. The **trucks**, **roads** and **retailers** are *purely reactive agents* (i.e. they have no goals and only reply when asked) while de **UDC** and **freight carriers** are *objective function agents* (i.e. they strive for a goal). In these models, collaboration between shippers and freight carriers is assumed as perfect as they act as one single agent (the upstream part of the supply chain is resumed in this assumption). The featured agents behave purely rationally to financial and/or added value motives determined per specific stakeholder.

The interaction among stakeholders (agents in the model) is based on: **goods**, which have a *place of demand* (expressed through a two-dimensional coordinate system) and a *volume* (expressed through specific unit size(s)), **information**, which can be *travel speed information from roads to trucks*, *UDC fees* and *travel costs and time between two nodes*, in order to calculate optimal routes, **money** and **emissions.**

Goods are transferred between trucks and freight carriers, UDC terminals or retailers. Information is transferred between roads and streets, freight carriers' terminals, UDC terminals and trucks. Nodes transfer information to or from freight carriers' terminals, UDC terminals and roads. Finally, roads present information to the freight carriers' terminals. Money travels between trucks and freight carriers' terminals or the UDC terminal and between trucks and roads. Also, money flows between freight carriers' terminals and the UDC. Emissions are emitted by trucks and collected by the roads.

At this point, a model for a UDC scheme aims to investigate the service cost and subsidy of that same scheme, where a fee setting for the UDC can be dynamic or fixed at certain levels. Input parameters to the model relate to these service costs, plus congestion rates, access costs (typically in the form of toll to the city centre and generated as policy measure, subject to investigation), delivery scheme variations like early delivery scheme, fixed time delivery or full truck delivery scheme.

With the input data, the model should then be able to develop a generic algorithm for solving truck routing and variable demand locations (the retailers). Both elements will cause variability in the output. This output is then recorded in the number of UDC deliveries, delivery costs for freight carriers and the UDC, kilometre count, emissions and the UDC financial performance.

## 3.3 MODEL CHOICE

Ultimately, the goal of modelling for urban distribution centres lies in defining a framework for properly optimizing, in a sustainable way (by assuming economically-viable, eco-friendly and socially-accepted solutions) the implementation of the platform serving a certain urban area.

With environmental issues becoming more and more important and new purchase channels as e-business modifying profiles of carrier customers, different organizations and services are implied. The setting up of an urban distribution centre can offer several possibilities as the use of electric vehicles (whose limited autonomy prevents from travelling long distances) or scheduling several successive deliveries or collection routes.

Though the performance of distribution centres can be analysed on different criteria, no model seems to allow quantifying, a priori, the effect of locating the centre at a given position. In this particular case study, adopting a model that allows this specific approach becomes interesting as a first step into evaluating the potential implementation of an urban distribution centre in Glasgow.

Being difficult to quantify acceptability from all the involved stakeholders, an approach of this nature could be able to estimate the easiness with which the centre could merge with the already built environment and its existing dynamics (freight in particular) estimating, indirectly, the viability of its integration among a consolidated urban area.

Also, taking into account the existing knowledge of some of Glasgow City Centre dynamics and preferences regarding deliveries, the integration and respect for this component in the model would allow to quantity the difficulty in having a UDC as a viable solution to solve urban logistics problems in the city centre.

To that intent, the selected approach – *Mathematical Programming Modelling and Resolution of the Location-Routing Problem in Urban Logistics* – suggested by (Muñoz-Villamizar, et al., 2014) considers the problem of locating urban distribution centres and proposes an exact method, based on integer linear programming, for strategic (choosing to set up a UDC), tactical (defining the UDC's size and location) and operational (delivery routes of vehicles assigned to the UDC) decision-making. It then aims to solve, in an integer manner, location, sizing and operation (vehicle routing) problems in the logistics platform.

In order to implement this design and operational methodology for UDCs, these three decision levels can then be integrated in a Location Routing Problem (LRP) – handling, integrally, the location of facilities within a set of potential spots and the design of routes between customers assigned to them. This allows to estimate the capacity or size of the facility and, if necessary, of the vehicles.

According to (Muñoz-Villamizar, et al., 2014), the development of an of an exact method to determine the location, size and operation of an Urban Distribution Centre could serve as an important tool for decision making which, when applied to real situations in cities wiling to develop these logistics platforms, could improve the competitiveness of the logistics system and its environmental and social conditions.

# 4 CASE STUDY: THE CITY OF GLASGOW

## 4.1 GEOGRAPHY AND ECONOMY

With a population of around 600,000, Glasgow is the largest city in Scotland and the fourth largest in the United Kingdom. Also, it is the commercial capital of Scotland and UK's largest retail centre after London. Glasgow is one of Europe's top 20 financial centres and is home to many Scotland's leading businesses. Despite the average 600,000 people living in Glasgow City Council area, around 2.3 million people live in the travel-to-work area of Glasgow (Glasgow Guide, 2008).

Glasgow grew from a small rural settlement on the River Clyde only to become one of the largest seaports in the United Kingdom. After World War I, with relative economic decline and rapid de-industrialization, there were active attempts at regeneration of the city, being set out a series of initiatives aimed at turning round that decline. This led to a big and radical programme of rebuilding and regeneration efforts that started in the mid-1950s and lasted into the late 1970s. Here, the city inclusively invested big on road infrastructure, with an extensive system of arterial roads and motorways that bisected the central area (Glasgow Guide, 2008).

By the late 1980s, there had been a significant resurgence in Glasgow's economic fortunes with initiatives that facilitated Glasgow's new role as a European centre for business services and finance and promoted an increase in tourism and inward investment. This economic revival persisted and ongoing regeneration of inner-city areas led to more affluent people moving back to live in the centre of Glasgow (Glasgow Guide, 2008).

## 4.2 THE CITY CENTRE

The city centre is bounded by the High Street to the east, the River Clyde to the south and the M8 motorway to the west and north. It is based on a grid system of streets on the north bank of the river, having its heart in George Square. The main shopping grounds feature Argyle Street, Sauchiehall Street and Buchanan Street, with more upmarket retail activity in that last one. Also, Buchanan Galleries and St. Enoch Centre constitute the main shopping centres in Glasgow city centre. The denoted intense retail activity places Glasgow as UK's second largest and most economically important retail sector after London Central, self-explaining the wide interest in the study of city logistics for this area.

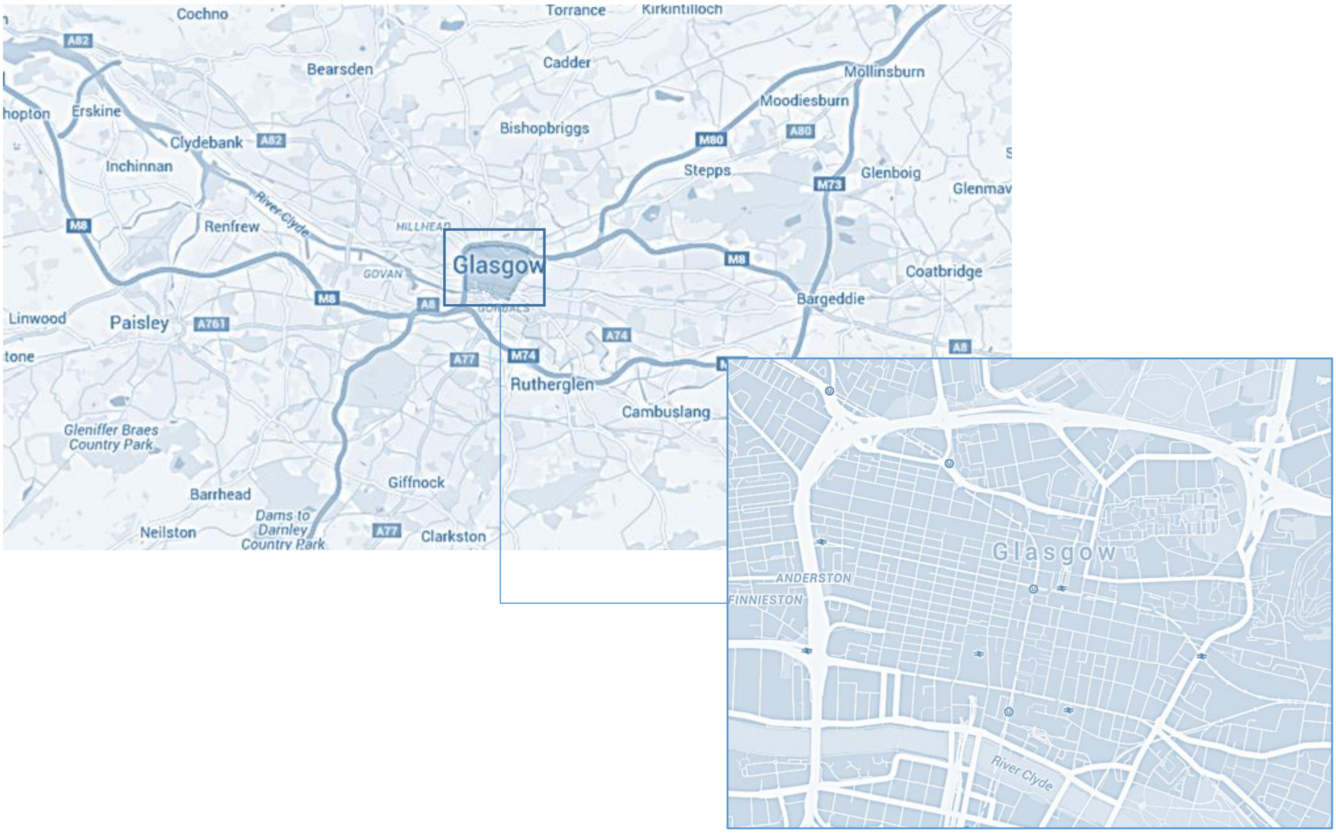


*Figure 4.1 – Glasgow City Centre*

In 2011, Glasgow made a strong statement of intent about the city's future, a vision of what the Council, partners and the people of Glasgow would wish for the city to be in the next fifty years. Here, the Council would commit to promoting active and sustainable travel as part of a healthy lifestyle through greater use of walking, cycling and public transport. To this end, the city centre has been declared as an Air Quality Management Area (AQMA) since 2004. The AQMA covers both $NO_2$ and $PM_{10}$ pollutants closely linked to transport (Appendix 1).

In November 2013, Glasgow City Council launched a City Centre Strategy aimed at tackling the centre's economic, planning, environmental and traffic issues where a Transport Strategy represented a vital share of the overall strategy. This strategy would come to cover the entire city centre area, with the boundaries referred above.

### 4.2.1 TRANSPORT ACTIVITY

The city centre is constantly changing and evolving as land-use developments are taken forward and economic activity generates turnover in existing land-uses. This changes the needs for transport, as the demand to travel to different parts of the city, disregarding purpose, may increase or decrease accordingly. Understanding the likely impacts of the major land-use development proposals is therefore critical to developing a transport strategy.

The effective and efficient movement of people, goods and vehicles of all forms to, from and within Glasgow City Centre is crucial for the economic, social and environmental well-being of the city, region and Scotland as a whole.

As is it recognized by public and private leaders, it is also vital that the attractiveness to private sector investment is maintained and enhanced for the benefit of the economy. As such, connectivity must be enhanced (both real and virtual) for the benefit of businesses and the city's people, with transport playing its part in contributing to Glasgow's continued economic vibrancy.

### 4.2.2 FREIGHT TRANSPORT ISSUES AND RELATED POLICIES

Taking into account the recognition of the need to involve transport for the success of a wider city development strategy, a series of objectives are set in Glasgow's *City Development Plan*:

- Supporting of better connectivity by public transport;
- Discouraging non-essential car journeys;
- Encouraging opportunities for active travel;
- Reducing pollution and other negative effects associated with vehicular traffic;
- Optimising the sustainable use of the transport infrastructure and supporting economic development.

These goals represent a dimension of transport that goes beyond freight but where freight activity consideration is essential for general success of a transport strategy. Freight movements play an important role on a city's economic development due to their strict relation with commercial activities. At the same time, a sustainable use of the transport infrastructure has to consider the significant presence of freight related traffic and subsequent impacts, with special focus on congestion and negative environmental effects. A transport strategy that accounts for freight is also on the right path for the reduction of vehicle journeys and the more efficient operation of other components of the transport system, namely public transport.

Glasgow City Centre currently faces a number of transport related problems which current strategies seek to address, identified through extensive consultation and analysis. Keeping in mind this study's dedicated interest in freight activity in urban areas, only freight relatable issues (Sustrans, 2014) are referred below:

- **Air Quality Issues**: poor air quality from high traffic flows make streets like Hope Street, Renfield Street and Union Street unattractive to pedestrians;
- **One-way System**: there is a complicated and confusing network of one-way streets that make getting around and across the city centre difficult, especially for those unfamiliar with the area;
- **Serving & Deliveries**: the city centre has a high dependency on deliveries to operate but, in some areas, difficulties assessing premises by goods vehicles can cause problems and lead to illegal parking and thus, congestion and pedestrian issues;
- **Peak Period Demand**: many key streets into and out of the city centre experience high levels of traffic during the morning and evening rush hours, as well as some key through routes in the city centre;
- **Loading activities**: which, generating a lot of **illegal parking**, disrupt the flow of traffic, causing **congestion**.

As part of the Regional Transport Strategy (RTS) for the west of Scotland, a Freight Action Plan was created by SPT (Strathclyde Partnership for Transport) to set out key issues, objectives and recommendations for freight transportation in the SPT area. The vision is to *"develop and maintain a safe, efficient and integrated sustainable freight transport system which supports the economy whilst taking account of the environment and improving quality of life in the region"*. The main goals of this strategy are then to:

- Maximise the efficient use of the existing transport infrastructure and services balancing freight and passenger requirements in order to support the region's economy;
- Identify opportunities for new infrastructure to improve overall connectivity;
- Support the development of intermodal hubs and connections to those hubs in order to improve accessibility and support the competiveness of the freight industry;
- Reduce the impact of congestion on freight transport;
- Take account of the inter-relationship between land-use planning strategies and freight transport;
- Encourage the transfer of freight from road to more sustainable modes such as rail and water;
- Review curfew restrictions and develop a best-practice guide for night-time delivery in sensitive areas;
- Review current delivery/collection arrangements in town centres and identify the opportunities for revising loading restrictions, and providing inset and kerbside loading bay and off-street delivery areas to achieve appropriate delivery/collection locations for all premises;
- **Study the opportunity of introducing consolidation centres and their financial viability;**
- Study the need to provide daytime parking areas and overnight parking areas and facilities for freight drivers in Strathclyde and identify suitable locations;
- Review signage to direct hauliers onto the most appropriate routes;
- Review the opportunity for increased use of cleaner fuelled vehicles.

Of course that this vision is somehow extended past the Glasgow City Centre area, being set to meet issues for the whole SPT influence area. However, there are some interesting concepts that can be transposed and applied to a strategy on a more local level, with special interest in urban distribution centres to be potentially located on the periphery (or even inside) of the city centre, dealing with both inbound and outbound traffic and thus being affected by larger network scale issues.

Glasgow City Centre Transport Strategy 2014-2024, as well as the Local Transport Strategy developed by Glasgow City Council, already forebodes key actions to better transport activity in the city centre:

- Restrict traffic access to Gordon Street between Renfield Street and West Nile Street;
- Investigate the implementation of a 20mph zone in the city centre;
- Undertake a review of loading and servicing facilities;
- Undertake a strategic review of parking facilities;
- Consider ways to introduce Low Emission Zones within an emerging national framework;
- Develop accessible loading/unloading facilities for freight;
- Provide safe access arrangements to pedestrian precincts;
- Improve enforcement of illegal parking in loading bays;
- Assist in the expansion of intermodal freight development;
- Review time restrictions giving access to pedestrian areas;
- Develop a signing strategy for freight movements to avoid residential or sub-standard routes;
- Encourage provision of suitable overnight lorry parking facilities;
- Produce maps showing key access information for freight companies;
- Direct development with high freight demand to locations with good quality links to the motorway/expressway;
- Insist on a Freight Quality Partnership;

Alongside these action points, proposals for more significant transport schemes such as urban distribution centres will have a major impact on the accessibility of various parts of the city centre as well as probably leading to some major transport routes shifting to new corridors. Understanding how these relate to existing and future demand to travel is crucial.

The recent awareness for freight related issues and the importance of mitigating them is denoted in SPT's intention of developing freight strategies for the timeframe of 2014 to 2017. In these 3 years, SPT is aiming to undertake a multi-modal freight study to gather appropriate regional and local data to improve transport planning for freight, identify local and regional barriers to more efficient freight movements and establish realistic opportunities to reduce these barriers.

As seen before, there is nowadays a wide range of policies that can be implemented to mitigate logistics activity in urban areas. The implementation of some of them is already visible in Glasgow City Centre while others are featured in the city's future plans for freight transport, aiming the establishment of a healthy framework within defined goals for Glasgow's sustainability, liveability and efficiency on the short, medium and long-term.

### 4.2.3 RETAIL ACTIVITY IN THE CITY CENTRE

The city centre has, over a considerable period, maintained a consistently high quality, range and choice of retailing, largely important to tourism and the wider Glasgow economy, supporting approximately 15,000 jobs. Substantial retail investment over the last fifteen years (approximately 140,000 square metres) has played a large part in sustaining Glasgow's position as UK's second largest retail centre. Factors such as growing car ownership and use, congestion and changing patterns of retail investment are altering the geographical pattern of retail expenditure in the West of Scotland.

The vitality of the city centre's retail activity is enhanced by the concentration of large-scale retail investment into a defined area, known as Principal Retail Area (PRA) focused on an almost 'Z' pattern formed by Sauchiehall Street, Buchanan Street and Argyle Street and definitely dominated by Buchanan Street. This area was defined in accordance with public transport accessibility and parking supply, concentration of retail outlets and quality of shopping environment. This provides consumers with easy and convenient access to a wide range of retail outlets and generates high levels of foot-fall and volumes of retail trade.

Moreover, a number of streets can be identified as having a retail function mostly concentrated in terms of prime rentals, Class 1 retail use (shops and retail outlets; prime retail function), the incidence of department and multiple stores and the extent of window frontage display space. These are:

- **Tier 1 Primary Retail Streets:** Sauchiehall Street, Buchanan Street, Gordon Street (east of Renfield Street) and Argyle Street (east of Renfield Street);
- **Tier 2 Primary Retail Streets:** Union Street, Queen Street and Ingram Street.

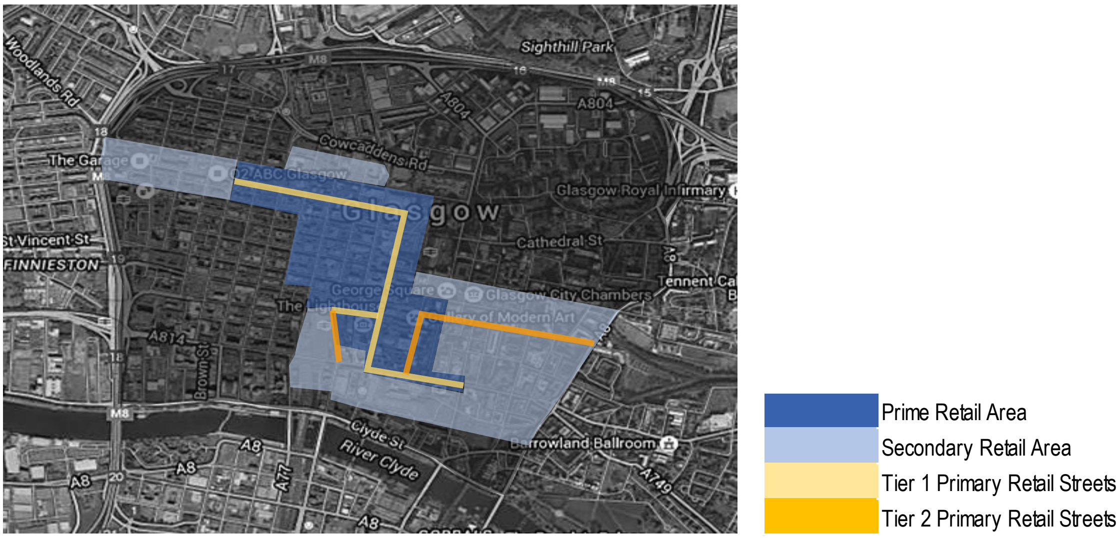


*Figure 4.2 – Retail areas in Glasgow City Centre*

The vitality of the city centre is also enhanced by local shops, especially those associated with the residential adjacent areas or linked to the Primary Retail Area. As a result, streets such as Trongate, Saltmarket, High Street and Cambridge Street all play a useful part in providing an extended retail street network.

Retail is then the major representative of Glasgow commercial activity and accounts for a large, if not main, part of freight movements inside the city centre. Due to the magnitude of this activity, it becomes interesting to have the study of city logistics revolve around this market where policies implemented within this context will account for effective mitigation of many of the impacts arising from goods distribution in the city centre.

Also, taking into account that this study spins around analysing the viability of a UDC scheme implementation as an alleviator of freight activity in the city centre, retail activity becomes the most attractive market element when thinking about the most likely entities to be attracted to a solution of this nature and how the adherence of a major slice of the commercial activity to a UDC scheme would be crucial for any chance at its implementation success.

### 4.2.4 LOGISTIC PATTERNS

Congestion, access restrictions, illegal parking and poor signing have been nationally identified as key problems facing companies and their drivers in delivering goods. Glasgow operates a wide variation in timescale restrictions for freight loading. On the radial route into the city centre, a peak hour time restriction is operated, while in the city centre itself restrictions apply during the working day.

Yellow marks on the kerb or at the edge of the road indicate that loading or unloading is prohibited at the times shown on vertical signage.

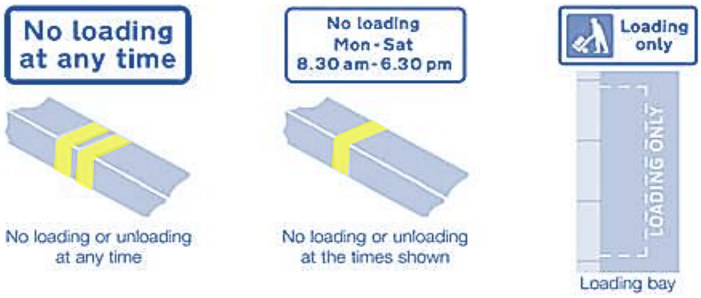


*Figure 4.3 – Loading/ unloading legislation in Glasgow City Centre*

Another policy that is well implemented in Glasgow city centre are the regulations of deliveries in time, regulated by specific time windows. As main retail street in Glasgow, Buchanan Street is classified as a pedestrian street where deliveries can only take place from 6 to 10am, having the street to be clear of traffic by that time. Cars are banned from Sauchiehall Street, Argyle Street and Buchanan Street where deliveries made to those streets have to respect the defined time windows.

Mostly because of those restrictions, when surveying retailers in streets like Ingram Street and Queen Street, some stated that early deliveries were prioritized to the above mentioned PRA streets, sometimes leading to delays on deliveries to secondary retail streets.

Access restrictions seem to be the most noted conflict between retailers and logistic providers. This is seen by far as the most common methods to discourage city centre deliveries at peak time, thus reducing congestion. On the other hand, smaller companies tend to attract deliveries direct from the supplier to the shop (Steer Davies Gleave, 2010)

It was also noticed that dispatches (mostly including inter-store transfers, old stock, slow selling stock, recycling and faulty goods) from stores were generally infrequent, at most once or twice a week and nearly all retailers would put them onto the morning delivery vehicle (Steer Davies Gleave, 2010).

The majority of deliveries for large and medium sized retailers start down south and are transported to Glasgow via either the companies' Scottish distribution centre or logistic providers' warehouse (Steer Davies Gleave, 2010).

As seen above, air quality and emissions control are big issues for policy makers in Glasgow, where work is constantly being carried out to develop air quality measures, with significant emphasis here to Low Emission Zones (LEZ). A measure of this nature (meaning an implicit access restriction) might be one of the ideal drivers for UDC in Glasgow.

In fact, back in 2007, Glasgow City Council contracted Hyder Consulting to undertake a study to look at options to reduce air pollution from road traffic in the city, which compared three different scenarios:

- The introduction of a LEZ;
- A 10% reduction in the number of HGVs (including buses) on the roads;
- A 50% reduction in the number of HGVs (including buses) on the roads.

Where the result of the exercise revealed that a LEZ would be the more effective option in bringing about a reduction in $NO_2$.

# 5 CASE STUDY: RETAILERS' CONSULTATION

## 5.1 INITIAL APPROACH

After defining the interest in exploring the viability of implementation of an urban distribution centre for retailers in Glasgow, the need for extensive information on inner dynamics of retail activity in the centre as well as retailers pre-disposition for embracing a scheme of this nature (highly dependent on their view of the logistics state) was crucial at this point of study of this potential solution.

The contact opportunity with Glasgow's freight related dynamics allowed the identification of three entities whose authority is relevant when dealing with both traffic and commercial issues:

- **Strathclyde Partnership for Transport (SPT)**: Regional transport partnership for the west of Scotland, created as part of the transport framework by the Scottish Government and being one of the seven regional transport partnership with Transport Scotland, the national transport agency. SPT has, as main roles, the planning and delivering of transport solutions for all modes across the region and the analysis of all travel need as well as the present and future development of the transport system. SPT is also a committed Community Planning partner and works with others to support the activities of Community Planning partnerships at a local level.
- **Glasgow City Council**: Entity responsible for policy development and ultimate implementation. The council operated its service delivery programme against a defined set of policies and strategies. In conformation with legislative aspects, the Council maintains as awareness and an input into broader aspects of policy-making in public services and community development, often partnering with Government, other public bodies and the private sector.
- **Glasgow Chamber of Commerce**: "The voice of business in Glasgow", the Chamber offers their members business solutions, cost savings and opportunities to expand networks and reach, by investing in training and workforce development, offering international trade support and developing affinity schemes and business solutions to help businesses become more successful.

After gathering information among these entities' available online data, a study report requested by SPT in 2010 on stakeholders' consultation on the possibility of implementing a freight consolidation centre serving Glasgow was found online. The major findings are described in this study, mainly stating that back in 2010, retailers' view of an urban distribution centre serving Glasgow suggested that the idea was not appealing enough as well as not needed due to considerable satisfaction with their current deliveries schemes.

At this point, it became interesting to explore retailers' current views on this matter in order to find out if, five years later, potential changes to freight dynamics and satisfaction with delivery schemes could support the reconsideration of an urban distribution centre. Moreover, retailers' general rejection of such scheme would be, as highlighted on literature review, a definite deal breaker for its viability and thus, stakeholder consultation is a vital step for a study of this nature.

Also, a survey to Glasgow's retailers would allow the collection of quantitative data on freight dynamics in the city centre such as carried volumes and delivery patterns and preferences. It is this last piece of information that, alongside retailers' current view of an urban distribution centre, those will allow to model its implementation based on real data i.e., taking into account actual average volumes to be transported, approximate number of needed vehicles, driven kilometres and delivery preferences among retailers, respecting that a viability study of a UDC serving a city centre as to consider and respect real established freight dynamics.

The following figure illustrates the steps and their sequence on the adopted methodology for case study elaboration.

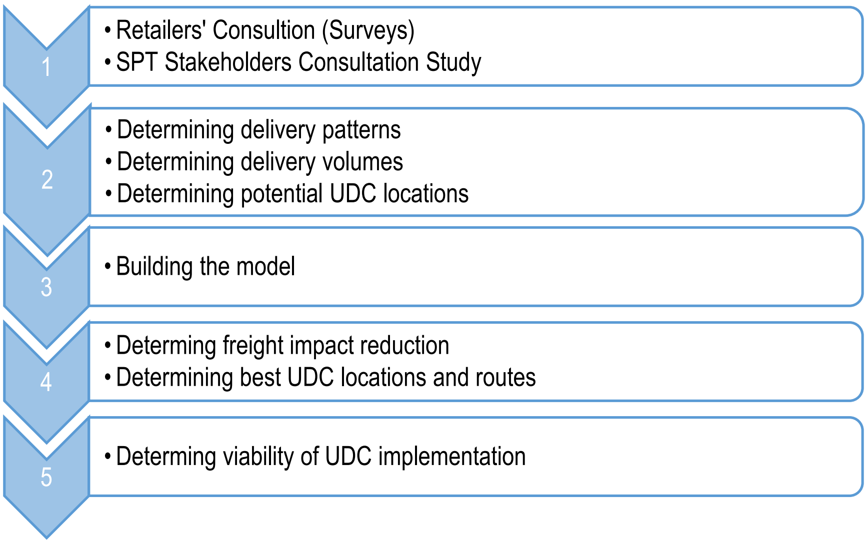


*Figure 5.1 – Methodology for case study elaboration*

Taking that last thought into account, it was decided that the best way to obtain information on delivery patterns and to probe retailers' pre-disposition for embracing a distribution centre serving their shops, would be to develop surveys to be completed by shop managers from the main retail streets in the city centre. Besides retailers' consultation, surveys' necessity was also due to the lack of available information on freight patterns in the city centre.

After survey completion, it became possible to address one of the members at SPT on the study made in 2010 about the viability of urban consolidation centres based on stakeholder consultation. At that meeting, the full study that originated the mentioned report was provided, allowing to make a more sustained and complete comparison between the feedback obtained back in 2010 and the survey results from 2014's research.

## 5.2 SAMPLE CHOICE

The set of stores qualifying as survey responders was too large of a universe to be surveyed by a single individual entity where an attempt to do so would only result in a statistically irrelevant sample and would be far from succeeding in being descriptive of the population in study.

Knowing that the potential implementation of an urban distribution centre would be, on an initial phase, merely experimental (as literature suggests it should, mainly due to funding issues), retailers that fall into a category of goods requiring special stocking characteristics would demand extra infrastructure costs for accommodating those needs and would then be difficult to fit in the system on a trial phase. Thus, on an initial approach, the universe formulation excludes:

- Shops that manage goods with temperature requirements, implying the need for infrastructure and vehicles that can provide those storage conditions
- Shops that deal with high-value goods, implying increased security in terms of infrastructure and vehicles (mainly jewellery)

Also, taking into account Glasgow City Centre dimensions, the implementation of a single urban distribution centre would not be enough to provide the system with efficiency on deliveries to every establishment. Therefore, focusing on a stricter area of the city centre would be initially more prudent. Knowing that commercial activity is more competitive on the Prime Retail Area (PRA) and that retailers on that area would be the ones that could firstly have an opinion on the benefits of a UDC, the survey scope was narrowed down to streets mainly belonging to the PRA.

It was also known that a project named **'The Style Mile'** was launched in August 2009 to ensure that Glasgow City Centre would maintain its position as a top retail and leisure destination in the UK. This project is a partnership between businesses and public sector agencies, coordinated by Glasgow Chamber of Commerce and Glasgow City Council to proactively deliver activities that promote retail and leisure in the city centre, aiming to drive footfall and enhance visitor experience.

Taking that project into consideration and knowing that most of the successful applications of UDC concepts were initiated based on a partnership of some sort between public and private entities, being representative of an orientation towards a common goal between stakeholders, the acknowledgement of this project in the study of an urban distribution centre could then be relevant when thinking of a partnership between projects: having an urban distribution centre dedicated to shops integrated in The Style Mile could enhance the possibility of finding common ground between retailers on a project that is managed by authorities that have the double interest of improving efficiency of commercial activity (Glasgow Chamber of Commerce) while providing more sustainable solutions in order to do so (Glasgow City Council).

Also, some of the shops integrated in The Style Mile are located inside shopping centres (both Buchanan Galleries and St Enoch Centre). Working on the assumption that these facilities organize their own delivery schemes within retailers belonging to each centre and can provide their own storage space outside shop areas, an urban distribution centre might not be, on a first instance, a scheme attractive enough when compared to their current conditions, when not dedicated strictly to the shopping centre.

Ultimately, by imposing some restrictive parameters to Glasgow retailers' universe, it is possible to reduce the scope of the survey to retailers that, simultaneously:

1. Currently integrate The Style Mile project
2. Do not manage goods requiring special storage and transport conditions
3. Have their shops located in the Prime Retail Area and adjacent relevant streets
4. Own high street shops

The table in Appendix 2 sums up the shops that respect the categorization described above.

The shops in the table above constitute a universe of **108** shops. The process of defining a sample size has to take into account logical levels of confidence and margins of error, ensuring that the surveyed sample is representative of general retailers' delivery patterns and vision of a UDC in Glasgow.

The table below displays the needed samples to respect reasonable choices of levels of confidence and margins of error.

*Table 5.1 – Samples choices for certain levels of confidence and margins of error*

| **Population Size** | **Confidence Level** | **Margin of error** | | | |
|---|---|---|---|---|---|
| | | 10% | 5% | 2% | 1% |
| **108** | 90% | 42 | 78 | 102 | 107 |
| | 95% | 52 | 85 | 104 | 107 |
| | 99% | 66 | 94 | 106 | 108 |

Also, taking into account that not all the elements of the selected sample will be willing to be surveyed, the sample size has to consider realistic response rates. Thus, the following table shows the number of retailers to be approached for theoretical response rates of 50% and 75%, set on a realistic view of the limitations of surveying with shortage of human resources.

*Table 5.2 – Sample choices considering hypothetical response rates*

| | | **Margin of error** | | | |
|---|---|---|---|---|---|
| **Confidence Level** | **Response Rate** | 10% | 5% | 2% | 1% |
| **90%** | 50% | 84 | 156 | 204 | 214 |
| | 75% | 56 | 104 | 136 | 143 |
| **95%** | 50% | 104 | 170 | 208 | 214 |
| | 75% | 69 | 113 | 139 | 143 |
| **99%** | 50% | 132 | 188 | 212 | 216 |
| | 75% | 88 | 125 | 141 | 144 |

Taking a confidence level of **95%** and a margin of error of **10%**, **69** retailers should be approached in order to obtain **52** responses for a response rate of **75%**.

Moreover, knowing that delivery patterns are somehow related to types of business, shops were placed into different categories, according to different types of retail activity in order to obtain answers that respect the proportions of each retail type in the city centre.

The table below displays the chosen categorization of shops and, based on the dimension of the population in study and the selected sample size, the number of retailers in each category that should be approached in order to obtain an approximation of real retail activity in the city centre.

*Table 5.3 – Shops' categorization and percentages to approach*

| Type of Shop | Population | Percentages (strata/population) | Sample |
|---|---|---|---|
| Clothing & Accessories | 51 | 47% | 25 |
| Sports | 9 | 8% | 4 |
| Culture & Leisure | 8 | 7% | 4 |
| Health & Beauty | 17 | 16% | 8 |
| Gifts & Souvenirs | 6 | 6% | 3 |
| Department Stores | 12 | 11% | 6 |
| Electronics | 5 | 5% | 2 |
| **TOTAL** | **108** | **100%** | **52** |

## 5.3 SURVEY STRUCTURE

The survey was then composed by six chapters (survey form in Appendix 3 to Appendix 9):

1. **Business/establishment characteristics**: business hours, type of business and ownership (or not) of warehouse space;
2. **General characteristics of deliveries**: number of suppliers, load factors of delivery vehicles and distance from vehicles' departure point;
3. **Specific characteristics of deliveries**: number of weekly deliveries, comparisons between a specific week (during Christmas) and a typical week, type of vehicles performing deliveries, time windows for delivery availability and satisfaction with deliveries scheme;
4. **Characteristics of the delivered goods:** size and amount per size of delivered goods, comparison between a specific week (during Christmas) and a typical week and online shopping services and volume of goods allocated to that service;
5. **Characteristics of loading and unloading operations:** identification of problems in loading/unloading operations;
6. **Urban distribution centres:** circumstances under which the integration in a UDC scheme would be accepted and priorities in the provision on that service.

The first five chapters aim at comprehending the delivery patterns to retailers in Glasgow and to what extent an urban distribution centre would fit those patterns and even come to solve some of the noticed problems among retailers. The last chapter tries to understand how receptive retailers would be of a UDC scheme, analysing which characteristics would be more appealing in its implementation and under which circumstances they would be willing to integrate it.

Ultimately, this survey would allow the modeller to analyse the outcome of an urban distribution centre's feasibility through collection of information like:

- Storage space requirements (according to volumes)
- Number of daily required vehicles to fit the delivery needs of retailers
- Preferable location of the UDC

- Preferable accompanying measures and incentives for participation
- Willingness to participate

The survey was carried out during three weeks: on the week before Christmas and on the first two weeks of January. Aiming to achieve higher response rates, the surveys were made on a "hand out and collection" basis, ideally approaching shop managers, explaining the aim of the survey and establishing a date to come back to the shop and pick it up.

Selecting a week during Christmas time was set to obtain a maximised number of deliveries and volumes for evaluating the most 'extreme' conditions for dimensioning the centre. Since part of the surveys were carried out in January, the answers were asked to be reported to that same week before Christmas, when applicable.

## 5.4 SURVEY PERFORMANCE

Among the built universe of shops, the ones featured in the sample were randomly selected. Lower than expected response rates obliged to select an extra number of shops within the universe for a second approach, in order to reach a number of responses closer to the one intended.

After survey completion, only **38** responses were obtained while **83** retailers were approached. This lower than expected value is thought to be mainly due to:

- Impossibility of shop managers of completing the survey without Head Office's authorization, where **23** fell under this category;
- No completion despite survey delivery, with **16** cases.

The following graph can then fully illustrate how the survey performed among approached retailers:

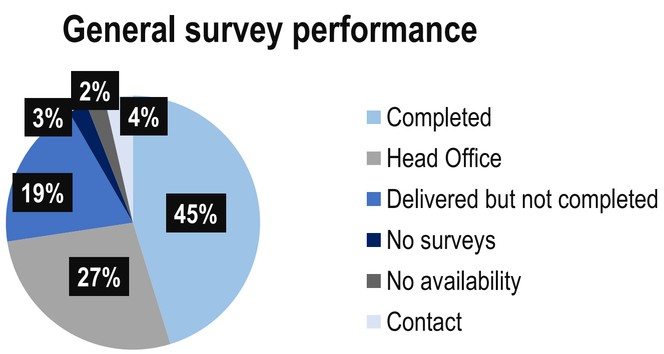


*Figure 5.2 – Survey's general performance*

The statistical relevance of the number of obtained responses can be seen in the table below:

*Table 5.4 – Confidence levels and margins of error of obtained sample sizes*

| Population Size | Obtained Sample Size | Confidence Level | Margin of Error |
|---|---|---|---|
| **108** | 38 | 90% | 10.79% |
| | | 95% | 12.86% |
| | | 99% | 16.9% |

Also and as referred before, the approached shops took into account a categorization made in terms of type of retail. As can be observed on the table below, the percentage of approached shops is fairly close to the aimed percentage that should have been surveyed in each category. However, the percentage of collected surveys does not quite match the aimed one, not respecting the initial aim of shop categorization.

*Table 5.5 – Percentages of collected, approached and aimed number of surveys*

| Type of Store | Number of collected surveys | Number of approached shops | Necessary number of shops | Collected % | Approached % | Aimed % |
|---|---|---|---|---|---|---|
| Clothing & Accessories | 23 | 42 | 25 | 60,5% | 51,2% | 47,0% |
| Sports | 3 | 7 | 4 | 7,9% | 8,5% | 8,0% |
| Culture & Leisure | 4 | 6 | 4 | 10,5% | 7,3% | 7,0% |
| Health & Beauty | 3 | 6 | 8 | 7,9% | 7,3% | 16,0% |
| Gifts & Souvenirs | 1 | 6 | 3 | 2,6% | 7,3% | 6,0% |
| Department Stores | 2 | 11 | 6 | 5,3% | 13,4% | 11,0% |
| Electronics | 2 | 4 | 2 | 5,3% | 4,9% | 5,0% |
| TOTAL | 38 | 82 | 52 | | | |

## 5.5 SPT STAKEHOLDERS' CONSULTATION

At this point of the study, it became interesting to compare the obtained results with the ones found on the study made for SPT in 2010. The study was developed by Steer Davies Gleave, an independent consultancy working across the transport sector, who were subcontracted by SPT to explore the possibility of implementing a freight consolidation centre serving Glasgow City Centre.

In order to do so, it was admitted that a concept of that nature would only make sense if retailers were willing to take part in such scheme, thus setting stakeholder consultation as core objective of the study.

The study raised awareness for the need to closely monitor freight movement within the chosen study area, determining volumes, mix and scheduling of deliveries and collections through surveys when information is not available, also reminding that retail outlets generate significant volumes of return product and packaging waste, often collected by separate vehicles that should obligatorily be accounted for.

The further chapters resume the most significant study findings.

### 5.5.1 RETAILERS' CONSULTATION

Focusing on retailers' involvement, Steer Davies Gleave affirms that, in the case of a large retail chain, the initial approach should be to the retailers' Head Office and that small independent retailers should be visited to their shops.

However, joining a consolidation centre scheme, retailers incur costs but are normally uncertain of the likely benefits, particularly at store-level. Moreover, individual branch-level managers may have little awareness of the upstream supply-chain and lack of authority to make strategic decisions and thus, generate an opinion on the subject.

The two statements above actually explain the lack of participation of the survey performed in 2015. In fact, as seen on Figure 5.2 – Survey's general performance, the main reasons for low response rates were the inability to take surveys without Head Office authorization and the uneasiness with the survey content.

The study sample showed a bias towards clothing retailers in the city centre, being a representation of the retail offer that area contains. The majority of deliveries for large and medium sized retailers start down south and are transported to Glasgow via either the companies' Scottish distribution centre or logistic providers' warehouse. On the other hand, smaller companies tend to attract deliveries direct from the supplier to the shop.

It was also noticed that dispatches (mostly including inter-store transfers, old stock, slow selling stock, recycling and faulty goods) from stores were generally infrequent, at most once or twice a week and nearly all retailers would put them onto the morning delivery vehicle.

The study highlights that a large proportion of retailers across the Glasgow area suggested that there were no delivery constraints to report whereas a further proportion suggested that time was a critical constraint and parking issues were noted to constrain some retailers.

It was noted that none of the store managers consulted during the 2010 process were aware of the retail consolidation centre concept, while in 2014 that statistic was improved, though unawareness of the concept was still present and was reason for lack of opinion on the chapter dedicated to that concept.

Retailers in Buchanan Street agreed that a freight consolidation centre, though not showing an urgent need for it, could be beneficial if supported by Glasgow City Council and leading to possible relaxation of delivery restrictions. Also, higher frequency of delivery, greater time reliability and reduced delivery movements were also agreed, by most, to be beneficial on the implementation of a consolidation centre. However, better understanding of the financial merits would need to be considered.

As for retailers in Argyle Street, it was of general belief that a freight consolidation centre would provide more reliable delivery times and less delay when required stock. However, they also thought that further handling brought by the centre would increases security risks, increase the cost of end-to-end journey and would require a change in logistics operation from Head Office. Similarly to Buchanan Street, most of the retailers did not express interest in the concept.

Resuming, shop managers in the city centre did not report serious issues or inefficiencies with their delivery systems that would require change. Also, restrictions on delivery vehicles to Buchanan Street after 10am did not seem to be a disadvantage for most of retailers, since the majority prefers early morning deliveries (or overnight deliveries) to allow shop floor to be fully replenished prior to opening time. Moreover, most of the stores seem to already process stock in an ‘auto-replenishment’ ‘just in time’ basis, not having storage rooms large enough that would justify transforming into extra retail space, reducing the potential attraction for an urban consolidation centre.

It then seemed that a high proportion of deliveries by logistic providers were already being combined with drop-offs to other stores on the same street, something that was still noted on when carrying out the 2014 survey. However, this was not the case for larger stores who employed company owned vehicles but had delivery volumes that justified individual delivery vehicles. The focus of a consolidation centre should therefore be on medium to small retailers.

For the majority of deliveries, company owned, TNT, UPS and DHL were the most common companies used to deliver their stock.

It was interesting to note that smaller stores with less available staff to process deliveries would commonly see and advantage in being able to control their deliveries to more convenient times. On the other hand, they felt like their delivery volumes did not justify any consolidation.

A common concern among retailers was the financial risk and security issues of holding stock in a warehouse that was not in their full control. Therefore, the environmental benefits of the consolidation centre concept while merited would have to be considered against financial incentives and be superior to that of the companies’ existing practices.

It was felt that most retailers would rather have their deliveries made either early morning or late afternoon/evening. This means that they are paying additional staff wages to see in the delivery, considering a cost that is overlooked when accounting for a consolidation centre offering.

### 5.5.2 NEED FOR ENCOURAGEMENT

As expected, it was concluded that for a consolidation centre to be effective and sustainable, it would need numerous retailers. Thus, as it would not be possible to deliver all of the products within the normal access restrictions, a relaxation on any parking or lorry delivery restrictions for consolidation centre vehicles, providing they would not endanger person or property in the process, was considered essential in attracting retailers.

Indeed, it was highlighted by logistic providers the need for Glasgow City Council and SPT to be active in this process and essentially leading a combined campaign to encourage retailers to participate in any trial. Service window restrictions and tightening controls on city centre lorry movements was considered to serve as encouragement. Restricted measures to current delivery schedules through delivery restrictions or even payment cordons rental of Local Authority rates/charges could also be an option.

Ultimately, it was established that the core service needed to be robust and reliable. Thus, it was seen as necessary, alongside any specific service restrictions which may be imposed, to identify tangible benefits to the retailers, where a lot comes down to value added initiatives. Either the need to see a financial benefit for using a distribution centre or a financial burden for not doing it was necessary for retailers' adherence, where public subsidy during the marketing period with incentives to retailers, like a "try before you buy" option would be needed.

### 5.5.3 LOGISTICS COMPANIES' CONSULTATION

Since it is the current logistics providers the ones who gained trust with existing retailers for performing their deliveries, it is only logic that they are the ones who can engage with the decision makers to promote the change required. They are also the ones with the knowledge of how a consolidation centre can benefit the demands of their clients.

According to Steer Davies Gleave, since the majority of retailers in Glasgow appeared to be satisfied with their current deliveries operations, the avenue for advancing a retail consolidation centre was to focus on logistic providers, with SPT facilitating this rather than as the deliver.

To that end, logistic providers were consulted on this subject, where nine of them had no interest or had no adequate infrastructure to deliver a consolidation centre, while other expressed a strong interest in the concept and wished to discuss it further.

Providers like John G Russell, Gordon Leslie Distribution, Pollock (Scotrans) Ltd, Clipper, WH Malcom, DHL and TNT had the appropriate infrastructure level to deliver the centre. In fact, all these hauliers currently provide retail deliveries to Glasgow City Centre and most already make efficiency savings by combining retail loads to reduce costs.

Managing over 60% surveyed retailers' deliveries and being already known and an integral part of the current retail supply chain, TNT could be the appropriate entity for managing a UDC in Glasgow.

When enquired, it was logistic providers' general opinion that, on an initial phase, the centre operation should on a small selected area which would focus on a cross-dock and onward shipment facility (no consolidation, only distribution), with value-added initiatives such as storage, recycle management and pre-retail services. This operation would then progress down the line as confidence build with the retails customers, and benefits are appreciated.

### 5.5.4 LOCATION

From literature review, it is known that, for any consolidation centre, property is usually 50% of the cost, and therefore building a new facility in a new location was not considered practical, cost-effective or the best use of resources. It was then seen that the need to integrate urban retail consolidation into existing logistics infrastructure confines choice of location existing distribution facilities.

Also, an ideal location for a consolidation centre would be close to a strategic road network on a major route and, according to best practices, no further than 15 miles from the retail centre (approximately 24 km).

### 5.5.5 PUBLIC SUBSIDY

As was estimated, mainly from literature review, that staffing and transport would account for 50% of the centre's implementation and operation costs. At this stage, none of the logistic providers were in a position to consider actual cost of providing this service, but felt it would not be high if based on the adaptation of an existing operation.

All logistic providers would expect subsidy cover at least the adaptation of the existing warehousing to accommodate this facility, branding, vehicles, etc., plus a trial period cost saving in order to be able to provide attractive rates to potential customers.

Furthermore, it was felt that the use of electric vehicles, whilst desirable, would result in an expensive initial investment, unless completely funded through public subsidy. Therefore, any funding resource would be best placed on the modification of existing vehicles to become more efficient, keeping the provision of an electric vehicle service as a long term goal.

Charging to retailers would be calculated on a menu of service, from simply cross docking to pre retail and timed deliveries where, for the cross dock and transport function it would usually be calculated on carton rate while other requests such as timed or double manned deliveries would attract a premium to cover costs. As for storage, it would be based on square footage required; additional charges would relate to segregated areas, as fixtures and fitting is required.

### 5.5.6 OPPORTUNITIES FOR A CONSOLIDATION CENTRE IN GLASGOW

The idea of a centre is, in principle, supported by several companies. However, without knowing who would run it and where it would be located, companies could not fully assess the advantages or disadvantages it would have for their particular activity.

As there were few serious constraints or issues with current delivery practice, the consulted retailers were naturally cold on the thought of change or alteration and therefore any significant progress on this matter would require attracting retailers to the consolidation centre by increasing city centre delivery restrictions or making the centre financially attractive to them.

### 5.5.7 LESSONS FOR FUTURE ATTEMPT OF UDC IMPLEMENTATION

- Choose a location from existing distribution facilities at a shorter than 24 km distance from the retail centre;
- The focus of the centre should be on medium to small retailers;
- The target group within the small to medium size retailers would be most receptive to the concept with increased servicing restrictions;
- Have a logistic provider operate the distribution centre;
- Public entities should facilitate the centre implementation (with appropriate regulation) rather than deliver it themselves;
- The centre operation should initially stick to a small selected area which would focus on a cross-dock and onward shipment facility, with value-added initiatives such as storage, recycle management and pre-retail services;

- The most appropriate time to introduce a consolidation centre would be on the run up to Christmas, during August/September, as retailers would be looking for additional storage space at this time;
- The core service needs to be reliable and robust;
- Retailers have to see either a financial benefit for integrating the centre or a financial burden for not doing it;
- Public subsidy during the marketing period is necessary;
- Glasgow City Council and SPT have to be active in the process;
- It is necessary to fully establish the complete retail vs supply demand pressures for the streets to be served by the distribution centre, aligning current delivery and waiting constraints with the appetite Glasgow City Council may have for tightening or lengthening any restrictions as a 'stick' measure;
- Remember that setting up a consolidation centre is just one of many ways of rationalising freight movement within urban areas and should not be considered to the exclusion of other schemes and techniques;
- Full understanding he problems to be resolvds, the alternative freight options available and support for the consolidation concept are required from relevant stakeholders;
- Urban retail consolidation is very seldom a panacea and is usually more beneficial when integrated within a package of freight measures.

## 5.6 SURVEY RESULTS

As said before, the number of responses obtained when surveying a sample of Glasgow City Centre retailers' population was not as significant as desired, making it more difficult to analyse retailers' current position towards distribution centres and comprehend if, based on the current logistic patterns, it would nowadays be able to serve the city centre. However, the obtained answers are still valid for speculation about possible scenarios for a UDC scheme implementation.

### 5.6.1 GENERAL RESULTS

The table below shows that, as referred on the study made by Steer Davies Gleave, many shops already had their deliveries coordinated, especially for larger stores that normally have dedicated vehicles performing deliveries to their multiple stores. Inclusively, a significant amount of shops has their deliveries made to stores of their chain located outside the city centre, prior to or after having their goods delivered to the Glasgow shop.

*Table 5.6 – Coordination of deliveries in the city centre*

| Type of business | Number of shops | Percentage of shops |
|---|---|---|
| Part of a chain of stores deliveries are coordinated | 25 | 66% |
| Independent store which arranges deliveries on its own | 13 | 34% |

Moreover, **87%** of the vehicles delivering to the surveyed stores make deliveries to multiple establishments whereas only **11%** make deliveries only to that single shop. This fact supports the idea that consolidation and coordination are somehow already implicit in deliveries to the city centre, validating the fact that there are already specific logistic providers delivering to different stores, typically in the same street, during a single trip, easing a possible attempt of having one of them operating the distribution centre and pulling already aggregated retailers towards the scheme.

Furthermore, despite a considerable percentage of unawareness of vehicle loads, 55% of retailers guaranteed that vehicles performing deliveries to their shops depart fully loaded from their point of origin - Table 5.7, which consolidates the line of thought developed above: retailers already coordinate deliveries between them and Glasgow does not seem to face the problem of poorly optimized vehicle loads, dismissing the need of a UDC to solve this problem.

*Table 5.7 – Loads for vehicles delivering to the City Centre*

| Vehicle loads | Number of Shops | Percentage of Shops |
|---|---|---|
| Fully loaded | 21 | 55% |
| Almost full | 2 | 5% |
| Depends on the supplier | 1 | 3% |
| Don't know | 14 | 37% |

Vehicles seem to depart, on their majority, from either a facility close to the city centre or far away from it where the ones departing from a farther point seem to be, in general, the ones integrated in a chain of multiple stores across Scotland. To the ones departing from a facility close to the city centre (37%) it could be easier to find a UDC location on the centre's periphery that would serve the same purposes of their current locations, accounting for their storage and transport needs. Establishments having their vehicles departing from a farther point suggest that their integration in a UDC scheme would alter their supply chain on a more upstream level, making it more difficult to accommodate this change.

*Table 5.8 – Points of origin of vehicles delivering to the City Centre*

| Vehicle trip's origin | Number of Shops | Percentage of Shops |
|---|---|---|
| Facility close to the city centre | 14 | 37% |
| Facility far from the city centre | 13 | 34% |
| Facility inside the city centre | 1 | 3% |
| Depends on the supplier | 1 | 3% |
| Don't know | 9 | 24% |

Dissatisfaction with current delivery schemes would be a great stimulator for UDC implementation perspectives. Therefore, evaluating the extent to which retailers were happy with the way deliveries were performed to their establishments felt as important. On that note, it was seen that the majority of retailers were satisfied with their current delivery scheme (61%) and 26% were even very satisfied.

*Table 5.9 – Satisfaction with current deliveries scheme*

| Satisfaction with current delivery scheme | Number of Shops | Percentage of Shops |
|---|---|---|
| Very satisfied | 10 | 26% |
| Satisfied | 23 | 61% |

| | | |
|---|---|---|
| Partially satisfied | 4 | 11% |
| Dissatisfied | 1 | 3% |

As identified through literature review, a set of problems normally affecting deliveries in urban areas were presented to retailers, requesting the identification of the ones affecting deliveries to their shops, with the following outcome:

*Table 5.10 – Delivery related problems identified by retailers*

| Identified Problems | Number of Shops | Percentage of Shops |
|---|---|---|
| Vehicles blocking other Vehicles | 16 | 42% |
| No space for manoeuvres | 11 | 29% |
| Few space for unloading operations | 17 | 45% |
| Congestion near shop | 20 | 53% |
| Delays due to mentioned issues | 12 | 32% |
| No problems | 10 | 26% |

A big majority of shops (82%) has storage areas for their shops, and 50% of them have those located outside the shop. This corroborates the idea that most of the stores already process their stock in an 'auto-replenishment', 'just in time' way since storage areas inside the shop have little significance or are non-existent. Thus, the possible advantage of transforming storage area into extra retail space brought by UDC schemes is not that appealing for retailers in Glasgow.

Regarding Urban Distribution Centres, a set of questions was formulated in order to understand what retailers would prioritize in the implementation of a scheme of this nature. To that intent, the survey attempted to comprehend the circumstances under which retailers would be willing to take part in the scheme, with the following options:

- "If a UDC was implemented, I would like my establishment's deliveries to be integrated in that scheme"
- "I would be interested in integrating a UDC scheme as long as it did not involve any extra operation costs to my business"
- "I would be interested in integrating a UDC scheme and have deliveries to my shop suffer alterations as long as their efficiency and punctuality were still guaranteed"
- "I would be interested in integrating a UDC scheme if deliveries to my shop did not suffer any alterations"
- "I would only integrate a UDC scheme if, through public policy changes regarding freight distribution, the UDC presented some degree of compulsion"

Despite the 38 collected surveys, some of the shop managers did not feel comfortable expressing their opinion regarding the UDC chapter, either because they were not familiar with the concept or because they felt it was a higher-level decision, belonging to Head Offices.

Nevertheless, the following table resumes retailers' position regarding they interest in integrating a UDC scheme. It is interesting to notice that none of the shop managers answered that, regardless of the conditions, they would be willing to integrate the UDC, expressing the already recognized idea that the implementation of a distribution centre would have to be accompanied of extra measures and incentives.

*Table 5.11 – Conditions set by retailers for integrating a UDC scheme*

| Retailers' conditions for integrating a UDC scheme in Glasgow | Number of Shops | Percentage of Shops |
|---|---|---|
| "As long as deliveries' efficiency and punctuality was still guaranteed" | 1 | 4% |
| "As long as it did not involve any extra operation costs to their business" | 10 | 40% |
| "If, through public policy changes regarding freight distribution, the UDC presented some degree of compulsion" | 3 | 12% |
| "If deliveries to their shop did not suffer any alterations" | 11 | 44% |
| **TOTAL** | **25 (66% of responses)** | |

Retailers' opinion on this matter reflects their satisfaction with their current deliveries scheme to the point of expressing their wish of not having any changes made to them as a priority. Also, the financial reservations of implementing a UDC are visible, since 40% of retailers were concerned about increases in operation costs.

Moreover, in spite of lower percentages, compulsion for centre integration was also seen as the only hypothesis for doing so among some of the retailers, corroborating the main conclusion of the SPT study that the implementation of an urban distribution centre in Glasgow would only be possible if presenting that degree of compulsion.

It was also asked of shop keepers to classify the main potential opportunities brought by a distribution centre according to their shop's priorities where a classification from 1 to 7 of the following potentialities was requested, being 7 the one with higher relevance and 1 the one considered to be less important.

*Table 5.12 – Priorities set by retailers for integrating a UDC scheme*

| | | |
|---|---|---|
| Ability to keep current deliveries scheme | 73 | 17% |
| Ability to keep (all) inventory at the UDC's location | 60 | 14% |
| Having the UDC located inside the City Centre's perimeter | 62 | 15% |
| Benefit from privileged freight distribution regulations | 62 | 15% |
| Ability to collect goods at the UDC whenever wanted | 48 | 11% |
| Ability to reduce the number of deliveries per week to the shop | 53 | 13% |
| Having an experienced/acknowledged entity operating the UDC | 62 | 15% |

The table above presents a sum of the points obtained by each opportunity according to the described classification. On that note, the ability to keep their current deliveries scheme is, for retailers, the priority that should be given to the formulation of a distribution scheme. Also, having the centre located inside the city centre with an experienced entity operating it and benefiting from privileged freight distribution regulations (such as extended time windows for deliveries) should be some of the centre's priorities.

On the other hand, the ability to collect goods at the UDC whenever wanted is not that appealing to retailers despite their wish to have the centre close to their establishments.

Being one of the aims of an Urban Distribution Centre to reduce the number of vehicles performing deliveries in the city centre and mitigate the use of heavy goods vehicles to do so, relying on more sustainable and light solutions, it was thought to be necessary to verify if that was indeed an issue for deliveries to Glasgow city centre.

*Table 5.13 – Type of delivery vehicles in the city centre per week*

| Type of vehicle | Number of vehicle trips in the city centre per week | Percentage of Vehicles |
|---|---|---|
| LGV | 80 | 38% |
| Small truck | 79 | 37% |
| HGV | 27 | 13% |
| Other (Courier and Post vans) | 25 | 12% |
| TOTAL | **211** | 100% |

As can be seen on the table above, a considerable percentage of the delivery trips in the city are already performed with light goods vehicles or small trucks (75%), indicating that mitigating the presence of heavy goods vehicles in the city centre might not be that difficult a task.

### 5.6.2 DEMANDS

In order to obtain an estimate of the demands per surveyed shop and ease the task of shop keepers of filling out that information, they were asked to classify their deliveries according to Figure 5.3 – Characterization of demands in bags and boxes, specifying the number of each type of box and bag that characterized their incoming volumes per week, both for a typical week and a week before Christmas (where volumes were expected to be greater). Similarly, for shops providing online shopping services with customer collection at the store, the respective volumes were also asked for.

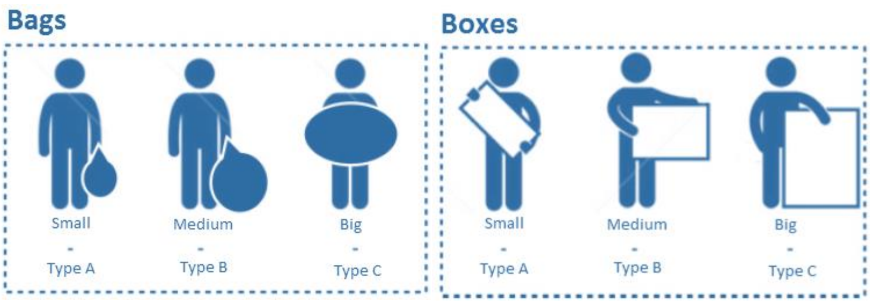


*Figure 5.3 – Characterization of demands in bags and boxes*

In order to convert bag and boxes into quantitative values of cargo, a research for real market volumes by transport companies was made where the solution that is currently described on DHL's Size & Price Guide was assumed. Since they only had box-based dimensions, the volume for bags was assuming as follows:

- **Type A Bag** – Half the size of Type A Box
- **Type B Bag** – ¾ of a Type B Box's size
- **Type C Bag** – ¾ of a Type C Box's size

Where these assumptions were simply based on visual analysis of Figure 5.3. The table below shows the box dimensions given by DHL for the chosen box sizes corresponding to each box type described on the survey (see Appendix 10 to Appendix 12 for visualization of box type).

*Table 5.14 – DHL Box formats' dimensions and volume*

| Box Type | Weight | Width (cm) | Depth (cm) | Height (cm) | Volume ($cm^3$) | Volume ($m^3$) |
|---|---|---|---|---|---|---|
| **Box 4** | 7Kg | 33.7 | 32.2 | 18 | 19532.5 | 0.0195 |
| **Box 6** | 18Kg | 33.7 | 32.2 | 34.5 | 37437.3 | 0.0374 |
| **Box 7** | 25Kg | 48.1 | 40.4 | 38.9 | 75592.0 | 0.0756 |

Based on DHL's box formats and on the assumption made for bags' size, Table 5.15 shows the volumes, in $m^3$ that will be used to estimate demands for retailers in Glasgow city centre.

*Table 5.15 – Relationship between volume in bags/boxes and kilograms*

| | Type A | Type B | Type C |
|---|---|---|---|
| **Bags** | 0.0098 $m^3$ | 0.0281 $m^3$ | 0.0567 $m^3$ |
| **Boxes** | 0.0195 $m^3$ | 0.0374 $m^3$ | 0.0756 $m^3$ |

Being now able to quantify demanded volumes per week for each surveyed shop and knowing the average number of deliveries per week to each of those shops, it is then possible to obtain an estimate of the demand of each shop per delivery, through data extrapolation.

It is important to refer that the volumes that will be taken into account for the effect of model development will be the ones collected for a "Christmas week", guaranteeing that the viability of a UDC will be explored for the heaviest scenario, i.e. where deliveries and volumes are heightened.

Note that the demand volumes to be extrapolated will not comprise demand volumes from e-commerce deliveries, since it was assumed that those values were already account for. In spite of that, it is still interesting to observe how a lot of shops have customers' online demands delivered at the shop for customer collection, while only 26% of surveyed shop keepers stated that online orders were only available for door-to-door delivery. Those last values will not be accounted for in this first phase implementation of the UDC.

*Table 5.16 – Delivered volumes per week for online shopping*

| Online Shopping | Number of Shops | Percentage of Shops |
|---|---|---|
| Door-to-door delivery | 10 | 26% |
| Customer collection in store | 2 | 5% |
| Both, according to customer preference | 21 | 55% |
| No online shopping services | 5 | 13% |

### 5.6.3 DATA EXTRAPOLATION

In order to enable the extrapolation of the information obtained from the **38** surveyed retailers to the built universe of **108** shops, a *multiple classification analysis* was used. This method is designed for use with predictor variables measured on nominal, ordinal or interval scales. On this note, and due to the lack of information that would allow a deeper comparison between shops, it was assumed, with the acknowledgment of a preeminent skew of data, that shops would take demand values corresponding to a weighted average of values obtained from the surveys per shop category and shop size.

Therefore, shops were classified according to the following table:

*Table 5.17 – Categorization of shops for extrapolation*

| Type of Shop | Size of Shop |
|---|---|
| Clothing & Accessories | Small |
| Sports | Small to Medium |
| Culture & Leisure | Medium |
| Health & Beauty | Medium to Big |
| Gifts & Souvenirs | Big |
| Department Stores | |
| Electronics | |

Appendix 13 shows the association of shops to each category (both surveyed and subject to extrapolation), according to the size of each of them and the retail category they fall under. According to that categorization, que average demand volumes for each category are given by the following table (based on values taken from surveyed shops):

*Table 5.18 – Demand volumes per shop category*

| | Small | Small to Medium | Medium | Medium to Big | Big |
|---|---|---|---|---|---|
| **Clothing & Accessories** | 0.0379 | 0.8084 | 0.8428 | 2.8231 | 0.4731 |
| **Sports** | - | - | 0.8782 | - | - |
| **Culture & Leisure** | 0.0416 | 0.0608 | 0.5010 | - | - |
| **Health & Beauty** | 0.4150 | 1.1980 | - | - | - |
| **Gifts & Souvenirs** | - | 2.3370 | - | - | - |

| | | | | | |
|---|---|---|---|---|---|
| **Department Stores** | - | - | - | - | 3.7437 |
| **Electronics** | - | 0.1326 | - | 1.4707 | - |

For shops that were subject to extrapolation and did not have available data from the surveys under their category, values only based on size were assumed. Volumes after extrapolation are available on Appendix 14 for population under study of 108 retailers.

# 6 CASE STUDY: VIABILITY OF AN URBAN DISTRIBUTION CENTRE

## 6.1 MODEL PRESENTATION AND ANALYSIS

### 6.1.1 OPTIMIZATION MODEL

The following mathematical model was developed by (Muñoz-Villamizar, et al., 2014) to solve the problem of optimal location and operation of urban distribution centres, assuming the following parameters as inputs:

- Number of customers and urban distribution centres as well as their location and respective distances and costs between each;
- Number of distribution centres to use/open;
- Number of vehicles used and their respective capacities;
- Customers' demands.

The acknowledgement of these parameters allows to set the model restrictions, where it seeks to minimize the cost of supplying the demand of each customer, determining the location, size and operation of the UDC.

The model's mathematical formulation was implemented in Xpress where majority of the mathematical formulation was kept as the original in spite of a few changes needed to adapt the model to the situation to be modelled, which will be interspersed with the model description that follows.

**MAIN SETS**

$$UDC = Urban\ Distribution\ Centres\ \{Albatrans, Eurogate, \dots, i\}$$

$$Node = Retailers\ \{Topshop, Wallis, \dots, j\}$$

$$Veh = Vehicles\ \ \{Veh1, Veh2, \dots, k\}$$

**DECISION VARIABLES**

$$A_i = \begin{cases} 1, & if\ a\ UDC\ is\ located\ in\ i \\ 0, & otherwise \end{cases}$$

$$X_{ijk} = \begin{cases} 1, & if\ vehicle\ k\ goes\ from\ UDC\ located\ in\ i\ to\ retailer\ j \\ 0, & otherwise \end{cases}$$

$$X_{jik} = \begin{cases} 1, & if\ vehicle\ k\ goes\ from\ retailer\ j\ to\ UDC\ located\ in\ i \\ 0, & otherwise \end{cases}$$

$$X_{jhk} = \begin{cases} 1, & if\ vehicle\ k\ goes\ from\ retailer\ j\ to\ retailer\ h \\ 0, & otherwise \end{cases}$$

**MODEL PARAMETERS**

$$C_{ij} = cost\ matrix\ of\ travelling\ from\ UDC\ located\ in\ i\ to\ retailer\ j$$

$$C_{ji} = cost\ matrix\ of\ travelling\ from\ retailer\ j\ to\ UDC\ located\ in\ i$$

$$C_{jh} = cost\ matrix\ of\ travelling\ from\ retailer\ j\ to\ retailer\ h$$

$$C_i = Fixed\ cost\ of\ UDC\ i$$

$$Max_{UDc} = number\ of\ UDCs\ to\ open$$

$$D_j = demand\ of\ retailer\ i$$

$$CAP_k = capacity\ of\ vehicle\ k$$

**OBJECTIVE FUNCTION**

$$Min\ Z = \sum_i \sum_j \sum_k C_{ij} \cdot X_{ijk} + \sum_i \sum_j \sum_k C_{ji} \cdot X_{jik} + \sum_i \sum_j \sum_k C_{jh} \cdot X_{jhk} \qquad (1)$$

This function seeks to minimize the total of supplying the demand of all customers, according to the location of the UDC(s).

**CONSTRAINTS**

$$\sum A_i \leq Max_{UDC} \qquad (2)$$

Constraint (2) specifies the maximum number of UDCs to be opened/located. Since only one UDC is to be open in an pilot phase, $Max_{UDC}$ will always be considered as 1.

$$Veh \cdot A_i \geq \sum_i \sum_k X_{ijk} \qquad \forall i \qquad (3)$$

Constraint (3) ensures that vehicle routes can be defined only if from a UDC that is open.

$$\sum_i \sum_j \sum_k X_{ijk} \geq \frac{\sum_j D_j}{CAP_k} \qquad (4)$$

Constraint (4) computes the minimum number of routes/vehicles required to meet the total demand where the number of vehicles can be defined as a fixed value if the right side of the inequality is changed to desired number of vehicles.

$$\sum_{i} X_{ijk} \leq \sum_{h} X_{jhk} \qquad \forall j, \forall k \tag{5}$$

Constraint (5) concerns two binary variables and ensures that if a shop is visited from a UDC, the vehicle must go to another shop, starting from the same visited shop and in the same vehicle. This constraint thus initializes the route and relates the first visited shop with the sequence of shops that should be visited.

$$\sum_{i} X_{ijk} + \sum_{h} X_{hjk} = \sum_{i} X_{jik} + \sum_{f} X_{jfk} \qquad \forall j, \forall k \tag{6}$$

Constraint (6) establishes the sequencing of the entire route for all shops, establishing that if a shop is visited, it should go to another shop or return to the UDC in the same vehicle performing the route.

$$\sum_{i}\sum_{k} X_{ihk} + \sum_{j}\sum_{k} X_{jhk} = 1 \qquad \forall h \tag{7}$$

Constraint (7) ensures that all shops are visited exactly once, either from a shop or from the UDC.

$$\sum_{h}\sum_{k} X_{ihk} + \sum_{i}\sum_{k} X_{jik} = 1 \qquad \forall j \tag{8}$$

Constraint (8) ensures that after a vehicle visits a shop it goes to another shop or returns back to the UDC.

$$\sum_{j} X_{ijk} = \sum_{h} X_{hik} \qquad \forall i, \forall k \tag{9}$$

Constraint (9) forces all vehicle routes to begin and end in the same UDC.

$$\sum_{i}\sum_{j} X_{ijk} \cdot D_j + \sum_{j}\sum_{h} X_{hjk} \cdot D_j \leq CAP_k \qquad \forall k \tag{10}$$

Constraint (10) defines capacity constraints through the delimitation of the route length.

$$\sum_{i}\sum_{j} X_{ijk} \leq 1 \qquad \forall k \tag{11}$$

Constraint (11) limits at most one route per vehicle.

$$\sum_{i}\sum_{j} X_{ijk} \geq X_{hjk} \qquad \forall k \tag{12}$$

Constraints (12) was not featured in the original model but it was proved to be necessary in order to guarantee that only vehicles that depart from a UDC can circulate within the city.

$$\sum_{j}\sum_{h} X_{jhk} \leq \left(\sum_{j}\sum_{h} X_{jhl}\right) - 1 \qquad \forall k, \forall l \tag{13}$$

$$\sum_{j}\sum_{h} X_{jhk} \leq \left(\sum_{j}\sum_{h} X_{jhl}\right) - 1 \qquad \forall i, \forall k \tag{14}$$

Constraints (13) and (14) ensure that the size of each route is similar; that is the load balancing constraint in the original formulation but, since they were not compulsory, were kept out of the optimization model.

**SUBTOUR ELIMINATION**

When performing test runs of the model, it was noted that sub tours within the solution were appearing. According to Muñoz-Villamizar, the constraint below would eliminate sub tours within the solution. However, the author himself does not explore the constrain past its presentation and a proper way to transpose that equation to Xpress was not found and it was thus impossible to eliminate sub tours with the aid of that constraint.

$$u_j - u_h + N \cdot X_{jhk} \leq N - 1 \qquad \forall j, \forall h, \forall k \tag{15}$$

To enable the elimination of sub tours in a different way, in spite of an acknowledged existence of associated errors, the model was programmed to detect the existence of sub tours in each route, easing the trouble to identify them and, afterwards, the whole route containing the sub tour would be subject to a new model run for only the featured retailers in the route, chosen UDC location and single vehicle.

The acknowledgment of a directly connected error to this solution comes from knowing that, without performing a model run for the entire system after sub tour elimination, there is the risk that retailers in the sub tour will be integrated in a route that is not optimized to them distance-wise, being limited to the original route they were integrated in.

The identification of sub tours was based on the formulation developed by (GAMS World , 2015) and can be seen in Appendix 15.

### 6.1.2 SOLUTION PROCEDURE

The solution procedure consisted of firstly programming the mathematical model in the Mosel language. As a method of solving, XPRESS was used. The objective function was defined as the minimization of the total distance to meet demand of all retailers with consideration for environmental impacts mitigation. Subsequently, with the actual coordinates of the stores in the city of Glasgow, the matrix of Euclidean distances was computed.

### 6.1.3 NETWORK

As referred before, the model to be developed will be optimized to a group of **108** retailers, belonging to the Style Mile retail project for the city centre. To that intent, all retailers were identified on the map with associated coordinates. Since the software does not operate on a GIS basis map, distances between nodes were computed into a matrix and measured with the aid of a *Google Maps* tool, *My Maps*, which allows to create customized maps and, within them, measure distances between points.

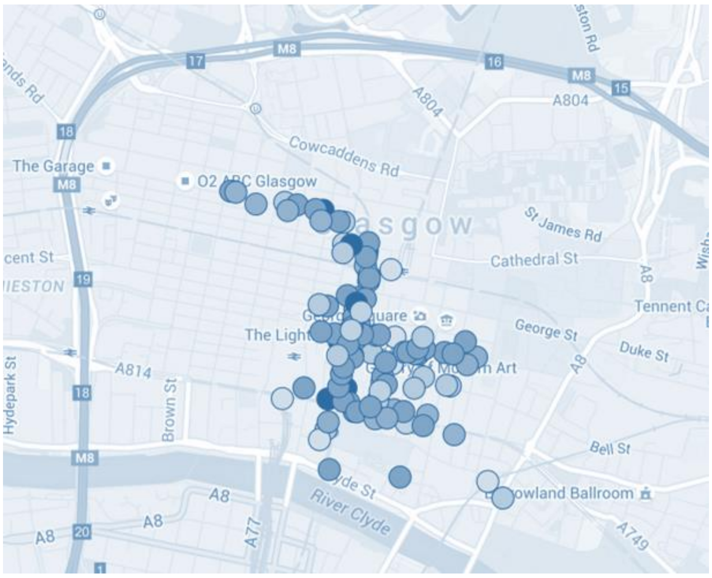


*Figure 6.1 – Mapping of Glasgow retailers on My Maps tool*


*Figure 6.2 – Measuring distances on My Maps tool*

No differentiation was made between street levels of hierarchy and all possible roads were considered for completion of the shortest trip, assuming that UDC movements would be offered specific route choice and preference throughout the city centre. Also, one way streets were taken into account and only the allowed direction was used within paths.

Moreover, and taking advantage of the city centre's regulation regarding delivery time windows for certain pedestrian streets (like Buchanan Street, and sections of Argyle Street and Sauchiehall Street), it was assumed that those streets could accommodate the presence of vehicles during the defined time windows.

### 6.1.4 DELIVERY POINTS

As referred above, 108 retailers were to be served in the implementation of an urban distribution centre serving Glasgow City Centre in an initial phase. When approaching the problem as an LRP, the amount of information to be processed by Xpress was too much to obtain reasonable optimization values within feasible running times for the model, not even being able to reach a close to best bound solution within 24 hours.

In order to correct that and alleviate the input information, the solution was to create delivery points (DP). Those delivery points would correspond to vehicle stops and, for shops within a range of **140 m**, deliveries would be made on foot from their assigned DP.

To optimize the location of those DPs within the network of retailers to serve, the approach was to consider it as a **p-median problem**, a problem of locating P delivery points (in this case) in relation to a set of retailers such that the sum of the shortest weighted distance between retailers and delivery points was minimized.

Because they were too far from the city centre to obtain distances smaller than 140m from any other retailer, **Wish Boutique**, **Slaters**, **Monorail Music** and **Beauty Kitchen** were not considered in the estimation of delivery points.

Mathematically, the problem can be described as follows:

**INPUTS**

$$h_i = demand\ for\ retailer\ i$$

$$d_{ij} = distance\ between\ retailer\ i\ and\ candidate\ DP\ j$$

$$DP = number\ of\ facilities\ to\ locate$$

$$Max_{cap} = maximum\ capacity\ of\ a\ delivery\ point$$

$$Max_{dist} = Maximum\ distance\ between\ DP\ and\ associated\ retailer$$

Distances $d_{ij}$ between retailers were placed on a 108x108 matrix (for the 108 retailers featured in the study). Similarly, their correspondent demands (extracted from the surveys and subsequent extrapolation) were inserted. Also, a maximum capacity of **9 m$^3$** was defined for each delivery point in order to consider the future implementation of smaller and more sustainable vehicles, with smaller capacities, guaranteeing that the demand of each DP can always be satisfied by a single vehicle.

**DECISION VARIABLES**

$$X_j = \begin{cases} 1, & if\ the\ DP\ is\ locate\ in\ j \\ 0, & otherwise \end{cases}$$

$$Y_{ij} = \begin{cases} 1, & if\ retailer\ i\ served\ by\ DP\ j \\ 0, & otherwise \end{cases}$$

$$CAP_j = \sum_i Y_{ij} \times h_i \,\forall j \leq Max_{cap} \quad \forall j$$

**OBJECTIVE FUNCTION**

The goal is to minimize the distance travelled distance between delivery points while guaranteeing that all retailers' demands are satisfied in the process with the minimum number of delivery points that satisfies both demands and maximum distances between retailers served by a certain DP. That goal can be expressed by the minimization of the following expression:

$$\sum_i \sum_j d_{ij} Y_{ij} + \sum_i X_j \tag{16}$$

**CONSTRAINTS**

$$\sum_i Y_{ij} = 1 \quad \forall i \tag{17}$$

$$\sum_j X_j = DP \tag{18}$$

$$Y_{ij} - X_j \leq 0 \quad \forall i, j \tag{19}$$

$$X_j = 0 \quad if \quad d_{ij} > Max_{dist} \quad \forall i, j \tag{20}$$

$$\sum_j X_j \leq DP \tag{21}$$

$$X_{ii} \geq X_{ij} \quad \forall i \neq j \tag{22}$$

Constraint (17) ensures that each retailer is assigned to exactly one facility while constraint (18) guarantees that exactly DP delivery points are located. Constraint (19) links the location variables and the allocation variables, constraint (20) ensures that a retailer is not associated to a delivery point that is located further than the maximum distance of 140 m from it and constraint (21) limits the amount of delivery points to the initially established number. Finally, constraint (22) ensures that a node can't simultaneously be a delivery point and be associated to a different delivery point.

As a method of solving, Xpress was used once more.

**OUTPUTS**

The table bellows shows the list of delivery points to be set, the associated retailers and the demands that conjoin in each delivery point.

*Table 6.1 – Selected deliveries points and respective conjoining demands*

| DP | Location of the Delivery Point | Retailers served by the delivery points | Delivery Point Demand (m³) |
|---|---|---|---|
| **1** | Slanj Kilts | Slanj Kilts, Toni & Guy | 0.453 |
| **2** | Wallis | Wallis, Evans, Foot Asylum, Debenhams, Accessorize | 7.309 |
| **3** | Deichman | Deichman, Dunnes | 6.567 |
| **4** | Topshop | Topshop, Fat Face, LOVEmusic, Paperchase, The Good Spirits Co, Skechers, GAP, Evans Cycles, City Barbers | 5.800 |
| **5** | USC | USC, Ann Summers, The Body Shop, Watt Brothers, BHS | 8.861 |
| **6** | Jigsaw | Jigsaw, Jaeger, Ralph Lauren, Bravissimo, James Duns House | 3.493 |
| **7** | Celtic Store | Celtic Store, Size? | 2.186 |
| **8** | Artstore | Artstore, Fast Frame, Osiris, Stons | 2.194 |
| **9** | Rubadub | Rubadub, Maplin, About Face | 1.927 |
| **10** | The White Company | The White Company, Diesel, Thomas Pink, Tiso, Mountain Warehouse, Rainbow Room International, Cath Kidston, Hector Russell Kiltmaker, Kilts & Cashmere of Scotland, Monsoon, Hobbs | 8.912 |
| **11** | Bose | Bose, Bang & Olufsen | 0.265 |
| **12** | Nike Store | Nike Store, Replay, Neal Yard Remedies, Coast, Holland & Barrett, Nailzone, Robertson Outerware, Tam Shepherd Trick Shop, Radley, LK Bennett | 8.460 |
| **13** | New Look | New Look, Camper, Forever 21, Forbidden Planet, Soletrader, Urban Outfitters, American Apparel, The North Face | 7.835 |
| **14** | DLC | DLC, Aldo, House of Fraser, Ted Baker | 8.725 |
| **15** | James Pringle Weavers of Inverness | James Pringle Weavers of Inverness, Whittard of Chelsea, Apple, TM Lewin, Zara | 8.805 |
| **16** | Next | Next, Primark | 7.487 |
| **17** | Miss Selfridge | Miss Selfridge, Marks & Spencer, WH Smith | 8.330 |
| **18** | HMV | HMV, Hugo Boss, Dune, TJ Hughes, G Star Raw, River Island, Missing Records | 8.700 |
| **19** | James Robertson Kiltmaker | James Robertson Kiltmaker, All Saints, TK Maxx, Lush, Greaves Sports | 8.681 |
| **20** | Agent Provocateur | Agent Provocateur, Pretty Green, Timberland, Cruise, Gant, Emporio Armani | 5.004 |

| | | | |
|---|---|---|---|
| **21** | Alan Edwards | Alan Edwards, Good Wins Hair and Nail Boutique, The Beauty Store, Merchant City Barbers | 1.660 |
| | | **TOTAL** | **121.660** |

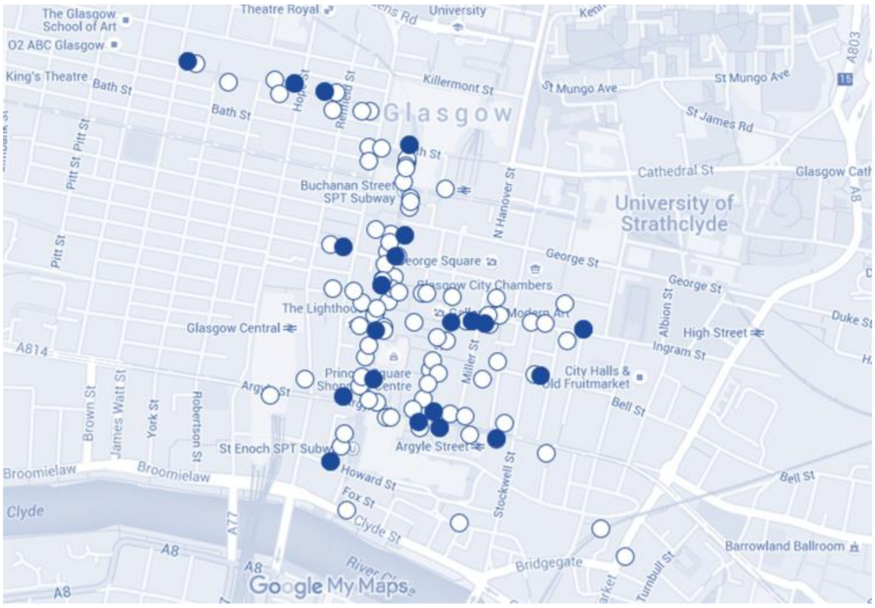


*Figure 6.3 – Location of delivery points in the city centre*

### 6.1.5 POTENTIAL LOCATIONS

As stated in Steer Davies Gleave SPT study, the logistics companies serving Glasgow that, in 2010, had the means to serve as potential freight consolidation centres were Gordon Leslie Distributions, John G Russel, Pollock, TNT, DHL, Clipper and WH Malcom.

However, being the aim of this work to locate urban distribution centres serving Glasgow City Centre close to the city centre periphery and, considering that computing information for 7 potential locations was too hard on the software, from the SPT study's list, only TNT and Clipper were kept as potential locations. TNT was kept because, according to the study, it would be the chosen location for a UDC since most of retailers' deliveries are already associated to that company. Clipper was kept because, from all the potential locations, it was the closest one to the city centre and, with the available data, costs for travelled distances are the only ones that could set these locations apart, making the excluded candidates always a worse solution than Clipper.

Moreover, it's was thought that it would be interesting to compare locations on the periphery of the city centre and inside the city centre. From the list provided by the report, Albatrans and Eurogate Logistics were logistics companies located inside the city centre.

However, Albatrans was not a potential location in the 2010 study because the company itself stated that their main business was international and therefore had no resource available for domestic market. As for Eurogate, they did not own their own vehicle fleet nor warehousing facility, making it difficult to operate in this market.

Nonetheless, both locations were considered in the study with assumed costs for warehouse space creation and vehicle fleet acquisition.

### 6.1.6 COST MATRIX

According to (Muñoz-Villamizar, et al., 2014), the costs to be considered in the model should be divided per type of movement: from a node to a potential UDC, from a potential UDC to a node and from a node to another node. Therefore, three cost matrixes have to be defined, for the costs of those three types of movements within the city.

First of all, it is important to define how these costs are built up to describe what is to be minimized when running the model. Taking into account that this project aims to reduce the impact of logistics activity in Glasgow City Centre while keeping its efficiency, the minimization of an objective function working towards that end should consider:

- The minimization of driven kilometres (distances), reflecting in a reduction of emissions;
- Less investment possible in putting up a UDC to serve Glasgow City Centre, considering costs to extend infrastructure and acquiring/extending vehicle fleets.

**TRAVELLING COSTS**

To compute the matrixes and as referred before, distances between nodes and UDCs were measured on *My Maps* where consideration of one way streets resulted in asymmetrical matrixes. To convert those distances into concrete costs, they are to be multiplied by the average cost of fuel (diesel) in Glasgow, which is **1.59 €/L** (The Automobile Association, 2015).

In order to obtained a €/Km value of fuel, average fuel consumption values were estimated based on (EMSD, 2015) tabled values.

*Table 6.2 – Fuel consumption per vehicle type (€/Km)*

| Vehicle Type | Fuel Consumption (L/km) | Fuel Costs (€/Km) |
|---|---|---|
| Light Goods Vehicle (3.5 Tonnes) | 0.11 | **0.1749** |
| Small Truck (3.5 to 7.5 Tonnes) | 0.193 | **0.3069** |
| Heavy Goods Vehicle (more than 7.5 Tonnes) | 0.258 | **0.4102** |
| Electric LGV | 0 | **0.0000** |

**VEHICLE EMISSIONS COSTS**

Taking into account that this is a work from public entities standpoint, as thus prioritizes the development of a sustainable solution, in each model run, for each scenario, a cost for vehicle emissions will be considered according to Table 6.3.

According to (Lemp & Kockelman, 2008), atmospheric damage cost can be assumed to be of $50 (**45€**) per ton of carbon-dioxide. Knowing that a short-ton (US) represents 907.184,74 grams, a gram of $CO^2$ has a cost of approximately **0.00005 €/g $CO^2$.**

Emissions values were based on (DfT, 2015).

*Table 6.3 – Fuel emission values (g $CO^2$/Km) and emissions costs (€/g $CO^2$.Km) per vehicle type*

| Vehicle Type | Tonnage | Fuel consumption (L/100Km) | Fuel Consumption (L/km) | Diesel Emissions (g $CO^2$/L) | Emissions (g $CO^2$/Km) | Emissions Costs (€/g $CO^2$.Km) |
|---|---|---|---|---|---|---|
| Light Goods Vehicle (3.5 Tonnes) | 2.5 | 11 | 0.11 | 2680 | 294.8 | **0.0147** |
| Small Truck (3.5 to 7.5 Tonnes) | 5.51-10 | 19.3 | 0.193 | 2680 | 517.24 | **0.0259** |
| Heavy Goods Vehicle (more than 7.5 Tonnes) | 10.01-15 | 25.8 | 0.258 | 2680 | 691.44 | **0.0346** |
| Electric LGV | - | 0 | 0 | 0 | 0 | **0** |

These values will especially useful when comparing *pre* and *post* UDC implementation scenarios.

**INFRASTRUCTURE AND VEHICLE COSTS**

As for costs of setting up each UDC in a certain location, a research for vehicle acquisition costs was done as well a research for land prices and warehouse rental prices in Glasgow City Centre. In this last one, few records of land for sale or warehouse space to rent in the city centre existed and thus, the information that supports these costs was only based on a single available value, as can be observed on Table 6.5. As for vehicle costs, Table 6.4 resumes the information found, based on IVECO models (for diesel vehicles) and on Smith Electric Vehicles for zero-emission vehicles.

*Table 6.4 – Vehicle acquisiton costs*

| Type of Vehicle | Model (Example) | Price (£) | Price (€) | Source |
|---|---|---|---|---|
| Light Goods Vehicle (3.5 Tonnes) | IVECO Daily Van 3.5T | 25 000 | **34 505** | (Auto Express, 2014) |
| Small Truck (3.5 to 7.5 Tonnes) | IVECO Eurocargo 7.5T | 36 995 | **51 061** | (Freight in the City , 2015) |
| Heavy Goods Vehicle (more than 7.5 Tonnes) | IVECO Stralis (28T) | 70 550 | **97 374** | (The Guardian, 2007) |
| Electric LGV Type 1 | Smith Edison | 57 500 | **79 362** | (VansA2Z, n.d.) |
| Electric LGV Type 2 | Smith Newton | 75 000 | **103 516** | (Business Insider, 2012) |

Furthermore, Smith Electric Vehicles are given incentives in the UK, where The Smith Edison™ is approved for the Government's Plug-In Van Grant of **11.000 €** (8.000 £). Plus, in Scotland, the Energy Saving Trust offers interest-free loans of up to **69.000 €** (50.000 £) to purchase Edison vehicles (Smith Electronic Vehicles, 2015).

The following warehouse rental value was found on (Movehut, 2015).

*Table 6.5 – Warehouse rental values in Glasgow City Centre*

| Address | m2 | £/year | €/year | €/m2.year |
|---|---|---|---|---|
| 120 Bothwell Street , Glasgow G2 7JS | 566 | £ 149 669.00 | 206 575.35 € | 364.97 € |

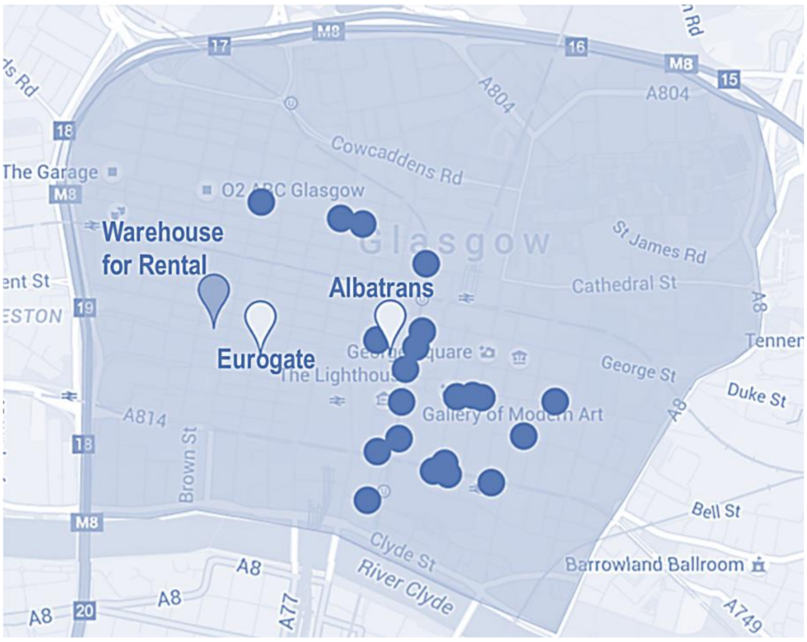


*Figure 6.4 – Location of considered-rent-value warehouse*

- **Albatrans:** Since this transport company claimed, back in 2014, they did not have enough resources to serve as an urban distribution centre, it was considered that, in order to upgrade them to do so, an expansion of current facility was needed, as well the acquisition of some more vehicles;
- **Eurogate:** Stated that they did not have their own vehicle fleet or warehousing facility. Thus, similarly to Albatrans, costs for a new facility and the acquisition of a vehicle fleet were considered;
- **TNT and Clipper:** Since, according to SPT's report, these facilities already gathered the physical and organizational structure to accommodate a UDC, no costs associated to infrastructure or acquisition of vehicles was considered.

Considering the need for space for vehicle parking, plus warehouse space and space for operations, 1000 $m^2$ were considered needed to make Albatrans fit to work as a UDC and 2000 $m^2$ for Eurogate.

Since transportation costs are reported to a daily timeframe, the same will be done to infrastructure and vehicle costs. Thus Table 6.6 and Table 6.7 show, respectively, daily costs of vehicle acquisition (per type of vehicle and assuming a 5 year payment plan) and for warehouse rental (per potential UDC location).

Daily vehicle costs are then obtained by dividing vehicle price per 5 years and 365 days and multiplying it for 6/7 (assuming that deliveries are only made 6 days a week).

*Table 6.6 – Daily vehicle costs per vehicle type*

| Type of Vehicle | Price (€) | Incentive per Vehicle (€) | Daily vehicle cost (€/day) |
|---|---|---|---|
| **Light Goods Vehicle (3.5 Tonnes)** | 34 505.37 € | - € | **16.21 €** |
| **Small Truck (3.5 to 7.5 Tonnes)** | 51 061.04 € | - € | **23.98 €** |
| **Heavy Goods Vehicle (more than 7.5 Tonnes)** | 97 374.14 € | - € | **45.73 €** |
| **Electric LGV Type 1** | 79 362.34 € | 11 000.00 € | **32.11 €** |
| **Electric LGV Type 2** | 103 516.10 € | - € | **48.62 €** |

*Table 6.7 – Daily warehouse rental costs per potential UDC location*

| Potential UDC location | Area to rent (m2) | Rental price (€/m2.year) | Rental price (€/day) |
|---|---|---|---|
| **Clipper** | 0 | 364.97 € | **- €** |
| **TNT** | 0 | | **- €** |
| **Eurogate** | 2000 | | **1 714.16 €** |
| **Albatrans** | 1000 | | **857.08 €** |

### 6.1.7 VEHICLE CAPACITY

In order to evaluate the amount of vehicles needed to satisfy the city centre's demand, vehicle capacities were researched for each type of vehicle based on (U-Haul, 2015), as shown on Table 6.8. Those are the values that will be computed in the model for vehicle capacities.

*Table 6.8 – Vehicle capacity per vehicle type*

| Vehicle Type | Volume (m3) |
|---|---|
| Light Goods Vehicle (3.5 Tonnes) | **14** |
| Small Truck (3.5 to 7.5 Tonnes) | **21** |
| Heavy Goods Vehicle (more than 7.5 Tonnes) | **40** |
| Electric LGV Type 1 | **14** |
| Electric LGV Type 2 | **21** |

### 6.1.8 SCENARIO CREATION AND RESULTS

The creation of a group of scenarios attempts to understand what would currently suit Glasgow best in the implementation of an urban distribution centre. Since the main goal is to explore a solution that prioritizes the sustainable distribution of freight in Glasgow city centre, the developed scenarios attempt at evaluating the location that presents the best trade-off between proximity to the city centre (and thus less pollutant delivery schemes from shorter tours) and investment costs (which, for potential locations further from the city centre are inferior).

Alongside that first goal of scenario creation, it is also an objective to extract information that allows comparison with the current delivery schemes and thus the impact of a UDC in the improvement of sustainability of delivery schemes.

All scenarios work on a total shift from heavy goods vehicles to lighter solutions, whether they are small trucks, light goods vehicles of electric vehicles, as will be seen below. Since the optimization model will use data reporting to one day of deliveries, every other data components will be shaped to fit that same timeframe.

**SCENARIO 1 – CITY CENTRE FACILITY; 21 $M^3$ CAPACITY VEHICLES**

*INPUTS*

As seen on Table 6.8, both small trucks and electric type 2 vehicles have an estimated vehicle capacity of 21$m^3$ (whereas heavy goods vehicles have an approximate capacity of 40$m^3$. In this scenario, a model run will be performed for those same vehicle capacities, aiming at estimating how many vehicles would be necessary to serve all the considered retailers for a daily delivery. Here, results will be adapted to performing the delivery with small trucks or electric vehicles.

Since the wished output contemplates an inside city centre UDC, this model run was only performed for Albatrans and Eurogate.

For small trucks, travelling and emissions costs come as follows:

- Vehicle emissions costs: **0.0259 €/g $CO^2$.Km**
- Travelling costs: **0.3069 €/Km**

As for electric vehicles, no emissions or travelling costs are considered. However, it has to be verified that those vehicles have enough autonomy to perform the suggested routing. On that note, it will be considered that electric vehicles have an autonomy of **90-160 Kms**, based on Newton™ by Smith Electronic Vehicles.

*RESULTS*

*Table 6.9 – Scenario 1 – General Solution*

| | |
|---|---|
| Chosen UDC | **Albatrans** |
| Used Vehicles | **7 Small trucks or 7 Type 2 Electric Vehicles** |

*Table 6.10 – Scenario 1 – Tour Specifications and outbound cargo before sub tour elimination*

| Vehicle | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|
| Vehicle 1 | 17.1854 | Albatrans; DLC; Nike Store; Albatrans | - |
| Vehicle 2 | 14.481 | Albatrans; Topshop; James Robertson Kiltmaker; Albatrans | - |
| Vehicle 3 | 19.1771 | Albatrans; Celtic Store; Wallis; Next; Artstore; Albatrans; Albatrans | - |
| Vehicle 4 | 16.6396 | Albatrans; New Look; James Pringle Weavers of Inverness; Albatrans | - |
| Vehicle 5 | 19.7877 | Albatrans; The White Company; Slanj Kilts; Albatrans; Jigsaw; Bose; Alan Edwards; Agent Provocateur; Jigsaw | Jigsaw; Bose; Alan Edwards; Agent Provocateur; Jigsaw |
| Vehicle 6 | 15.4277 | Albatrans; Deichman; USC; Albatrans | - |

| | | | |
|---|---|---|---|
| Vehicle 7 | 18.9574 | Albatrans; Rubadub; Miss Selfridge; HMV; Albatrans | - |
| **TOTAL** | **121.66** | | |

*Table 6.11 – Scenario 1 – Distribution costs using small trucks before sub tour elimination*

| | | | | **Small Trucks** | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€)** | **Emissions Costs (€/g $CO^2$)** | **Vehicle Costs (€/day)** | **Infrastructure Costs (€/day)** | |
| Vehicle 1 | Small Truck | 1.198 | 0.37 € | 0.03 € | 23.98 € | | |
| Vehicle 2 | Small Truck | 1.333 | 0.41 € | 0.03 € | 23.98 € | | |
| Vehicle 3 | Small Truck | 1.73 | 0.53 € | 0.04 € | 23.98 € | | |
| Vehicle 4 | Small Truck | 0.66 | 0.20 € | 0.02 € | 23.98 € | **857.08 €** | |
| Vehicle 5 | Small Truck | 1.48 | 0.45 € | 0.04 € | 23.98 € | | |
| Vehicle 6 | Small Truck | 1.756 | 0.54 € | 0.05 € | 23.98 € | | |
| Vehicle 7 | Small Truck | 3.175 | 0.97 € | 0.08 € | 23.98 € | | |
| **TOTAL** | | **11.332** | **3.48 €** | **0.29 €** | **167.87 €** | **857.08 €** | **1 028.43 €** |

*Table 6.12 – Scenario 1 –Distribution costs using electric vehicles before sub tour elimination*

| | | | | **Electric Vehicles Type 2** | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€)** | **Emissions Costs (€/g $CO^2$)** | **Vehicle Costs (€/day)** | **Infrastructure Costs (€/day)** | |
| Vehicle 1 | Small Truck | 1.198 | - € | - € | 48.62 € | | |
| Vehicle 2 | Small Truck | 1.333 | - € | - € | 48.62 € | | |
| Vehicle 3 | Small Truck | 1.73 | - € | - € | 48.62 € | | |
| Vehicle 4 | Small Truck | 0.66 | - € | - € | 48.62 € | 857.08 € | |
| Vehicle 5 | Small Truck | 1.48 | - € | - € | 48.62 € | | |
| Vehicle 6 | Small Truck | 1.756 | - € | - € | 48.62 € | | |
| Vehicle 7 | Small Truck | 3.175 | - € | - € | 48.62 € | | |
| **TOTAL** | | **11.332** | **- €** | **- €** | **340.33 €** | **857.08 €** | **1 197.41 €** |

The model run performance statistics can be seen in Appendix 16.

Since a sub tour was detected on the route performed by vehicle 5, it has to be eliminated prior to scenario analysis. On that note, a model run was performed only for delivery points in that route (The White Company, Slanj Kilts, Jigsaw, Bose, Alan Edwards, Agent Provocateur and Jigsaw), with a single vehicle and setting Albatrans as the chosen UDC. Model performance can be seen in Appendix 17 and results after sub tour elimination can be observed in the three tables below.

*Table 6.13 – Scenario 1 – Tour Specifications and outbound cargo after sub tour elimination*

| Vehicle | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|
| Vehicle 1 | 17.1854 | Albatrans; DLC; Nike Store; Albatrans | - |
| Vehicle 2 | 14.481 | Albatrans; Topshop; James Robertson Kiltmaker; Albatrans | - |
| Vehicle 3 | 19.1771 | Albatrans; Celtic Store; Wallis; Next; Artstore; Albatrans | - |
| Vehicle 4 | 16.6396 | Albatrans; New Look; James Pringle Weavers of Inverness; Albatrans | - |
| Vehicle 5 | 19.7877 | Albatrans; The White Company; Alan Edwards; Bose; Agent Provocateur; Jigsaw; Slanj Kilts; Albatrans | - |
| Vehicle 6 | 15.4277 | Albatrans; Deichman; USC; Albatrans | - |
| Vehicle 7 | 18.9574 | Albatrans; Rubadub; Miss Selfridge; HMV; Albatrans | - |
| **TOTAL** | **121.66** | | |

*Table 6.14 - Scenario 1 – Distribution costs using small trucks after sub tour elimination*

| | Small Trucks | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Small Truck | 1.198 | 0.37 € | 0.03 € | 23.98 € | 857.08 € | |
| Vehicle 2 | Small Truck | 1.333 | 0.41 € | 0.03 € | 23.98 € | | |
| Vehicle 3 | Small Truck | 1.73 | 0.53 € | 0.04 € | 23.98 € | | |
| Vehicle 4 | Small Truck | 0.66 | 0.20 € | 0.02 € | 23.98 € | | |
| Vehicle 5 | Small Truck | 2.31 | 0.71 € | 0.06 € | 23.98 € | | |
| Vehicle 6 | Small Truck | 1.756 | 0.54 € | 0.05 € | 23.98 € | | |
| Vehicle 7 | Small Truck | 3.175 | 0.97 € | 0.08 € | 23.98 € | | |
| **TOTAL** | | **12.162** | **3.73 €** | **0.31 €** | **167.87 €** | **857.08 €** | **1 028.69 €** |

The final value of **1028.69 €** only considers travelling costs and vehicles and infrastructure costs since emissions costs are not direct costs in the distribution operation of the UDC.

*Table 6.15 - Scenario 1 –Distribution costs using electric vehicles after sub tour elimination*

| | Electric Vehicles Type 2 | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Small Truck | 1.198 | - € | - € | 48.62 € | 857.08 € | |
| Vehicle 2 | Small Truck | 1.333 | - € | - € | 48.62 € | | |
| Vehicle 3 | Small Truck | 1.73 | - € | - € | 48.62 € | | |
| Vehicle 4 | Small Truck | 0.66 | - € | - € | 48.62 € | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vehicle 5 | Small Truck | 2.31 | - € | - € | 48.62 € | | |
| Vehicle 6 | Small Truck | 1.756 | - € | - € | 48.62 € | | |
| Vehicle 7 | Small Truck | 3.175 | - € | - € | 48.62 € | | |
| **TOTAL** | | **12.162** | **- €** | **- €** | **340.33 €** | **857.08 €** | **1 197.41 €** |

According to the initial considerations regarding vehicle autonomy, all vehicles included in this scenario travel less kilometres than their autonomy limits. The final value of **1197.41 €** does no considered emissions costs.

**SCENARIO 2 – CITY CENTRE PERIPHERY FACILITY; 21 $M^3$ CAPACITY VEHICLES**

*INPUTS*

For scenario 2, the same considerations regarding the vehicle fleet are made as the ones in scenario 1. For this scenario, only Clipper and TNT will be considered in the model run so that the output is given for a facility located in the periphery of the urban area.

Despite knowing that a solution having a UDC located in the periphery of the city will involve more travelled kilometres, the objective of this scenario analysis is to evaluate the trade-off between travelling bigger distances and saving in vehicle and infrastructure costs.

*RESULTS*

*Table 6.16 – Scenario 2 – General Solution*

| | |
|---|---|
| Chosen UDC | **TNT** |
| Used Vehicles | **6 Small trucks/ 6 Type 2 Electric Vehicles** |

*Table 6.17 – Scenario 2 – Tour Specifications and outbound cargo before sub tour elimination*

| Vehicle | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|
| Vehicle 1 | 20.3265 | TNT; DLC; Rubadub; TNT; Celtic Store; Next; Celtic Store | Celtic Store; Next; Celtic Store |
| Vehicle 2 | 19.4671 | TNT; Bose; Alan Edwards; TNT; James Robertson Kiltmaker; USC; James Robertson Kiltmaker | James Robertson Kiltmaker; USC; James Robertson Kiltmaker |
| Vehicle 3 | 20.2015 | TNT; Deichamn; Topshop; New Look; TNT | - |
| Vehicle 4 | 20.3634 | TNT; Artstore; James Pringle Weavers of Inverness; The White Company; Slanj Kilts; TNT | - |
| Vehicle 5 | 20.6533 | TNT; Jigsaw; Nike Store; HMV; TNT | - |
| Vehicle 6 | 20.644 | TNT; Miss Selfridge; Wallis; Agent Provocateur; TNT | - |
| **TOTAL** | **121.66** | | |

*Table 6.18 – Scenario 2 – Distribution costs using small trucks before sub tour elimination*

| | | | | Small Trucks | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Small Truck | 41.87 | 12.85 € | 1.08 € | - € | | |
| Vehicle 2 | Small Truck | 36.72 | 11.27 € | 0.95 € | - € | | |
| Vehicle 3 | Small Truck | 40.14 | 12.32 € | 1.04 € | - € | - € | |
| Vehicle 4 | Small Truck | 38.86 | 11.93 € | 1.01 € | - € | | |
| Vehicle 5 | Small Truck | 38.25 | 11.74 € | 0.99 € | - € | | |
| Vehicle 6 | Small Truck | 38.83 | 11.92 € | 1.01 € | - € | | |
| **TOTAL** | | **234.67** | **72.02 €** | **6.08 €** | **- €** | **- €** | **72.02 €** |

*Table 6.19 – Scenario 2 – Distribution costs using electric vehicles before sub tour elimination*

| | | | | Electric Vehicles Type 2 | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Small Truck | 41.87 | - € | - € | 48.62 € | | |
| Vehicle 2 | Small Truck | 36.72 | - € | - € | 48.62 € | | |
| Vehicle 3 | Small Truck | 40.14 | - € | - € | 48.62 € | - € | |
| Vehicle 4 | Small Truck | 38.86 | - € | - € | 48.62 € | | |
| Vehicle 5 | Small Truck | 38.25 | - € | - € | 48.62 € | | |
| Vehicle 6 | Small Truck | 38.83 | - € | - € | 48.62 € | | |
| **TOTAL** | | **234.67** | **- €** | **- €** | **340.33 €** | **- €** | **340.33 €** |

The model run performance statistics can be seen in Appendix 18.

Again, sub tours were detected on the chosen routing scheme, having to be eliminated prior to scenario analysis. One that note, two new model runs were performed only for delivery points in the routes containing sub tours.

For the elimination of the first sub tour, only DLC, Rubadub, Celtic Store and Next were included in the model, TNT set as UDC location a single vehicle was allocated to the tour. Similarly, with the same UDC and number of vehicles, for the elimination of the second sub tour, only Bose, Alan Edwards, James Robertson Kiltmaker and USC were considered in the model run.

Model performance can be seen in Appendix 19 for vehicle 1 sub tour elimination and Appendix 20 vehicle 2 for sub tour elimination. The routing scheme after sub tour elimination can be seen in the three tables below.

*Table 6.20 – Scenario 2 – Tour Specifications and outbound cargo after sub tour elimination*

| Vehicle | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|
| Vehicle 1 | 20.3265 | TNT; Celtic Store; DLC; Rubadub; Next; TNT | - |
| Vehicle 2 | 19.4671 | TNT; Alan Edwards; Bose; USC; James Robertson Kiltmaker; TNT | - |
| Vehicle 3 | 20.2015 | TNT; Deichamn; Topshop; New Look; TNT | - |
| Vehicle 4 | 20.3634 | TNT; Artstore; James Pringle Weavers of Inverness; The White Company; Slanj Kilts; TNT | - |
| Vehicle 5 | 20.6533 | TNT; Jigsaw; Nike Store; HMV; TNT | - |
| Vehicle 6 | 20.644 | TNT; Miss Selfridge; Wallis; Agent Provocateur; TNT | - |
| **TOTAL** | **121.66** | | |

*Table 6.21 – Scenario 2 – Distribution costs using small trucks after sub tour elimination*

| | | | | Small Trucks | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Small Truck | 32.939 | 10.11 € | 0.85 € | - € | | |
| Vehicle 2 | Small Truck | 38.946 | 11.95 € | 1.01 € | - € | | |
| Vehicle 3 | Small Truck | 40.144 | 12.32 € | 1.04 € | - € | - € | |
| Vehicle 4 | Small Truck | 38.86 | 11.93 € | 1.01 € | - € | | |
| Vehicle 5 | Small Truck | 38.254 | 11.74 € | 0.99 € | - € | | |
| Vehicle 6 | Small Truck | 38.833 | 11.92 € | 1.01 € | - € | | |
| **TOTAL** | | **227.98** | **69.97 €** | **5.90 €** | **- €** | **- €** | **69.97 €** |

Since TNT was the selected UDC location, taking into account the considerations made above for all potential UDC locations in terms of fleet acquisition costs and infrastructure costs, TNT does not have any infrastructure costs nor vehicle acquisition costs since it is assumed that its current fleet and infrastructure characteristics fit the requirements of a UDC scheme.

*Table 6.22 – Scenario 2 – Distribution costs using electric vehicles after sub tour elimination*

| | | | | Electric Vehicles Type 2 | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Small Truck | 32.939 | - € | - € | 48.62 € | | |
| Vehicle 2 | Small Truck | 38.946 | - € | - € | 48.62 € | | |
| Vehicle 3 | Small Truck | 40.144 | - € | - € | 48.62 € | - € | |
| Vehicle 4 | Small Truck | 38.86 | - € | - € | 48.62 € | | |
| Vehicle 5 | Small Truck | 38.254 | - € | - € | 48.62 € | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vehicle 6 | Small Truck | 38.833 | - € | - € | 48.62 € | | |
| **TOTAL** | | **227.98** | **- €** | **- €** | **340.33 €** | **- €** | **340.33 €** |

Despite considering TNT's aptitude to serve as a UDC without major changes in terms of vehicles and infrastructure, it has been considered that this transport company does not yet feature electric vehicles in their vehicle fleet. Therefore, the acqusiton of the necessary vehicles was considered here.

According to the initial considerations regarding vehicle autonomy, all vehicles included in this scenario travel less kilometres than their autonomy limits.

**SCENARIO 3 – CITY CENTRE FACILITY; MIX OF 21 M$^3$ AND 14 M$^3$ VEHICLES**

*INPUTS*

In this scenario, the goal is to make a shift to even lighter vehicles. However, a shift of that nature has repercussions in vehicle capacities, having to increase the amount of vehicles driving in the city and thus, the investment costs of expanding (or acquiring a new vehicle fleet) which are to be analysed.

A mix between 21 $m^3$ vehicles and 14 $m^3$ was made because when attempting the Xpress would not find any integer solutions for a model run with only 14 $m^3$ capacity vehicles.

For small trucks, travelling and emissions costs come as follows:

- Vehicle emissions costs: **0.0259 €/g $CO^2$.Km**
- Travelling costs: **0.3069 €/Km**

As for light goods vehicles (LGV):

- Vehicle emissions costs: **0.0147 €/g $CO^2$.Km**
- Travelling costs: **0.1749 €/Km**

*RESULTS*

*Table 6.23 – Scenario 3 – General Solution*

| | |
|---|---|
| Chosen UDC | **Albatrans** |
| Used Vehicles | **6 LGVs/ 6 Type 1 Electric Vehicles + 3 Small Trucks/ 3 Type 2 Electric Vehicles** |

*Table 6.24 – Scenario 3 – Tour Specifications and outbound cargo before sub tour elimination*

| Vehicle | Vehicle Type | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|---|
| Vehicle 1 | LGV/ Type 1 EV | 13.8533 | Albatrans; Jigsaw; Alan Edwards; HMV; Albatrans | - |
| Vehicle 2 | LGV/ Type 1 EV | 10.5241 | Albatrans; Miss Selfridge; Artstore; Albatrans | - |

| | | | | |
|---|---|---|---|---|
| Vehicle 3 | LGV/ Type 1 EV | 13.6347 | Albatrans; Topshop; New Look; Albatrans | - |
| Vehicle 4 | LGV/ Type 1 EV | 10.3875 | Albatrans; Nike Store; Rubadub; Albatrans | - |
| Vehicle 5 | LGV/ Type 1 EV | 9.31383 | Albatrans; Slanj Kilts; USC; Albatrans | - |
| Vehicle 6 | LGV/ Type 1 EV | 10.9117 | Albatrans; Celtic Store; DLC; Albatrans | - |
| Vehicle 7 | Small Truck/ Type 2 EV | 20.0663 | Albatrans; Bose; Agent Provocateur; Albatrans; Wallis; Next; Wallis | Wallis; Next; Wallis |
| Vehicle 8 | Small Truck/ Type 2 EV | 17.7167 | Albatrans; James Pringle Weavers of Inverness; The White Company; Albatrans | - |
| Vehicle 9 | Small Truck/ Type 2 EV | 15.2478 | Albatrans; Deichman; James Robertson Kiltmaker; Albatrans | - |
| **TOTAL** | | **121.66** | | |

*Table 6.25 – Scenario 3 – Distribution costs using diesel vehicles before sub tour elimination*

| Diesel Vehicles | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | LGV | 2.139 | 0.37 € | 0.03 € | 16.21 € | 857.08 € | |
| Vehicle 2 | LGV | 2.014 | 0.35 € | 0.03 € | 16.21 € | | |
| Vehicle 3 | LGV | 0.984 | 0.17 € | 0.01 € | 16.21 € | | |
| Vehicle 4 | LGV | 2.804 | 0.49 € | 0.04 € | 16.21 € | | |
| Vehicle 5 | LGV | 1.215 | 0.21 € | 0.02 € | 16.21 € | | |
| Vehicle 6 | LGV | 1.273 | 0.22 € | 0.02 € | 16.21 € | | |
| Vehicle 7 | Small Truck | 1.837 | 0.56 € | 0.05 € | 23.98 € | | |
| Vehicle 8 | Small Truck | 0.774 | 0.24 € | 0.02 € | 23.98 € | | |
| Vehicle 9 | Small Truck | 1.738 | 0.53 € | 0.05 € | 23.98 € | | |
| **TOTAL** | | **14.778** | **3..16 €** | **0.27 €** | **169.20 €** | **857.08 €** | **1 029.44 €** |

*Table 6.26 – Scenario 3 – Distribution costs using electric vehicles before sub tour elimination*

| Electric Vehicles | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Type 1 EV | 2.139 | - € | - € | 26,71 € | 857,08 € | |
| Vehicle 2 | Type 1 EV | 2.014 | - € | - € | 26,71 € | | |
| Vehicle 3 | Type 1 EV | 0.984 | - € | - € | 26,71 € | | |
| Vehicle 4 | Type 1 EV | 2.804 | - € | - € | 26,71 € | | |
| Vehicle 5 | Type 1 EV | 1.215 | - € | - € | 26,71 € | | |
| Vehicle 6 | Type 1 EV | 1.273 | - € | - € | 26,71 € | | |
| Vehicle 7 | Type 2 EV | 1.837 | - € | - € | 48,62 € | | |
| Vehicle 8 | Type 2 EV | 0.774 | - € | - € | 48,62 € | | |
| Vehicle 9 | Type 2 EV | 1.738 | - € | - € | 48,62 € | | |
| **TOTAL** | | **14.778** | **- €** | **- €** | **306,11 €** | **857,08 €** | **1 163,19 €** |

The model run performance statistics can be seen in Appendix 21.

Again, one sub tour was detected on the route performed by vehicle 7, which has to be eliminated prior to scenario analysis. One that note, a new model run was performed only for delivery points in the route containing sub tours.

For the elimination of the sub tour, only Bose, Agent Provocateur; Wallis and Next were included in the model, with Albatrans set as UDC location and a single vehicle allocated to the tour.

Model performance of sub tour elimination can be seen in Appendix 22. The routing scheme after sub tour elimination can be seen in the three tables below.

*Table 6.27 – Scenario 3 – Tour Specifications and outbound cargo after sub tour elimination*

| Vehicle | Vehicle Type | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|---|
| Vehicle 1 | LGV/ Type 1 EV | 13.8533 | Albatrans; Jigsaw; Alan Edwards; HMV; Albatrans | - |
| Vehicle 2 | LGV/ Type 1 EV | 10.5241 | Albatrans; Miss Selfridge; Artstore; Albatrans | - |
| Vehicle 3 | LGV/ Type 1 EV | 13.6347 | Albatrans; Topshop; New Look; Albatrans | - |
| Vehicle 4 | LGV/ Type 1 EV | 10.3875 | Albatrans; Nike Store; Rubadub; Albatrans | - |
| Vehicle 5 | LGV/ Type 1 EV | 9.31383 | Albatrans; Slanj Kilts; USC; Albatrans | - |
| Vehicle 6 | LGV/ Type 1 EV | 10.9117 | Albatrans; Celtic Store; DLC; Albatrans | - |
| Vehicle 7 | Small Truck/ Type 2 EV | 20.0663 | Albatrans; Agent Provocateur; Bose; Next; Wallis; Albatrans | - |
| Vehicle 8 | Small Truck/ Type 2 EV | 17.7167 | Albatrans; James Pringle Weavers of Inverness; Thw White Company; Albatrans | - |
| Vehicle 9 | Small Truck/ Type 2 EV | 15.2478 | Albatrans; Deichman; James Robertson Kiltmaker; Albatrans | - |
| **TOTAL** | | **121.66** | | |

*Table 6.28 – Scenario 3 – Distribution costs using diesel vehicles after sub tour elimination*

| | | | | Diesel Vehicles | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | LGV | 2.139 | 0.37 € | 0.03 € | 16.21 € | 857.08 € | |
| Vehicle 2 | LGV | 2.014 | 0.35 € | 0.03 € | 16.21 € | | |
| Vehicle 3 | LGV | 0.984 | 0.17 € | 0.01 € | 16.21 € | | |
| Vehicle 4 | LGV | 2.804 | 0.49 € | 0.04 € | 16.21 € | | |
| Vehicle 5 | LGV | 1.215 | 0.21 € | 0.02 € | 16.21 € | | |
| Vehicle 6 | LGV | 1.273 | 0.22 € | 0.02 € | 16.21 € | | |
| Vehicle 7 | Small Truck | 2.63 | 0.81 € | 0.07 € | 23.98 € | | |
| Vehicle 8 | Small Truck | 0.774 | 0.24 € | 0.02 € | 23.98 € | | |
| Vehicle 9 | Small Truck | 1.738 | 0.53 € | 0.05 € | 23.98 € | | |
| **TOTAL** | | **15.571** | **3.40 €** | **0.29 €** | **169.20 €** | **857.08 €** | **1 029.68 €** |

Again, costs for vehicle fleet acquisition and warehouse space renting were considered according to Albatrans specifications.

*Table 6.29 – Scenario 3 – Distribution costs using electric vehicles after sub tour elimination*

| Electric Vehicles | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vehicle | Vehicle Type | Driven Kms | Travelling Cost (€/Km) | Emissions Costs | Vehicle Costs/Day | Infrastructure Costs/Day | |
| Vehicle 1 | Type 1 EV | 2.139 | - € | - € | 26.71 € | 857.08 € | |
| Vehicle 2 | Type 1 EV | 2.014 | - € | - € | 26.71 € | | |
| Vehicle 3 | Type 1 EV | 0.984 | - € | - € | 26.71 € | | |
| Vehicle 4 | Type 1 EV | 2.804 | - € | - € | 26.71 € | | |
| Vehicle 5 | Type 1 EV | 1.215 | - € | - € | 26.71 € | | |
| Vehicle 6 | Type 1 EV | 1.273 | - € | - € | 26.71 € | | |
| Vehicle 7 | Type 2 EV | 2.63 | - € | - € | 48.62 € | | |
| Vehicle 8 | Type 2 EV | 0.774 | - € | - € | 48.62 € | | |
| Vehicle 9 | Type 2 EV | 1.738 | - € | - € | 48.62 € | | |
| **TOTAL** | | **15.571** | **- €** | **- €** | 306.11 € | **857.08 €** | **1 163.19 €** |

In this scenario, since 14 m$^3$ vehicles are being considered, type 1 electric vehicles are the ones to be purchased in the cost description using electric vehicles.

As seen on 6.1.6, Edison™ Smith Electric vehicles get loans up to **69000 €** from the Energy Saving Trust in Scotland. Thus, for a fleet acquisition of 6 type 1 electric vehicles, the daily cost per vehicle comes as follows:

$$32.11€ - \frac{69000€}{6 \times 5 \times 365 \times \frac{6}{7}} = 26.71€$$

Dividing that total loan per 6 acquired vehicles, in a payment plan of 5 years, considering deliveries only 6 put of 7 days a week, a daily cost of 26.71 € is associated with the purchasing of each vehicle for this scenario.

**SCENARIO 4 – CITY CENTRE PERIPHERY FACILITY; MIX OF 21 M3 AND 14 M3 VEHICLES**

*INPUTS*

For this scenario, the same considerations in terms of travelling and emissions costs for diesel vehicles are considered, as are the acquisition costs of electric vehicles. The creation of this scenario follows the same principle as scenario 2, aiming at comparing, for the same vehicle fleet type, the costs of having a facility in the periphery of the city centre, instead of inside it.

*RESULTS*

*Table 6.30 – Scenario 4 – General Solution*

| | |
|---|---|
| Chosen UDC | **TNT** |
| Used Vehicles | **5 LGVs/ 5 Type 1 Electric Vehicles + 3 Small Trucks/ 3 Type 2 Electric Vehicles** |

*Table 6.31 – Scenario 4 – Tour Specifications and outbound cargo before sub tour elimination*

| Vehicle | Vehicle Type | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|---|
| Vehicle 1 | LGV/ Type 1 Electric Vehicle | 13.8762 | TNT; Wallis; Deichman; TNT | - |
| Vehicle 2 | LGV/ Type 1 EV | 13.8093 | TNT; James Pringle Weavers of Inverness; Agent Provocateur; TNT | - |
| Vehicle 3 | LGV/ Type 1 EV | 13.6347 | TNT; Topshop; New Look; TNT | - |
| Vehicle 4 | LGV/ Type 1 EV | 12.1931 | TNT; Jigsaw; HMV; TNT | - |
| Vehicle 5 | LGV/ Type 1 EV | 10.1269 | TNT; Slanj Kilts; Celtic Store; Next; TNT | - |
| Vehicle 6 | LGV/ Type 1 EV | 19.4671 | TNT; Bose; Alan Edwards; TNT; USC; James Robertson Kiltmaker; USC | USC; James Robertson Kiltmaker; USC |
| Vehicle 7 | Small Truck/ Type 2 EV | 19.8308 | TNT; The White Company; DLC; Artstore; TNT | - |
| Vehicle 8 | Small Truck/ Type 2 EV | 18.7178 | TNT; Nike Store; Rubadub; Miss Selfridge; TNT | - |
| **TOTAL** | | **121.66** | | |

*Table 6.32 – Scenario 4 – Distribution costs using diesel vehicles before sub tour elimination*

| Diesel Vehicles | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | LGV | 39.695 | 6.94 € | 0.58 € | - € | | |
| Vehicle 2 | LGV | 37.986 | 6.64 € | 0.56 € | - € | | |
| Vehicle 3 | LGV | 37.735 | 6.60 € | 0.55 € | - € | | |
| Vehicle 4 | LGV | 37.719 | 6.60 € | 0.55 € | - € | | |
| Vehicle 5 | LGV | 38.089 | 6.66 € | 0.56 € | - € | - € | |
| Vehicle 6 | Small Truck | 36.717 | 11.27 € | 0.95 € | - € | | |
| Vehicle 7 | Small Truck | 37.618 | 11.54 € | 0.97 € | - € | | |
| Vehicle 8 | Small Truck | 38.87 | 11.93 € | 1.01 € | - € | | |
| **TOTAL** | | **304.429** | **68.19 €** | **5.74 €** | **- €** | **- €** | **68.19 €** |

*Table 6.33 – Scenario 4 – Distribution costs using electric vehicles before sub tour elimination*

| Electric Vehicles | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Type 1 EV | 39.695 | - € | - € | 25.63 € | | |
| Vehicle 2 | Type 1 EV | 37.986 | - € | - € | 25.63 € | | |
| Vehicle 3 | Type 1 EV | 37.735 | - € | - € | 25.63 € | | |
| Vehicle 4 | Type 1 EV | 37.719 | - € | - € | 25.63 € | - € | |
| Vehicle 5 | Type 1 EV | 38.089 | - € | - € | 25.63 € | | |
| Vehicle 6 | Type 2 EV | 36.717 | - € | - € | 48.62 € | | |
| Vehicle 7 | Type 2 EV | 37.618 | - € | - € | 48.62 € | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Vehicle 8 | Type 2 EV | 38.87 | - € | - € | 48.62 € | | |
| **TOTAL** | | **304.429** | **- €** | **- €** | **274.00 €** | **- €** | **274.00 €** |

The model run performance statistics can be seen in Appendix 23.

A sub tour was perceived on the route performed by vehicle 6, which again has to be eliminated prior to scenario analysis. One that note, a new model run was performed only for delivery points in the route containing sub tours.

For the elimination of the sub tour, only Bose, Alan Edwards, USC and James Robertson Kiltmaker were included in the model, with TNT set as UDC location and a single vehicle allocated to the tour.

Model performance of sub tour elimination can be seen in Appendix 24. The routing scheme after sub tour elimination can be seen in the three tables below.

*Table 6.34 – Scenario 4 – Tour Specifications and outbound cargo after sub tour elimination*

| Vehicle | Vehicle Type | Outbound Cargo (m3) | Chosen Tour | Sub tours |
|---|---|---|---|---|
| Vehicle 1 | LGV/ Type 1 Electric Vehicle | 13.8762 | TNT; Wallis; Deichman; TNT | - |
| Vehicle 2 | LGV/ Type 1 EV | 13.8093 | TNT; James Pringle Weavers of Inverness; Agent Provocateur; TNT | - |
| Vehicle 3 | LGV/ Type 1 EV | 13.6347 | TNT; Topshop; New Look; TNT | - |
| Vehicle 4 | LGV/ Type 1 EV | 12.1931 | TNT; Jigsaw; HMV; TNT | - |
| Vehicle 5 | LGV/ Type 1 EV | 10.1269 | TNT; Slanj Kilts; Celtic Store; Next; TNT | - |
| Vehicle 6 | LGV/ Type 1 EV | 19.4671 | TNT; Alan Edwards; Bose; USC; James Robertson Kiltmaker; TNT | - |
| Vehicle 7 | Small Truck/ Type 2 EV | 19.8308 | TNT; The White Company; DLC; Artstore; TNT | - |
| Vehicle 8 | Small Truck/ Type 2 EV | 18.7178 | TNT; Nike Store; Rubadub; Miss Selfridge; TNT | - |
| **TOTAL** | | **121.66** | | |

*Table 6.35 – Scenario 4 – Distribution costs using diesel vehicles after sub tour elimination*

| Diesel Vehicles | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | LGV | 39.695 | 6.94 € | 0.58 € | - € | - € | |
| Vehicle 2 | LGV | 37.986 | 6.64 € | 0.56 € | - € | | |
| Vehicle 3 | LGV | 37.735 | 6.60 € | 0.55 € | - € | | |
| Vehicle 4 | LGV | 37.719 | 6.60 € | 0.55 € | - € | | |
| Vehicle 5 | LGV | 38.089 | 6.66 € | 0.56 € | - € | | |
| Vehicle 6 | Small Truck | 38.946 | 11.95 € | 1.01 € | - € | | |
| Vehicle 7 | Small Truck | 37.618 | 11.54 € | 0.97 € | - € | | |
| Vehicle 8 | Small Truck | 38.87 | 11.93 € | 1.01 € | - € | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **TOTAL** | **306.658** | **68.87 €** | **5.80 €** | **- €** | **- €** | **68.87 €** |

Identical to scenario 3, which also had TNT has solution for UDC location, no diesel vehicles or infrastructure acquisition was considered. Similarly, the need for acquisition of an electric vehicle fleet was acknowledged.

*Table 6.36 – Scenario 4 – Distribution costs using electric vehicles after sub tour elimination*

| **Electric Vehicles** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Vehicle** | **Vehicle Type** | **Driven Kms** | **Travelling Cost (€/Km)** | **Emissions Costs** | **Vehicle Costs/Day** | **Infrastructure Costs/Day** | |
| Vehicle 1 | Type 1 EV | 39.695 | - € | - € | 25.63 € | - € | |
| Vehicle 2 | Type 1 EV | 37.986 | - € | - € | 25.63 € | | |
| Vehicle 3 | Type 1 EV | 37.735 | - € | - € | 25.63 € | | |
| Vehicle 4 | Type 1 EV | 37.719 | - € | - € | 25.63 € | | |
| Vehicle 5 | Type 1 EV | 38.089 | - € | - € | 25.63 € | | |
| Vehicle 6 | Type 2 EV | 38.946 | - € | - € | 48.62 € | | |
| Vehicle 7 | Type 2 EV | 37.618 | - € | - € | 48.62 € | | |
| Vehicle 8 | Type 2 EV | 38.87 | - € | - € | 48.62 € | | |
| **TOTAL** | | **306.658** | **- €** | **- €** | **274.00 €** | **- €** | **274.00 €** |

Again, when considering type 1 electric vehicles, a loan of **69000 €** can be taken into account in the acquisition of those vehicles. On that note, the daily purchasing cost of each vehicle comes as follows:

$$32.11€ - \frac{69000€}{5 \times 5 \times 365 \times \frac{6}{7}} = 26.71€$$

Dividing that total loan per 6 acquired vehicles, in a payment plan of 5 years, considering deliveries only 6 put of 7 days a week, a daily cost of 26.71 € is associated with the purchasing of each vehicle for this scenario.

According to the initial considerations regarding vehicle autonomy, all vehicles included in this scenario travel less kilometres than their autonomy limits.

### 6.1.9 MODEL VALIDATION

Because the optimization model was fully adapted from (Muñoz-Villamizar, et al., 2014), the mathematical formulation is considered valid for shaping the problem at hand.

In terms of model running, the obtained results do not reflect the best optimization of costs for each scenario since, due to computational constraints, the presented solutions were kept somehow far from best bounds as can be observed on the table below.

*Table 6.37 – Model runs overview*

| Scenarios | Best Bound | Best Solution | Gap (%) | Time (s) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **Scenario 1** | 7126.56 | 11287 | 36.86 % | 3336.7 |
| **Scenario 2** | 9498.13 | 28477.6 | 66.65 % | 9879.8 |
| **Scenario 3** | 9574.36 | 14778 | 35.21 % | 5703.4 |
| **Scenario 4** | 52570.1 | 304429 | 82.73 % | 7185.4 |

Moreover, the developed process for sub tour elimination is not the most adequate one. Here, for proper model validation, sub tour elimination should be performed according to equation (15), through the solving of the best way to integrate it in the model.

## 6.2 SCENARIO COMPARISON

The table below summarizes scenario results in terms of obtained costs. The goal at this point is to choose the scenario, i.e. the solution in terms of UDC location and vehicle fleet dimensioning that best fits Glasgow City Centre according to best practices in terms of logistics activity mitigation and success factors of implementation.

*Table 6.38 – Summary of scenario results*

| | | Travelling Costs | Emissions Costs | Vehicle Costs/Day | Infrastructure Costs/Day | Total Daily Costs |
|---|---|---|---|---|---|---|
| **Scenario 1** | Diesel Vehicles | 3.73 € | 0.31 € | 167.87 € | 857.08 € | 1 028.68 € |
| | Electric Vehicles | - € | - € | 340.33 € | 857.08 € | 1 197.41 € |
| **Scenario 2** | Diesel Vehicles | 69.97 € | 5.90 € | - € | - € | 69.97 € |
| | Electric Vehicles | - € | - € | 340.33 € | - € | 340.33 € |
| **Scenario 3** | Diesel Vehicles | 3.40 € | 0.29 € | 169.20 € | 857.08 € | 1 029.68 € |
| | Electric Vehicles | - € | - € | 306.11 € | 857.08 € | 1 163.19 € |
| **Scenario 4** | Diesel Vehicles | 68.87 € | 5.80 € | - € | - € | 68.87 € |
| | Electric Vehicles | - € | - € | 274.00 € | - € | 274.00 € |

As can be seen on the table above, Scenario 3 represents the lowest travelling costs, justified by having a facility inside the city centre as UDC location. Through the same logic, it is also the one with least emissions costs, resulting from less driven kilometres and the use of light goods vehicles (less pollutant than small trucks). In terms of vehicle costs per day, when using diesel vehicles, Scenario 1 is the one with less investment costs since the dimensioned fleet for that scenario is composed by less vehicles (in comparison to Scenario 3, since the other two do not contemplate the acquisition of diesel vehicles). When considering the same scenarios running with electric vehicles, Scenario 4 has the lower investment costs in a vehicle fleet since it considers Type 1 Electric Vehicles, which have an extra associated incentive of 69 000 € for electric fleet acquisition and contemplate more of those type of vehicles than Scenario 3.

Regarding infrastructure costs, having the UDC located in TNT (Scenarios 2 and 4) will always represent less costs since no renting of warehouse space is considered necessary. Having Albatrans serving as UDC for the other two scenarios, the daily infrastructure costs will be constant.

In terms of total daily costs, Scenario 4 is the most economic scenario for both diesel and electric vehicles consideration.

When choosing the best scenario, one thing that should also be taken into account is the respect for established legislation in Glasgow City Centre regarding time windows for deliveries. As seen on 4.2, Buchanan Street has a time window for deliveries from 6 am to 10am (4 hours).

Assuming that very same time window for the whole city centre, it will assumed that each vehicle should not have a permanency inside it longer than 4 hours. To evaluate compliance with that rule, driven distances inside the city centre were calculated based on the sum of distances from nodes to other nodes (which always occur inside the city centre) and the parcel of distance inside the city centre from the UDC to a node and back.

Road chiefs in Glasgow City Council plan to roll out a scheme in March 2016 establishing a maximum speed of 32 Km/h (20mph) as a low emission zone (LEZ) definition policy. The goal is to reduce the number of vehicles circulating in the city centre, thus limiting the number of accidents and traffic severity (Evening Times, 2015). With that limit in mind, an average travel speed of **30 km/h** was considered for vehicles driving inside the city centre, allowing to obtain the total time of driving inside it per vehicle.

Moreover, for each delivery point, the sum of distances between all retailers associated to each DP was calculated and a **15 minute** period was considered necessary for loading and unloading operations for each retailer. Assuming that, for each vehicle, there are two people performing walking deliveries to each retailer at a speed of **3 Km/h** (average walking speed for a grown human is 5 Km/h), the **total walking distance per route** can be given by:

$$\sum_{DP}\left(\frac{dist_{DP}}{3\ Km/h} + N_{DP} \times \frac{15\ min}{60 \times 2}\right)$$

Where $dist_{DP}$ represents the total waking distance associated to a delivery point DP and $N_{DP}$ represents the number of retailers in each delivery point. Appendix 25 shows the walking and distribution distances per delivery point. With the above consideration in mind, Table 6.39 to Table 6.42 show the total time inside the city centre for each scenario which will be the criteria for evaluating respect for times windows.

*Table 6.39 – Scenario 1 – Total time inside the city centre*

| Scenario 1 | | | | | | |
|---|---|---|---|---|---|---|
| **Vehicle** | Total driven distance (Km) | Driven distance inside the city centre (Km) | Driven distance outside the city centre (Km) | Time driving inside the city centre (hours) | Time walking inside the city centre (hours) | Total time inside the city centre (hours) |
| **Vehicle 1** | 1.20 | 1.20 | 0 | 0.04 | 1.89 | 1.93 |
| **Vehicle 2** | 1.33 | 1.33 | 0 | 0.04 | 1.23 | 1.27 |
| **Vehicle 3** | 1.73 | 1.73 | 0 | 0.06 | 1.71 | 1.77 |
| **Vehicle 4** | 0.66 | 0.66 | 0 | 0.02 | 1.75 | 1.77 |
| **Vehicle 5** | 2.3 | 2.31 | 0 | 0.08 | 4.00 | 4.07 |
| **Vehicle 6** | 1.76 | 1.76 | 0 | 0.06 | 0.93 | 0.99 |
| **Vehicle 7** | 3.18 | 3.18 | 0 | 0.11 | 2.43 | 2.53 |

*Table 6.40 – Scenario 2 – Total time inside the city centre*

| Scenario 2 | | | | | | |
|---|---|---|---|---|---|---|
| **Vehicle** | Total driven distance (Km) | Driven distance inside the city centre (Km) | Driven distance outside the city centre (Km) | Time driving inside the city centre (hours) | Time walking inside the city centre (hours) | Total time inside the city centre (hours) |
| **Vehicle 1** | 32.94 | 5.78 | 27.16 | 0.19 | 1.46 | 1.65 |
| **Vehicle 2** | 38.95 | 3.45 | 35.50 | 0.12 | 2.19 | 2.30 |
| **Vehicle 3** | 40.14 | 2.62 | 37.53 | 0.09 | 2.56 | 2.64 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Vehicle 4** | 38.86 | 3.82 | 35.04 | 0.13 | 1.52 | 1.65 |
| **Vehicle 5** | 38.25 | 3.82 | 34.43 | 0.13 | 3.02 | 3.15 |
| **Vehicle 6** | 38.83 | 3.72 | 35.12 | 0.12 | 1.89 | 2.01 |

*Table 6.41 – Scenario 3 – Total time inside the city centre*

| **Scenario 3** | | | | | | |
|---|---|---|---|---|---|---|
| **Vehicle** | Total driven distance (Km) | Driven distance inside the city centre (Km) | Driven distance outside the city centre (Km) | Time driving inside the city centre (hours) | Time walking inside the city centre (hours) | Total time inside the city centre (hours) |
| **Vehicle 1** | 2.14 | 2.14 | 0 | 0.07 | 2.20 | 2.27 |
| **Vehicle 2** | 2.01 | 2.01 | 0 | 0.07 | 0.91 | 0.97 |
| **Vehicle 3** | 0.98 | 0.98 | 0 | 0.03 | 2.30 | 2.33 |
| **Vehicle 4** | 2.80 | 2.80 | 0 | 0.09 | 1.77 | 1.86 |
| **Vehicle 5** | 1.22 | 1.22 | 0 | 0.04 | 0.93 | 0.97 |
| **Vehicle 6** | 1.27 | 1.27 | 0 | 0.04 | 0.80 | 0.84 |
| **Vehicle 7** | 2.63 | 2.63 | 0 | 0.09 | 2.02 | 2.10 |
| **Vehicle 8** | 0.77 | 0.77 | 0 | 0.03 | 2.12 | 2.14 |
| **Vehicle 9** | 1.74 | 1.74 | 0 | 0.06 | 0.97 | 1.03 |

*Table 6.42 – Scenario 4 – Total time inside the city centre*

| **Scenario 4** | | | | | | |
|---|---|---|---|---|---|---|
| **Vehicle** | Total driven distance (Km) | Driven distance inside the city centre (Km) | Driven distance outside the city centre (Km) | Time driving inside the city centre (hours) | Time walking inside the city centre (hours) | Total time inside the city centre (hours) |
| **Vehicle 1** | 39.70 | 4.60 | 35.10 | 0.15 | 0.91 | 1.07 |
| **Vehicle 2** | 37.99 | 3.65 | 34.33 | 0.12 | 1.52 | 1.64 |
| **Vehicle 3** | 37.74 | 2.23 | 35.51 | 0.07 | 2.30 | 2.38 |
| **Vehicle 4** | 37.72 | 3.00 | 34.72 | 0.10 | 1.66 | 1.76 |
| **Vehicle 5** | 38.09 | 3.72 | 34.37 | 0.12 | 0.53 | 0.65 |
| **Vehicle 6** | 38.95 | 3.45 | 35.50 | 0.12 | 1.56 | 1.68 |
| **Vehicle 7** | 37.62 | 3.30 | 34.32 | 0.11 | 2.50 | 2.60 |
| **Vehicle 8** | 38.87 | 4.32 | 34.55 | 0.14 | 2.15 | 2.29 |

Another aspect to evaluate is the significance of emissions reduction for each scenario, being one the most important decision factors. In order to estimate that reduction in comparison to the current scenario (without UDC), the survey answers for the number and type of vehicles performing deliveries to each establishment were taken into account.

Counting with 37 retailers under survey who provided an answer to that field, the average number of vehicles per type and per delivery for all surveyed retailers was obtained by diving the number of vehicles performing deliveries in a week by the given number of deliveries in a week.

By dividing those last values by **37**, a rough estimate of the amount of vehicles per surveyed retailer was obtained. Multiplying that value by the total population of **108** retailers, the total number of vehicles per type and per delivery was obtained for the whole population. As seen on Table 5.6, **66%** of the inquired retailers claimed they already had their deliveries coordinated. Thus, it will be assumed that the number of vehicles to be considered is 66% of the estimated value in order to consider that coordination factor. The table below demonstrates the line of thought described above as does Appendix 26.

*Table 6.43 – Estimation of the number of vehicles in the city centre per delivery (prior to UDC implementation)*

| | LGV | Small Truck | HGV |
|---|---|---|---|
| Average number of vehicles per delivery for all surveyed retailers | 15.9 | 15.5 | 3.9 |
| Average number of vehicles per delivery per retailer | 0.4 | 0.4 | 0.1 |
| Total number of vehicles per delivery for the population | 46.3 | 45.2 | 11.4 |
| Total number of vehicles (considering coordination of deliveries | 30.6 | 29.8 | 7.5 |

To estimate the emissions per kilometre for the current situation in Glasgow City Centre, the tabled values for emissions (in Table 6.3) were applied in this case.

Moreover, knowing that 37% of surveyed retailers claimed that had their deliveries come from a facility outside the city centre, it will be assumed that vehicles have route lengths corresponding to serving two retailers, on average, from a facility close to the city centre (a value of 35 Km will be assumed based on values obtained on the scenario results), allowing to make an estimate of the total of emissions for the current scenario in g $CO^2$ for a day of deliveries.

*Table 6.44 – Emissions reduction per scenario*

| | Total emissions (g CO2/Km) | Total emissions (g CO2) | Emissions reduction (g CO2( Km) | Emissions reduction (g CO2) |
|---|---|---|---|---|
| **Current Scenario** | 29610.0 | 296100 | - | - |
| **Scenario 1** | 3620.7 | 6290.7 | 25989.3 | 1030059 |
| **Scenario 2** | 3103.4 | 12005.1 | 26506.6 | 1024345 |
| **Scenario 3** | 3320.5 | 5734.1 | 26289.5 | 979009 |
| **Scenario 4** | 2803.3 | 10028.8 | 26806.7 | 936062 |

At this point, Scenario 1 is the only one that does not comply with legislation regarding time windows for one of its routes and the one with less reduction of emissions per kilometre. Moreover, when compared to Scenario 3, that runs with the same UDC, this last one represents a better option in fleet dimensioning for emissions and daily costs.  Therefore, Scenario 1 does not qualify as best scenario.

When comparing Scenario 2 with Scenario 4, where both have TNT as UDC location, Scenario 4 represents less total daily costs and emissions, meaning that Scenario 4 will always be a best choice when compared to Scenario 2.

Scenario 3 represents smaller values of total emissions than Scenario 4. However, the vehicle fleet dimensioned for Scenario 4 represents a bigger amount of emissions reduction (g $CO_2$/Km) where a higher value of total emissions for this scenario is explained by the extra kilometres that vehicles coming from TNT have to drive from the moment they enter the city centre to the moment of arrival to the retail area, which will always be associated with a distribution centre located in the periphery.

Coming down to choosing between Scenario 1 and Scenario 4 practically means choosing to locate the UDC inside the city centre or on its periphery. At this point, acknowledging past considerations on best practices for UDC implementation from literature review and Steer Davies Gleave study, the decision criteria will lay on those considerations for a UDC in trial phase.

On that note, according to Steer Davies Gleave study, the cost of property for an urban distribution centre represents about 50% of the total investment costs of setting up the whole operation. In all cases, the idea of building a purpose built facility to deliver a city centre service is seen, by logistics providers, unpractical, not cost effective and not the best use of resources. As for staffing and transportation costs (which represent the other half of investment costs), it was believed, by logistics providers in Glasgow, that those costs would not be that high if based on the adaption of their existing operation. Also, as seen on literature review of existing urban distribution centres studies in other European cities, the number of users is a crucial factor in all success and failure cases.

Scenario 4 is thus the one that best fits the above considerations: it would be based on a facility that has already the proper infrastructure to accommodate a distribution centre and TNT has the biggest market share of deliveries in Glasgow City Centre (60% among surveyed retailers by Steer Davies Gleave), being on the right track to guarantee a certain number of retailers joining the scheme. Moreover, the success of Albatrans (in Scenario 3) has an urban distribution centre would be highly dependent on the ability to adapt its infrastructure to a UDC scheme, especially in terms of warehousing space.

Finally, back in 2010, in the SPT study, it was felt that electric vehicles, while desirable, would be an expensive investment unless fully funded by public subsidy and any funding resource would be, in the short term, best placed to modify existing vehicles to become more efficient with a long term goal of providing an electric vehicle service.

The graph below represents a visual output of the positioning of each scenario in three of the main fronts analysed in analysis of the optimization model results: total costs, emissions reduction and time of permanence in the city centre. To build this graph, the following was considered:

- **Time permanence in the city centre**: Average time spent by vehicles in each scenario, in hours;
- **Total costs**: Sum of operation costs and investment costs for each scenario;
- **Emissions reduction**: total value of emissions reduction for each scenario, when compared to the current scenario (without the UDC) in g $CO^2$.

Those values were then reported to a unitary scale to present a uniform output.

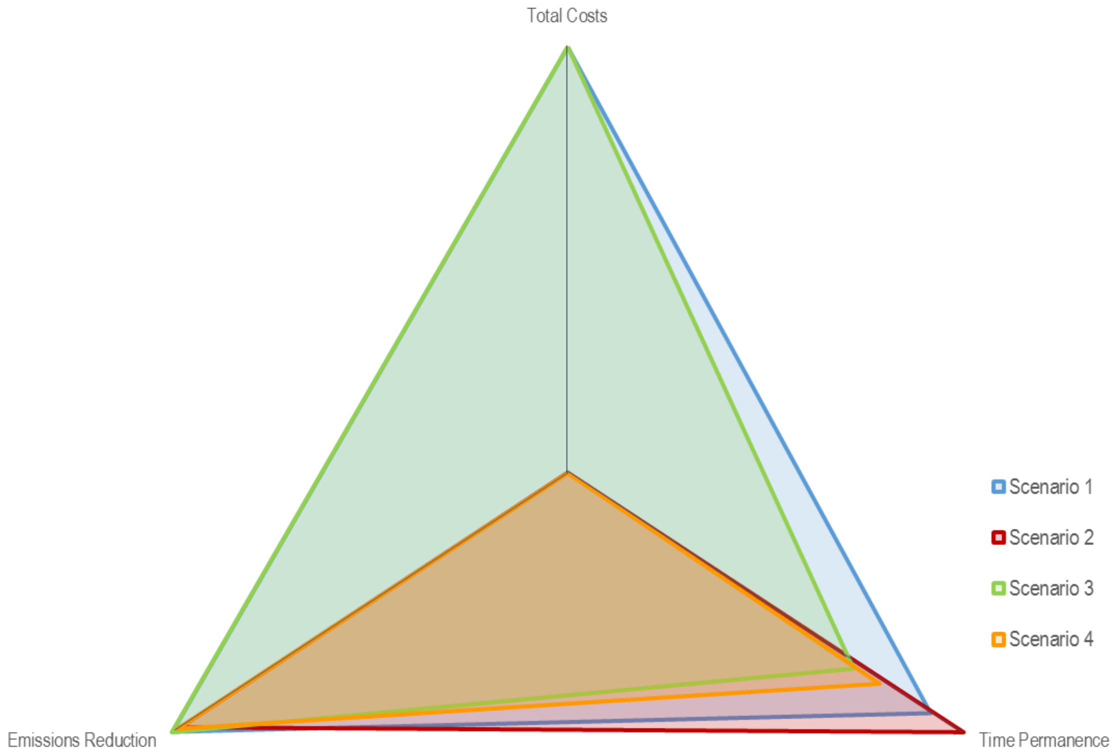


*Figure 6.5 – Scenarios Trade-Off*

Through this output, it can be seen that every scenario has similar proportions of inside the city centre emissions reductions, very independent of the centres' location. As for time of permanence in the city centre, Scenarios 3 and 4 have the lowest time of permanence in the city centre demonstrating that UDC proximity to the city centre is not related, a priori, to less or more time of permanence inside the city centre. As for total costs, scenario 2 and scenario 4 have considerably lower costs due to less investment costs. With this in mind, choosing a location outside the city centre represents a good trade-off between driving bigger distances to reach the city centre and avoiding investment costs in setting up the urban distribution centre while maintaining a component of respect for emissions and time of permanence in the city centre.

# 7 CONCLUSIONS AND FUTURE WORKS

## 7.1 REVIEW OF OBJECTIVES

The main goal of this work was to evaluate the degree of implementation and adequacy of an urban distribution centre in the City Centre of Glasgow, through public entities standpoint and its capability to alleviate city logistics associated issues in the study area.

To that end, the study firstly aimed at recognizing the importance of public entities in the field of city logistics for the development of any strategy that would aim at mitigating freight activity in urban areas. Through extensive consultation, a successful review of the dynamics involved in city logistics and the involvement of public bodies in those dynamics, the extent of their intervention and limitations in action was provided in this study.

Moreover, through an informed selection of best practices and mitigation strategies, this work was able to provide a widespread framework for intervention on the reduction of impacts caused by freight activity in urban areas. That same assessment allowed the identification of a specific mitigation strategy that could, when applied to a case study area, be explored in order to test its validity, based on an approximation of reality in terms of data quantification and stakeholders' behaviour.

One of the most challenging tasks of this work was the attainment of concrete data to model the solution to be explored. Here, the obtained results fell somehow far from what was expected in terms of data relevance: the number of collected responses was not entirely representative of the population under study and the provided answers contained a certain degree of unawareness from shop keepers regarding urban distribution centres and their own delivery schemes, where direct approach to Head Offices would have solved this last gap in knowledge.

Finally, for completion of the main goal of this work, a comparison between the implementation of different scenarios and the current scenario (without the implementation of an urban distribution centre) was to be made, taking advantage of all the work that had been carried so far, crossing the assessment of best practices and past studies with the knowledge of Glasgow's freight dynamics. In this last field, much because of limitations in data obtainment and computational constraints, it was felt that the work did not live up to its full potential.

Instead, the output represents more of an indicative procedure on how the viability of implementation of an urban distribution centre serving Glasgow City Centre should be studied, providing the guidelines for a work to be carried with extensive collection of data on freight dynamics and stakeholders view on the implementation of the concept. Here, a full assessment of the willingness of retailers to take part in an urban distribution centre and the disposition of logistics providers to adapt their facilities to the concept, with full awareness of the involved costs and changes in the city's deliveries schemes is thought to be crucial.

## 7.2 FUTURE WORKS FOR UDC IMPLEMENTATION IN GLASGOW CITY CENTRE

It then is still very important to determine the most appropriate scale of a freight mitigation strategy as is defining a 'where to start' point of a detailed study on this field, which is highly dependent on the complete establishment of the retail versus supply/ demand pressures for the prime retail area, aligning current delivery and waiting constraints with the appetite Glasgow City Council may have for tightening or lengthening any restrictions as a 'stick' measure.

A comprehensive audit of all delivery and stock movements is therefore essential to fully understand the delivery profile for the whole retail area rather than applying an average approach from the data made available through retailers' consultation process. Moreover, a selection process should be completed in order to establish the most adequate logistics partner to serve as a UDC, offering much more credibility and weight for establishing such a service.

Also, patterns of freight movements within the chosen area must be closely monitored. When suitable data is already available, new surveys should be conducted to determine the volumes, mix and scheduling of deliveries and collections. Retail outlets generate significant volumes of return product and packaging waste that if often collected by separate vehicles, which was not a consideration made in this study.

It is also questionable the level of public funding that may be required to set up such a service. The need for subsidizing appears to be focused during the setup period as the distribution centre establishes itself in the market. However, the possibility of having the whole trial service with the full support of the public bodies is thought to be necessary for the success of the UDC. The necessity comes from the need to cover adaption costs for existing warehousing space plus a trial period cost saving in order to be able to provide attractive rates to potential customers to increase customer retention.

For a distribution centre to be effective and sustainable, it would need numerous retailers. This, as would not be possible to deliver all products within the normal access restrictions, would need a relaxation of any parking or delivery restrictions for vehicles associated with the UDC. In Glasgow, it was especially obvious that the willingness of retailers to join an urban distribution centre was very dependent on time-related issues. Retailers in Glasgow city centre have their deliveries occur according to their economic capability for having out-of-hours employees receiving the deliveries or, on the other hand, having them delivered before store-opening, on a very strict and specific time frame. In fact, when surveying retailers, the majority said that the deal breaker for joining a distribution centre would be the alteration of their delivery schemes. Therefore, if wanting to implement a UDC serving Glasgow's retail centre, retailers' individual preferences regarding deliveries (period for delivery, number of deliveries a week, delivery costs) would have to be very carefully evaluated.

Briefly, the implementation of an urban distribution centre should play on three main fronts:

1. The attraction of a significant amount of retailers, manageable through the respect for their preferences regarding deliveries as well as the introduction of a certain degree of compliance, attainable through the limitation of access conditions, both physical and time-related;
2. The interest of public bodies, mainly SPT and Glasgow City Council, to recognize an urban distribution centre as a valid solution for freight activity mitigation (this acknowledgment is essential mainly due to the need for public funding for a successful building up of the operation);

3. The study of logistics providers stands towards the UDC concept, guaranteeing that none see it as an attempt of monopolizing the market since it is these entities that are able to gain trust with existing clients and who can then engage with the decision makers to promote the change required at the same time they have the knowledge of how an urban distribution centre could benefit the demands of their clients.

In the end, is it the willingness of this group of stakeholders in welcoming the UDC concept that will determine the success of its implementation. Unfortunately, the degree of understanding of that stigma in this study only scratches the surface. The study of freight dynamics is still very incomplete and thus the output of modelling for UDC implementation presents a merely indicative suggestion of the best path for UDC implementation in Glasgow.

The need to quantify all involved costs in the built up of this operation is still to be done as is the collection of more concrete data for comparison of scenarios with and without the urban distribution centre. The usage of delivery points, though interesting to explore less intrusive delivery solutions (based on on-foot or bicycle deliveries) is not optimized nor viable to offer retailers the stands they demand for delivery times. Also, the estimation made for infrastructure and vehicle costs is merely indicative and does not reflect real associated costs to the setting up of a UDC.

In what concerns the ideal location of an urban distribution centre, this work corroborates the conclusions made by Steer Davies Gleave in 2010, stating that the ideal location should be associated with an accredited logistics provider who could deliver the right infrastructure without significant investment. Also, the purchasing of electric vehicles should not be done at an early stage of the UDC implementation but it would be important to develop the scheme with that medium-term goal in mind for the design of the operation.

Regarding the optimization model, eventual carrying of future work should be able to surpass some of the computational constraints denoted is this study, mainly related to the elimination of sub tours and a best approximation to more optimized solutions for a bigger quantity of data.

Further work is then essential to fully appreciate the benefits of creating a retail focused distribution centre. If deciding to do so in order to develop a real attempt at UDC implementation, stakeholders should be approached at an early stage of the process, guaranteeing that their levels of interest are fully assessed

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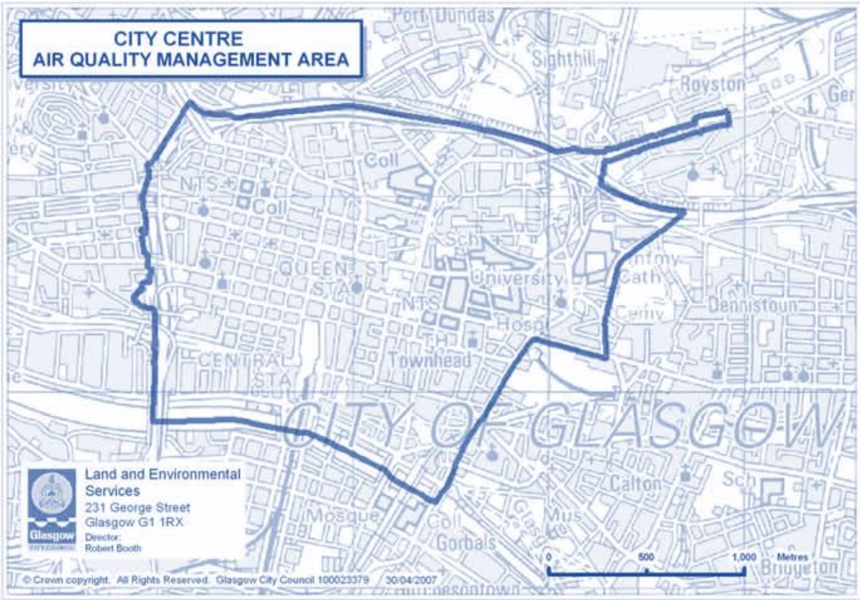
# APPENDIXES




*Appendix 1 - City Centre Air Quality Management Area (AQMA) (Source: Glasgow City Council)*

| Shop | Address |
|---|---|
| Agent Provocateur | 213 Ingram Street |
| Aldo | 64 Buchanan Street |
| All Saints | 98 Buchanan Street |
| American Apparel | 77 Nelson Mandela Place |
| Ann Summers | 55-57 Sauchiehall Street |
| Bravissimo | 229 Ingram Street |
| Camper | 160 Buchanan Street |
| Cath Kidston | 18 Gordon Street |
| Coast | 34 Buchanan Street |
| Cruise | 180 Ingram Street |
| Deichmann Shoes | 250-252 Sauchiehall Street |
| Diesel | 116-120 Buchanan Street |
| Dune | 105 Buchanan Street |
| Emporio Armani | 19 John Street, the Italian Centre |
| Evans | 137-143 Argyle Street |
| Fat Face | Unit 4 185-221 Buchanan Street |
| Footasylum | 116-120 Argyle Street |
| G Star Raw | 135 Argyle Street |
| Gant | 207 Ingram Street |
| GAP | 201 Buchanan Street |
| Hector Rusell Kiltmaker | 110-112 Buchanan Street |
| Hobbs | 127 Buchanan Street |

| | |
|---|---|
| Hugo Boss | 55 Buchanan Street |
| Jaeger | 206 Ingram Street |
| James Robertson Kiltmaker | 118 Sauchiehall Street |
| Jigsaw | 177 Ingram Street |
| Kilts & Cashmere of Scotland | 36 Gordon Street |
| LK Bennett | 32 Royal Exchange Square |
| Miss Selfridge | 8 Argyle Street |
| Monsoon | 66-70 Buchanan Street |
| New Look | 150 Buchanan Street |
| Osiris | 55 Queen Street |
| Pretty Green | 201 Ingram Street |
| Radley | 14 Royal Exchange Square |
| Ralph Lauren | 208 Ingram Street |
| Replay | 162-166 Ingram Street |
| River Island | 18-20 Argyle Street |
| Robertson Outwear | 42-44 Queen Street |
| Size? | 17 Union Street |
| Slanj Kilts | 80 St Vincent Street |
| Slaters | 165 Howard Street |
| Soletrader | 164A Buchanan Street |
| Stons | 81 Queen Street |
| Ted Baker | 61 Buchanan Street |
| Thomas Pink | 1 Royal Bank Place |
| TM Lewin | 133 Buchanan Street |
| Topshop | 229 Buchanan Street |
| Urban Outfitters | 157 Buchanan Street |
| USC | 104 Sauchiehall Street |
| Wallis | 149 Argyle Street |
| Wish Boutique | 266 Clyde Street |
| Zara | 12-16 Buchanan Street |
| Skechers | 213 Buchanan Street |
| Greaves Sports | 82 Sauchiehall Street |
| Tiso | 129 Buchanan Street |
| The Celtic Store | 154 Argyle Street |
| Timberland | 91 Buchanan Street |
| Nike Store | 20-26 Buchanan Street |
| Mountain Warehouse | 7 Gordon Street |
| Evans Cycles | 19 Bath Street |
| LOVEmusic | 34 Dundas St Glasgow |
| Missing Records | 247 Argyle Street |
| Monorail Music | 12 King St Glasgow |
| Rubadub | 35 Howard Street Glasgow |
| Artstore | 94 Queen Street |
| Forbidden Planet | 168 Buchanan Street |
| Tam Sheperds Trick Shop | 33 Queen Street |
| Fast Frame | 82 Queen Street |

| | |
|---|---|
| About Face | 40 St Enoch Square |
| Alan Edwards | 56-58 Wilson Street |
| Beauty Kitchen | 117 Saltmarket |
| City Barbers | 99 West Nile Street |
| DLC | 10 A Mitchell Lane |
| Good Win's Hair and Nail Boutique | 61 Virginia Street |
| Holland & Barrett | 9 Queen Street |
| James Dun's House | 4 Hanover Street |
| Lush | 136 Sauchiehall Street |
| Merchant City  Barbers | 62 Wilson Street |
| Nailzone | 53 Queen Street |
| Neal's Yard Remedies | 11 Royal Exchange Square |
| Rainbow Room International | 125 Buchanan Street |
| The Beauty Store | Virginia Court |
| The Body Shop | 31 Sauchiehall Street |
| Toni&Guy | 96 St Vincent Street |
| James Pringle Weavers of Inverness | 130 Buchanan Street |
| Paperchase | 197 Buchanan Street |
| The Good Spirits Co. | 23 Bath Street |
| The White Company | 123 Buchanan Street |
| WH Smith | 53-55 Argyle Street |
| Apple | 147 Buchanan Street |
| Bose | 136 Ingram Street |
| HMV | 6 Argyle Street |
| Bang & Olufsen | 153 Ingram Street |
| Maplin Electronics | 30 St Enoch Square |
| Accessorize | 96 Argyle Street |
| BHS | 67-81 Sauchiehall Street |
| Debenhams | 97 Argyle Street |
| Dunnes | 222 Sauchiehall Street |
| Forever 21 | 185 Buchanan Street |
| House of Fraser | 45 Buchanan Street |
| Marks&Spencer | 2-12 Argyle Street |
| Next | 70-76 Argyle Street |
| The North Face | 153-155 Buchanan Street |
| TJ Hughes | 127-135 Trongate |
| TK Maxx | 179 Sauchiehall Street |
| Primark | 56 Argyle Street |
| Watt Brothers | 119-121 Sauchiehall Street |
| Whittard of Chelsea | 95 Buchanan Street |

*Appendix 2 – Shops to be featured in the survey*

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

University of Strathclyde Engineering

## Retail deliveries in Glasgow City Centre

Thank you for reading this.

Within the scope of my MSc dissertation, regarding city logistics and freight distribution in Glasgow City Centre, I am conducting this survey as an essential part of my study, at the University of Strathclyde.

I would then like to invite you to take part in this research study by completing the questionnaire that follows. You have been identified as a potential respondent by being aware of or responsible for the freight operations taking place in a certain retail store located in Glasgow City Centre.

Please answer all the questions.

Information used will be protected under the terms of the Data Protection Act. Any information supplied by you will be exclusively used for the purposes of the research programme and will not be passed to others or used for any other purposes. All information will be published in aggregated form so that individuals cannot be identified. The data will be held and disposed of securely when its purpose for collection is over.

If you have any queries regarding this survey please contact, at any time:

Catarina Duarte Gomes
catarina.duarte-gomes.2014@uni.strath.ac.uk

The same email address will be valid if you wish to learn more about the results of the research.

Thank you for your collaboration.

Yours sincerely,

Catarina Maria Duarte Gomes

*Appendix 3 - Survey to Retailers in Glasgow City Centre – Ethics*

## Business/ Establishment Characteristics

**1.1 Establishment Name**

______________________________

**1.2 Business Hours** (please indicate all that apply)

☐ Weekdays ☐ Saturdays ☐ Sundays and holidays

**1.3 This establishment is:**

☐ An independent store which arranges deliveries on its own

☐ An independent store which arranges deliveries in cooperation with other stores in Glasgow most of the time

☐ An independent store which occasionally arranges deliveries in cooperation with other stores in Glasgow

☐ Part of a chain of stores whose deliveries are coordinated

☐ Other (please specify): ___________

**1.4 Does your establishment own a warehouse/storage area**

☐ Yes ☐ No

**1.5 If yes, is it located inside the store?**

☐ Yes ☐ No

## 2. General Characteristics of Deliveries

**2.1 Your establishment gets its goods from:**

☐ A single supplier ☐ Multiple suppliers (if so, please specify how many): ___

**2.2 Vehicles performing deliveries to your establishment perform, in a single trip:**

☐ Deliveries to multiple establishments

☐ Deliveries only to your establishment

☐ Other (please specify):______________________________

**2.3 Vehicles performing deliveries to your establishment typically depart from their origin:**

☐ Fully loaded

☐ Almost full

☐ Half full

☐ Almost empty

☐ You don't know

**2.4 Vehicles performing deliveries to your establishment <u>typically</u> depart from:**

☐ A facility inside the City Centre

☐ A facility close to the City Centre

☐ A facility far away from the City Centre

☐ You don't know

## 3. Specific Characteristics of Deliveries

For the following questions, please have **<u>Christmas Season</u>** deliveries as a reference.

**3.1 What was the average number of deliveries made to your establishment during a <u>week</u> of <u>Christmas Season</u>?**

Total: ____

**3.2 How does that number compare to a <u>typical week</u>'s number of deliveries?**

☐ Around 50% less

☐ Around 25% less

☐ Same as usual

☐ Around 25% more

☐ Around 50% more

Please specify a more accurate value, if within your knowledge: _____

**3.3 What type of vehicles performs the deliveries to your establishment in a <u>typical week</u>?**
(please write down the number of times a week each type of vehicle performs those deliveries)

| Type of Vehicle | Number of times a week |
|---|---|

| | |
|---|---|
| Light Goods Vehicle (3.5 Tones) | ☐ |
| Small Truck (3.5 to 7.5 Tones) | ☐ |
| Heavy Goods Vehicle (more than 7.5 Tones) | ☐ |
| Other (please specify): ____________ | ☐ |

**3.4 When are you willing to receive deliveries to your establishment?**

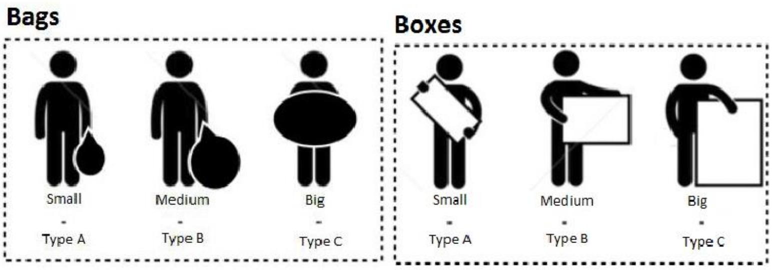
| | Before Opening Time | During Business Hours | After Hours |
|---|---|---|---|
| **Weekdays** | ☐ | ☐ | ☐ |
| **Saturdays** | ☐ | ☐ | ☐ |
| **Sundays** | ☐ | ☐ | ☐ |
| 6 am | 9am | 6pm | 8pm |

**3.5 How satisfied are you with your current deliveries scheme?**

☐ Very satisfied ☐ Satisfied ☐ Partially satisfied ☐ Dissatisfied

## 4. Characteristics of the delivered goods

For questions **4.1**, **4.2** and **4.5**, please take into account the following model:




**4.1 Please give an estimate of the total number of deliveries belonging to each category that were made to your establishment during a week of Christmas Season?** (please write down the number of bags/boxes based on the model above)

| | Type A | Type B | Type C |
|---|---|---|---|
| **Bags** | ☐ | ☐ | ☐ |
| **Boxes** | ☐ | ☐ | ☐ |

**4.2 Please give an estimate of the total number of deliveries belonging to each category that were made to your establishment on a typical week?** (please write down the number of bags/boxes based on the model above)

| | Type A | Type B | Type C |
|---|---|---|---|
| **Bags** | ☐ | ☐ | ☐ |
| **Boxes** | ☐ | ☐ | ☐ |

**4.3 Does your business provide online shopping services?**

☐ Yes ☐ No

**4.4 If yes, the goods ordered online are:**

☐ Delivered to the store for customer collection

☐ Delivered door-to-door

☐ Both (according to customer preference)

**4.5 If the goods ordered online are delivered to the store for customer collection, please give an estimate of the total number of deliveries coming from online shopping, belonging to each category that were made to your establishment on a typical week?** (please write down the number of bags/boxes based on the model above)

| | Type A | Type B | Type C |
|---|---|---|---|
| **Bags** | ☐ | ☐ | ☐ |
| **Boxes** | ☐ | ☐ | ☐ |

## 5. Characteristics of loading and unloading operations

**5.1 Do you identify any of the following problems in the way loading/unloading operations are performed to your establishment?** (please indicate all that apply)

☐ Vehicles blocking other vehicles

☐ No space for manoeuvres

☐ Few space for unloading operations

☐ Congestion near the establishment

☐ Delays due to the issues mentioned above

☐ No problems identified

☐ Other (please specify):___________________________________________________________

## 6. Urban Distribution Centres

*By coordinating deliveries with other stores, it is thought that Urban Distribution Centres offer the prospect of reducing traffic in city centres without compromising the efficiency of deliveries to shops.*

**6.1 Under which circumstances would you integrate your deliveries in an Urban Distribution Centre (UDC) scheme?** (please choose the statement that better reflects your opinion)

☐ "If a UDC was implemented, I would like my establishment's deliveries to be integrated in that scheme"

☐ "I would be interested in integrating a UDC scheme as long as it did not involve any extra operation costs to my business"
☐ "I would be interested in integrating a UDC scheme and have deliveries to my shop suffer alterations as long as their efficiency and punctuality was still guaranteed"
☐ "I would be interested in integrating a UDC scheme if deliveries to my shop did not suffer any alterations"
☐ "I would only integrate a UDC scheme if, through public policy changes regarding freight distribution, the UDC presented some degree of compulsion"

**6.2 If a UDC was to be implemented in Glasgow City Centre and participation was compulsory, which characteristics would you prioritize in order to favour/improve your business?**

Please rank from **1** to **7**, from least important to most important

☐ Ability to keep your current deliveries scheme/schedule

☐ Ability to keep (all) inventory at the UDC's location

☐ Having the UDC located inside the City Centre's perimeter

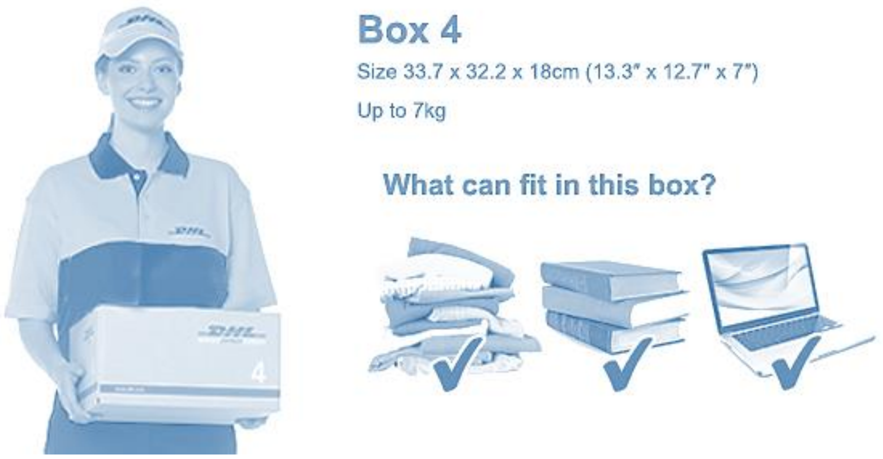
☐ Benefit from privileged freight distribution regulations (e.g. flexible delivery timeframes)

☐ Ability to collect goods at the UDC whenever wanted, instead of having them delivered to the shop

☐ Ability to reduce the number of deliveries per week to the shop

☐ Having an experienced/acknowledged entity operating the UDC

Thank you for your collaboration.




*Appendix 10 – DHL's Box 4 Type scheme*


*Appendix 11 - DHL's Box 6 Type scheme*


*Appendix 12 - DHL's Box 7 Type scheme*

| | | Small | Small to Medium | Medium | Medium to Big | Big |
|---|---|---|---|---|---|---|
| **Clothing & Accessories** | **Surveyed** | Slanj Kilts | Ann Summers, Camper, Thomas Pink, Size, Wallis, Fat Face, Replay, Pretty Green | Topshop, Timberland, Jaeger, USC, Evans, Dune, Hugo Boss | Deichman | Slaters |
| | **For extrapolation** | James Robertson Kiltmaker, Kilts & Cashmere of Scotland, Soletrader, Wish Boutique | Robertson Outwear, Agent Provocateur, Bravissimo, Hobbs, Size?, Stons, Hector Russel Kiltmaker, Radley, Diesel, Gant, LK Bennet, TM Lewin, Emporio Armani, Ralph Lauren, Jigsaw, Ted Baker | Footasylum, Cruise, Urban Outfitters, GAP, Miss Selfridge, Osiris, American Apparel, River Island, G Star Raw, Coast, New Look, Accessorize | Monsoon, All Saints, Zara | - |
| **Sports** | **Surveyed** | - | - | Mountain Warehouse, Celtic Store, Tiso | - | - |
| | **For extrapolation** | | | | Nike Store | - |
| **Culture & Leisure** | **Surveyed** | Rubadub | Monorail Music | Artstore | - | - |
| | **For extrapolation** | Forbidden Planet, Fast Frame, Missing Records, Tam Shepherd's Trick Shop, LOVEmusic | - | - | - | - |
| **Health & Beauty** | **Surveyed** | Neal Yard's Remedies | The Body Shop | - | - | - |
| | **For extrapolation** | About Face, Good Wins Hair Boutique, Nailzone, Beauty Kitchen, The Beauty Store, City Barbers, Merchant City Barbers, Toni & Guy, Alan Edwards, DLC | Holland & Barret, Rainbow Room International, Lush | - | - | - |
| **Gifts & Souvenirs** | **Surveyed** | - | Whittard of Chelsea, The White Company | - | - | - |
| | **For extrapolation** | The Good Spirits | James Pringle Weavers of Inverness | WH Smith | Paperchase | |
| **Department Stores** | **Surveyed** | - | - | - | - | Forever 21 |
| | **For extrapolation** | - | - | - | - | House of Fraser, Marks & Spencer, Next, TJ Hughes, Debenhams, Primark, BHS, TK Maxx, Watt Brothers, Dunnes |
| **Electronics** | **Surveyed** | - | Bose | - | Maplin | - |
| | **For extrapolation** | - | Bang & Olufsen | - | Apple Store, HMV | - |

*Appendix 13 – Categorization of shops for data extrapolation*

| Shop | Volume (m3) | Shop | Volume (m3) | Shop | Volume (m3) | Shop | Volume (m3) |
|---|---|---|---|---|---|---|---|
| **Pretty Green** | 0,0374 | **Rubadub** | 0,0416 | **Coast** | 0,8428 | **Osiris** | 0,8428 |
| **Jaeger** | 0,6532 | **LOVEmusic** | 0,0416 | **GAP** | 0,8428 | **Robertson Outerwear** | 0,8084 |
| **Replay** | 0,2995 | **Neal Yard Remedies** | 0,4150 | **Hobbs** | 0,8084 | **Stons** | 0,8084 |
| **Ann Summers** | 0,1380 | **The Body Shop** | 1,1980 | **New Look** | 0,8428 | **Tam Sheperd Trick Shop** | 0,0416 |
| **Slanj Kilts** | 0,0379 | **The White Company** | 1,0092 | **Ted Baker** | 0,8084 | **Radley** | 0,8084 |
| **Hugo Boss** | 0,8510 | **Whittard of Chelsea** | 3,6648 | **The North Face** | 0,8782 | **LK Bennett** | 0,8084 |
| **Wallis** | 0,1872 | **Forever 21** | 3,7437 | **Evans Cycles** | 0,8782 | **Dunnes** | 3,7437 |
| **Deichman** | 2,8231 | **House of Fraser** | 3,7437 | **City Barbers** | 0,4150 | **TK Maxx** | 3,7437 |
| **Dune** | 0,9071 | **Maplin** | 1,4707 | **Toni&Guy** | 0,4150 | **Lush** | 1,1980 |
| **Evans** | 1,6928 | **Bose** | 0,1326 | **DLC** | 0,4150 | **Watt Brothers** | 3,7437 |
| **Topshop** | 0,0593 | **Paperchase** | 2,1084 | **James Pringle Weavers Of Inverness** | 0,0379 | **James Robertson Kiltmaker** | 0,0379 |
| **Camper** | 0,6047 | **The Good Spirits Co** | 0,0416 | **Marks&Spencer** | 3,7437 | **Greaves Sports** | 0,8782 |
| **Foot Asylum** | 0,8428 | **Apple** | 1,4707 | **Next** | 3,7437 | **BHS** | 3,7437 |
| **Fat Face** | 0,5348 | **AboutFace** | 0,4150 | **TJ Hughes** | 3,7437 | **Bang&Olufsen** | 0,1326 |
| **Diesel** | 0,8084 | **Rainbow Room International** | 0,4150 | **Primark** | 3,7437 | **Cruise** | 0,8428 |
| **Thomas Pink** | 0,9071 | **Skechers** | 0,8782 | **WH Smith** | 3,7437 | **Gant** | 0,8084 |
| **All Saints** | 2,8231 | **NikeStore** | 2,8231 | **Miss Selfridge** | 0,8428 | **Agent Provocateur** | 0,8084 |
| **USC** | 0,0374 | **Forbidden Planet** | 0,0416 | **G Star Raw** | 0,8428 | **Ralph Lauren** | 0,8084 |
| **Aldo** | 3,7581 | **CathKidston** | 0,0379 | **RiverIsland** | 0,8428 | **Bravissimo** | 0,8084 |
| **Timberland** | 1,6990 | **Hector Russel Kiltmaker** | 0,8084 | **Debenhams** | 3,7437 | **Emporio Armani** | 0,8084 |
| **Slaters** | 0,4731 | **Kilts & Cashmere Of Scotland** | 0,0379 | **Size?** | 0,8084 | **James Duns House** | 0,4150 |
| **Jigsaw** | 0,8084 | **Monsoon** | 2,8231 | **Missing Records** | 0,0416 | **Good Wins Hair And Nail Boutique** | 0,4150 |
| **Celtic Store** | 1,3781 | **Soletrader** | 0,0379 | **HMV** | 1,4707 | **The Beauty Store** | 0,4150 |
| **Tiso** | 0,8072 | **TM Lewin** | 0,8084 | **Accessorize** | 0,8428 | **Merchant City Barbers** | 0,4150 |
| **Mountain Warehouse** | 0,4492 | **Urban Outfitters** | 0,8428 | **Holland & Barrett** | 1,1980 | **Alan Edwards** | 0,4150 |
| **Monorail Music** | 0,0608 | **Zara** | 2,8231 | **Nailzone** | 0,4150 | **Wish Boutique** | 0,4150 |
| **Artstore** | 0,5010 | **American Apparel** | 0,8428 | **Fast Frame** | 0,0416 | **Beauty Kitchen** | 0,4150 |

*Appendix 14 – Extrapolated demand volumes for each shop*

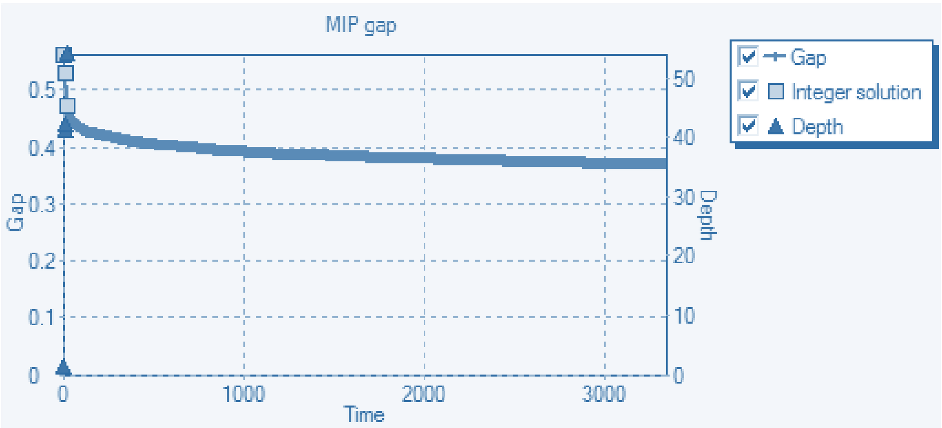
```
declarations
TOUR:array(VEH) of set of string
       nextNode:array(NODES) of string
end-declarations

forall(k in VEH) do
       if(sum(i in UDC, j in NODES) getsol(ASSIGN_UDC2NODE(i,j,k)) > 0) then
              forall(i in UDC, j in NODES) do
                     if(getsol(ASSIGN_UDC2NODE(i,j,k))=1) then
                            TOUR(k)+={i}
                            udc:=i
                            firstNode:=j
                     end-if
              end-do
              forall(i in NODES, j in UDC) do
                     if(getsol(ASSIGN_NODE2UDC(i,j,k))=1) then
                            nextNode(i):=j
                     end-if
              end-do
              forall(i,j in NODES) do
                     if(getsol(ASSIGN_NODE2NODE(i,j,k))=1) then
                            nextNode(i):=j
                     end-if
              end-do
              repeat
                     TOUR(k)+={firstNode}
                     firstNode:=nextNode(firstNode)
              until firstNode=udc
              TOUR(k)+={firstNode}
       end-if
end-do
writeln("\n***CHOSEN TOUR***")
forall(k in VEH) do
       write(k,"\t", sum(i,j in NODES) getsol(ASSIGN_NODE2NODE(i,j,k)) +
                                sum(i in UDC, j in NODES)
getsol(ASSIGN_UDC2NODE(i,j,k)) +
                                sum(i in NODES, j in UDC)
getsol(ASSIGN_NODE2UDC(i,j,k)), "\t",getsize(TOUR(k)),"\t")
       writeln(TOUR(k))
end-do
```

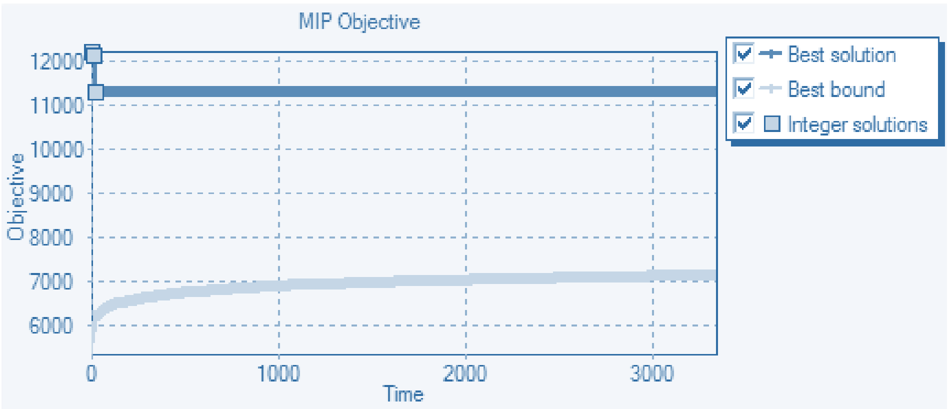
*Appendix 15 – Mosel formulation for sub tour identification*

| Matrix: | | Presolved: | |
|---|---|---|---|
| Rows(constraints): | 504 | Rows(constraints): | 503 |
| Columns(variables): | 4831 | Columns(variables): | 4600 |
| Nonzero elements: | 32971 | Nonzero elements: | 31180 |
| Global entities: | 4621 | Global entities: | 4600 |
| Sets: | 0 | Sets: | 0 |
| Set members: | 0 | Set members: | 0 |

Overall status: **Finished global search.**

| LP relaxation: | | Global search: | |
|---|---|---|---|
| **Algorithm:** | **Newton Barrier** | Current node: | 301375 |
| Iterations: | 6 | Depth: | 20 |
| Primal objective: | 5346.06 | Active nodes: | 122574 |
| Dual objective: | 5345.98 | Best bound: | 7126.56 |
| Status: | Unfinished | Best solution: | 11287 |
| Time: | 0.0s | Gap: | 36.8604% |
| | | Status: | At least one solution found |
| | | Time: | 3336.7s |



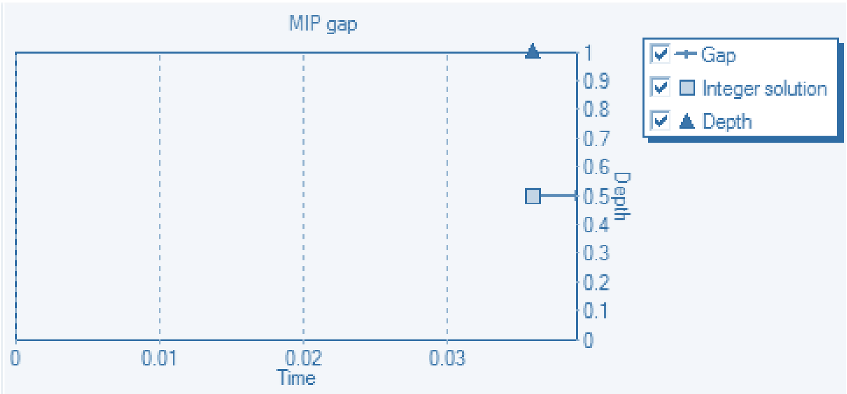



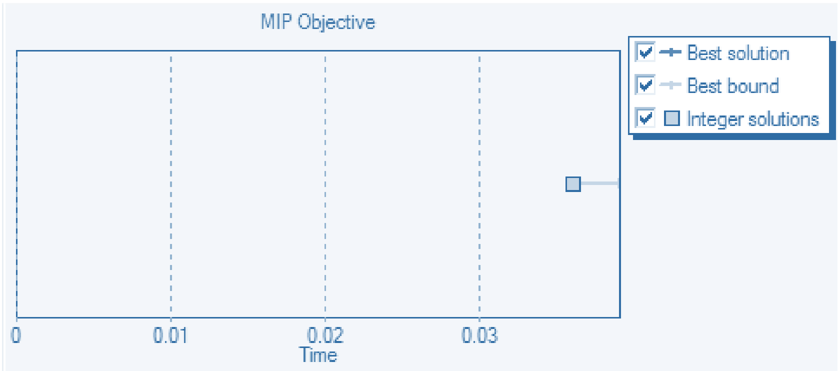

*Appendix 16 – Model performance – Scenario 1*

| Matrix: | | Presolved: | |
|---|---|---|---|
| Rows(constraints): | 30 | Rows(constraints): | 18 |
| Columns(variables): | 49 | Columns(variables): | 36 |
| Nonzero elements: | 313 | Nonzero elements: | 78 |
| Global entities: | 43 | Global entities: | 36 |
| Sets: | 0 | Sets: | 0 |
| Set members: | 0 | Set members: | 0 |

Overall status: **Finished global search.**

| LP relaxation: | | Global search: | |
|---|---|---|---|
| **Algorithm:** | **Simplex dual** | Current node: | 1 |
| Simplex iterations: | 15 | Depth: | 1 |
| Objective: | 2310 | Active nodes: | 0 |
| Status: | Unfinished | Best bound: | 2310 |
| Time: | 0.0s | Best solution: | 2310 |
| | | Gap: | 0% |
| | | Status: | Solution is optimal. |
| | | Time: | 0.0s |



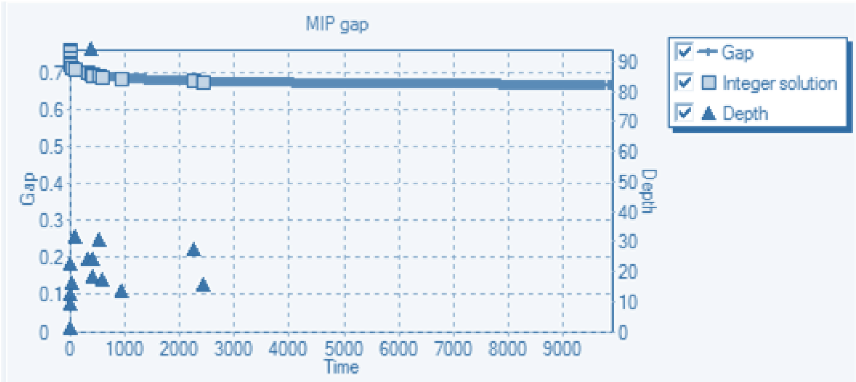



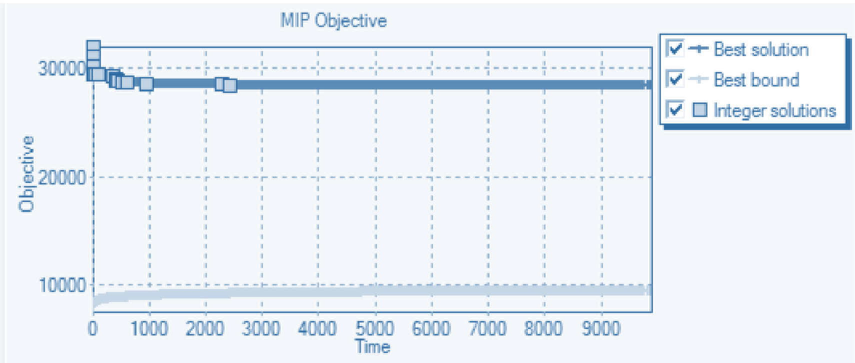

*Appendix 17 - Model Performance – Scenario 1 – Sub tour elimination*

| Matrix: | | Presolved: | |
|---|---|---|---|
| Rows(constraints): | 504 | Rows(constraints): | 503 |
| Columns(variables): | 4831 | Columns(variables): | 4600 |
| Nonzero elements: | 32971 | Nonzero elements: | 31180 |
| Global entities: | 4621 | Global entities: | 4600 |
| Sets: | 0 | Sets: | 0 |
| Set members: | 0 | Set members: | 0 |

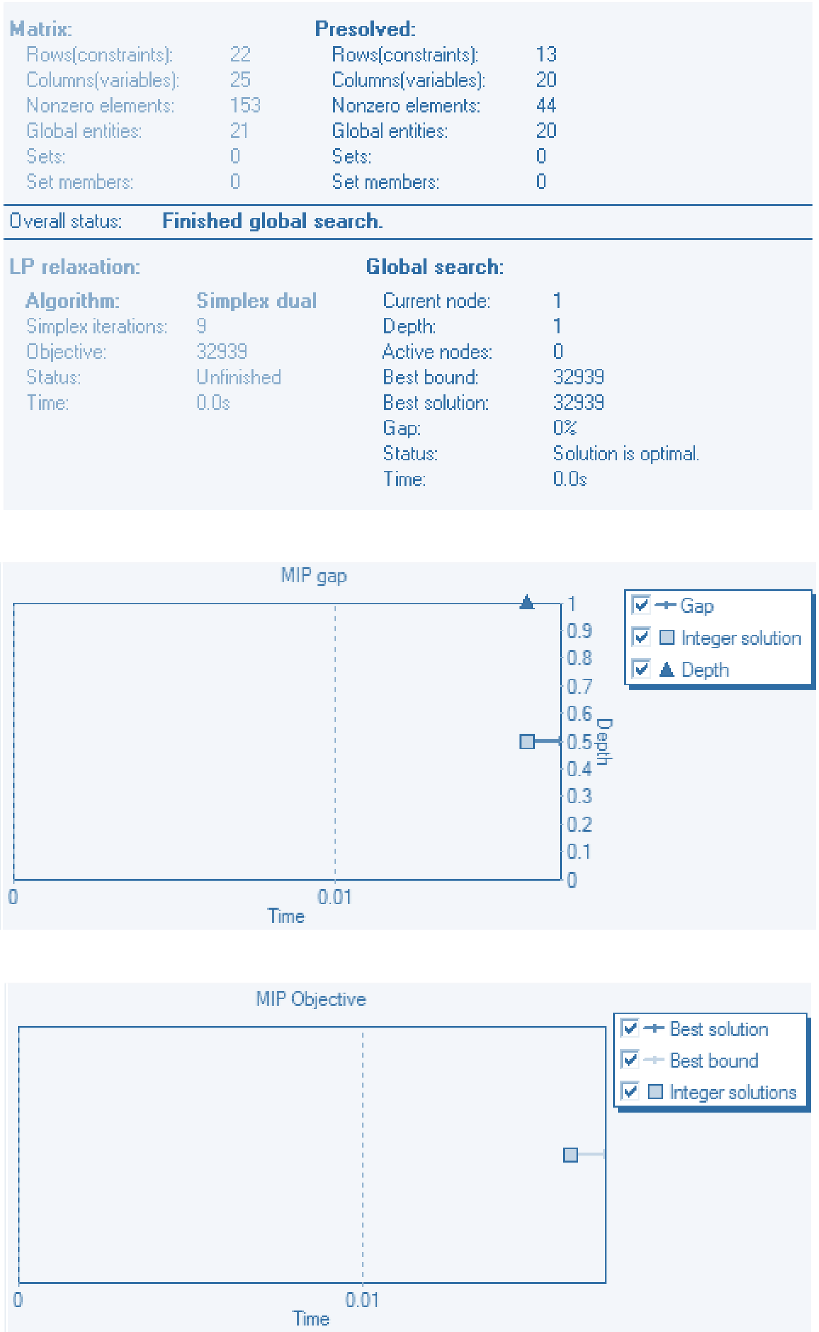
Overall status: **Finished global search.**

| LP relaxation: | | Global search: | |
|---|---|---|---|
| **Algorithm:** | **Newton Barrier** | Current node: | 552330 |
| Iterations: | 5 | Depth: | 34 |
| Primal objective: | 10598.1 | Active nodes: | 207997 |
| Dual objective: | 4347.51 | Best bound: | 9498.13 |
| Status: | Unfinished | Best solution: | 28477.6 |
| Time: | 0.0s | Gap: | 66.647% |
| | | Status: | At least one solution found |
| | | Time: | 9879.8s |




*Appendix 18 - Model Performance – Scenario 2*




*Appendix 19 - Model Performance – Scenario 2 – Vehicle 1 sub tour elimination*

**Matrix:**

| | |
|---|---|
| Rows(constraints): | 22 |
| Columns(variables): | 25 |
| Nonzero elements: | 153 |
| Global entities: | 21 |
| Sets: | 0 |
| Set members: | 0 |

**Presolved:**

| | |
|---|---|
| Rows(constraints): | 13 |
| Columns(variables): | 18 |
| Nonzero elements: | 40 |
| Global entities: | 18 |
| Sets: | 0 |
| Set members: | 0 |

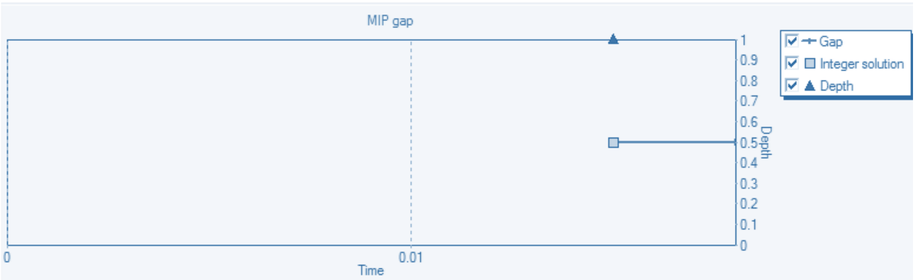
Overall status: **Finished global search.**

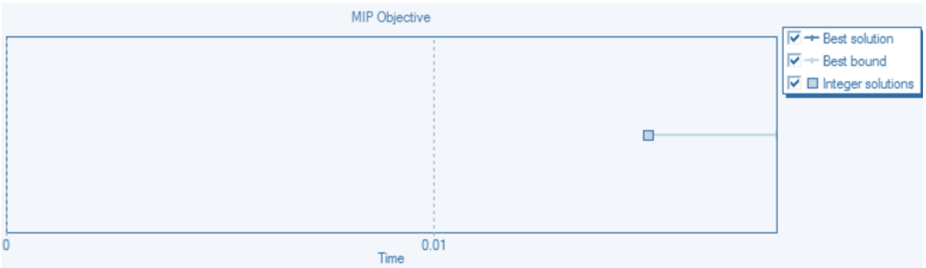
**LP relaxation:**

| | |
|---|---|
| **Algorithm:** | **Simplex dual** |
| Simplex iterations: | 9 |
| Objective: | 38946 |
| Status: | Unfinished |
| Time: | 0.0s |

**Global search:**

| | |
|---|---|
| Current node: | 1 |
| Depth: | 1 |
| Active nodes: | 0 |
| Best bound: | 38946 |
| Best solution: | 38946 |
| Gap: | 0% |
| Status: | Solution is optimal. |
| Time: | 0.0s |




*Appendix 20 - Model Performance – Scenario 2 – Vehicle 2 sub tour elimination*

**Matrix:**

| | |
|---|---|
| Rows(constraints): | 596 |
| Columns(variables): | 5797 |
| Nonzero elements: | 39565 |
| Global entities: | 5545 |
| Sets: | 0 |
| Set members: | 0 |

**Presolved:**

| | |
|---|---|
| Rows(constraints): | 595 |
| Columns(variables): | 5520 |
| Nonzero elements: | 37416 |
| Global entities: | 5520 |
| Sets: | 0 |
| Set members: | 0 |

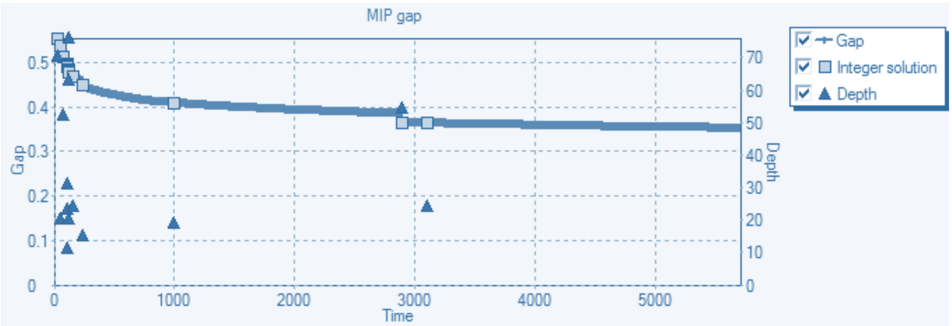
Overall status: **Finished global search.**

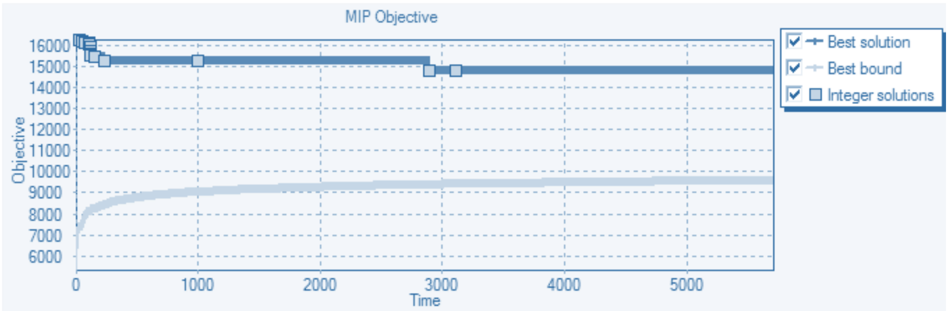
**LP relaxation:**

| | |
|---|---|
| **Algorithm:** | **Newton Barrier** |
| Iterations: | 3 |
| Primal objective: | 12652.9 |
| Dual objective: | 1341.01 |
| Status: | Unfinished |
| Time: | 0.0s |

**Global search:**

| | |
|---|---|
| Current node: | 390569 |
| Depth: | 37 |
| Active nodes: | 147541 |
| Best bound: | 9574.36 |
| Best solution: | 14778 |
| Gap: | 35.2121% |
| Status: | At least one solution found |
| Time: | 5703.4s |



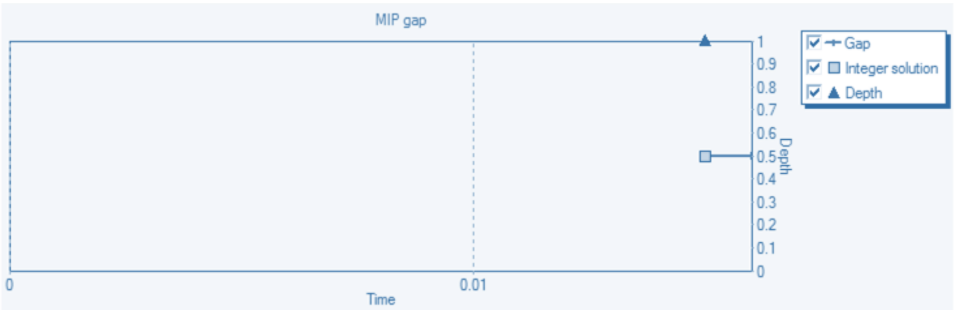



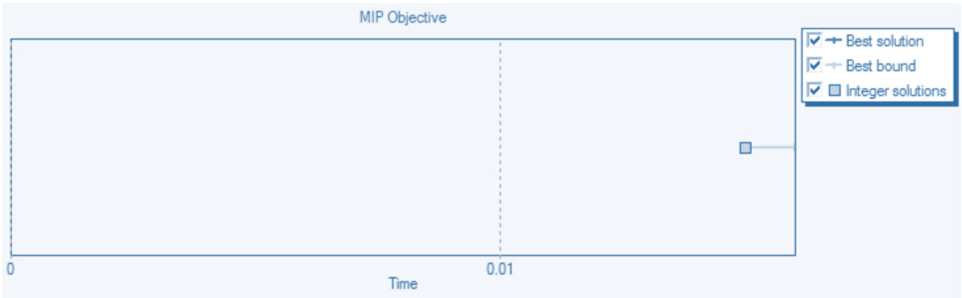

*Appendix 21 - Model Performance – Scenario 3*

| **Matrix:** | | **Presolved:** | |
|---|---|---|---|
| Rows(constraints): | 22 | Rows(constraints): | 13 |
| Columns(variables): | 25 | Columns(variables): | 18 |
| Nonzero elements: | 153 | Nonzero elements: | 40 |
| Global entities: | 21 | Global entities: | 18 |
| Sets: | 0 | Sets: | 0 |
| Set members: | 0 | Set members: | 0 |

Overall status: **Finished global search.**

| **LP relaxation:** | | **Global search:** | |
|---|---|---|---|
| **Algorithm:** | **Simplex dual** | Current node: | 1 |
| Simplex iterations: | 6 | Depth: | 1 |
| Objective: | 2630 | Active nodes: | 0 |
| Status: | Unfinished | Best bound: | 2630 |
| Time: | 0.0s | Best solution: | 2630 |
| | | Gap: | 0% |
| | | Status: | Solution is optimal. |
| | | Time: | 0.0s |



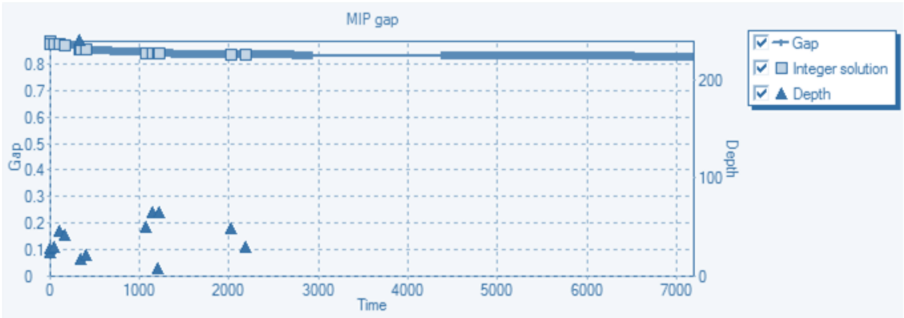



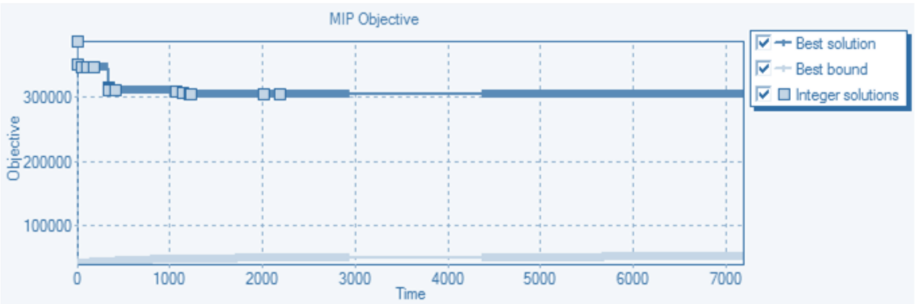

*Appendix 22 - Model Performance – Scenario 3 – Sub tour elimination*

| Matrix: | | Presolved: | |
|---|---|---|---|
| Rows(constraints): | 596 | Rows(constraints): | 595 |
| Columns(variables): | 5797 | Columns(variables): | 5520 |
| Nonzero elements: | 39565 | Nonzero elements: | 37416 |
| Global entities: | 5545 | Global entities: | 5520 |
| Sets: | 0 | Sets: | 0 |
| Set members: | 0 | Set members: | 0 |

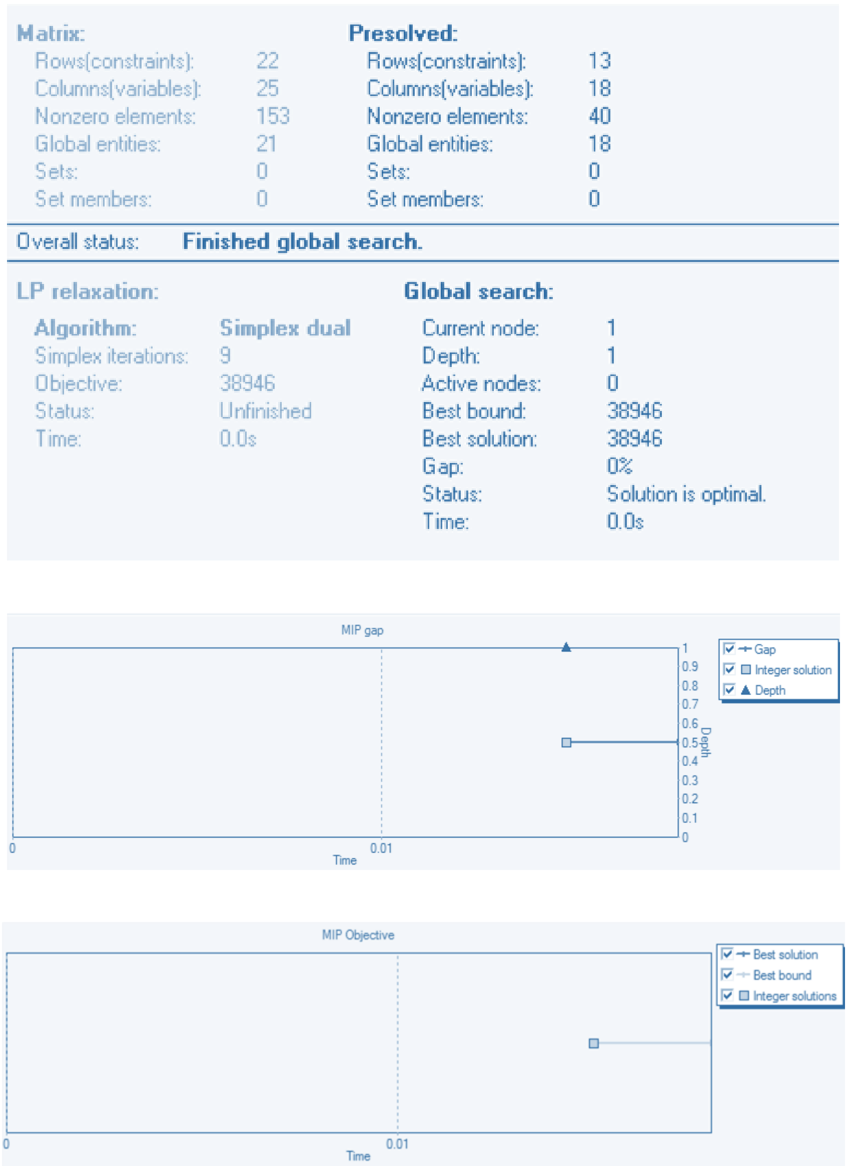
Overall status: **Finished global search.**

| LP relaxation: | | Global search: | |
|---|---|---|---|
| **Algorithm:** | **Newton Barrier** | Current node: | 246071 |
| Iterations: | 7 | Depth: | 69 |
| Primal objective: | 41269.3 | Active nodes: | 108950 |
| Dual objective: | 41245.2 | Best bound: | 52570.1 |
| Status: | Unfinished | Best solution: | 304429 |
| Time: | 0.0s | Gap: | 82.7316% |
| | | Status: | At least one solution found |
| | | Time: | 7185.4s |




*Appendix 23 - Model Performance – Scenario 4*




*Appendix 24 - Model Performance – Scenario 4 – Sub tour elimination*

|  | DP | Number of retailers | Total Walking distance (m) | Total Walking distance (km) | Total Time Walking (hours) | Total time for loading/unloading operations (hours) | Total time per delivery point (hours) |
|---|---|---|---|---|---|---|---|
| **1** | Slanj Kilts | 2 | 36 | 0.04 | 0.11 | 0.50 | 0.61 |
| **2** | Wallis | 5 | 206 | 0.21 | 0.62 | 1.25 | 1.87 |
| **3** | Deichman | 2 | 21 | 0.02 | 0.06 | 0.50 | 0.56 |
| **4** | Topshop | 9 | 615 | 0.62 | 1.85 | 2.25 | 4.10 |
| **5** | USC | 5 | 289 | 0.29 | 0.87 | 1.25 | 2.12 |
| **6** | Jigsaw | 5 | 194 | 0.19 | 0.58 | 1.25 | 1.83 |
| **7** | Celtic Store | 2 | 115 | 0.12 | 0.35 | 0.50 | 0.85 |
| **8** | Artstore | 4 | 134 | 0.13 | 0.40 | 1.00 | 1.40 |
| **9** | Rubadub | 3 | 184 | 0.18 | 0.55 | 0.75 | 1.30 |
| **10** | The White Company | 11 | 394 | 0.39 | 1.18 | 2.75 | 3.93 |
| **11** | Bose | 2 | 32 | 0.03 | 0.10 | 0.50 | 0.60 |
| **12** | Nike Store | 10 | 672 | 0.67 | 2.02 | 2.50 | 4.52 |
| **13** | New Look | 8 | 445 | 0.45 | 1.34 | 2.00 | 3.34 |
| **14** | DLC | 4 | 181 | 0.18 | 0.54 | 1.00 | 1.54 |
| **15** | James Pringle Weavers of Inverness | 5 | 307 | 0.31 | 0.92 | 1.25 | 2.17 |
| **16** | Next | 2 | 38 | 0.04 | 0.11 | 0.50 | 0.61 |
| **17** | Miss Selfridge | 3 | 46 | 0.05 | 0.14 | 0.75 | 0.89 |
| **18** | HMV | 7 | 737 | 0.74 | 2.21 | 1.75 | 3.96 |
| **19** | James Robertson Kiltmaker | 5 | 565 | 0.57 | 1.70 | 1.25 | 2.95 |
| **20** | Agent Provocateur | 6 | 573 | 0.57 | 1.72 | 1.50 | 3.22 |
| **21** | Alan Edwards | 4 | 247 | 0.25 | 0.74 | 1.00 | 1.74 |

*Appendix 25 – Walking and distribution distances per delivery point*

| | | Number of vehicles per week | | | Number of vehicles per delivery | | |
|---|---|---|---|---|---|---|---|
| | Average number of deliveries | LGV | Small Trucks | HGV | LGV | Small Trucks | HGV |
| Pretty Green | 2 | 3 | 0 | 0 | 1.5 | 0 | 0 |
| Jaeger | 3 | 0 | 3 | 0 | 0 | 1 | 0 |
| Replay | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| Ann Summers | 3 | 0 | 1 | 0 | 0 | 0.333 | 0 |
| Slanj Kilts | 25 | 1 | 0 | 0 | 0.040 | 0 | 0 |
| Hugo Boss | 3 | 0 | 3 | 0 | 0 | 1 | 0 |
| Wallis | 4 | 0 | 0 | 4 | 0 | 0 | 1 |
| Celtic Store | 10 | 10 | 0 | 0 | 1 | 0 | 0 |
| Tiso | 6 | 4 | 0 | 0 | 0.667 | 0 | 0 |
| The White Company | 6 | 0 | 4 | 0 | 0 | 0.667 | 0 |
| Deichmann | 1 | 0 | 3 | 0 | 0 | 1 | 0 |
| Dune | 4 | 0 | 4 | 0 | 0 | 1 | 0 |
| Evans | 4 | 0 | 4 | 0 | 0 | 1 | 0 |
| Topshop | 13 | 5 | 2 | 6 | 0.385 | 0.154 | 0.462 |
| Camper | 2 | 0 | 2 | 0 | 0 | 1 | 0 |
| Fat face | 3 | 3 | 0 | 0 | 1 | 0 | 0 |
| Foot Asylum | 6 | 6 | 0 | 0 | 1 | 0 | 0 |
| Diesel | 50 | 50 | 0 | 0 | 1 | 0 | 0 |
| Thomas Pink | 2 | 0 | 2 | 0 | 0 | 1 | 0 |
| All Saints | 6 | 0 | 7 | 0 | 0 | 1.167 | 0 |
| USC | 3 | 3 | 0 | 0 | 1 | 0 | 0 |
| Aldo | 1 | 1 | 0 | 0 | 1 | 0 | 0 |
| Whittard of Chelsea | 5 | 0 | 0 | 5 | 0 | 0 | 1 |
| Maplin | 5 | 0 | 3 | 0 | 0 | 0.600 | 0 |
| Timberland | 5 | 0 | 0 | 5 | 0 | 0 | 1 |
| Mountain Warehouse | 5 | 5 | 0 | 0 | 1 | 0 | 0 |
| Neal Yard Remedies | 2 | 2 | 0 | 0 | 1 | 0 | 0 |
| The Body Shop | 3 | 0 | x | 0 | 0 | 1 | 0 |
| House of Fraser | 4 | 4 | 0 | 0 | 1 | 0 | 0 |
| Forever 21 | 5 | 0 | 5 | 0 | 0 | 1 | 0 |
| Monorail Music | 15 | 0 | 10 | 5 | 0 | 0.667 | 0.333 |
| Artstore | 5 | 5 | 0 | 0 | 1 | 0 | 0 |
| Rubadub | 20 | 10 | 8 | 2 | 0.5 | 0.4 | 0.1 |
| LOVE music | 20 | 12 | 8 | 0 | 0.6 | 0.4 | 0 |
| Bose | 3 | 1 | 5 | 0 | 0.333 | 1.667 | 0 |
| Slaters | 12 | 5 | 5 | 0 | 0.417 | 0.417 | 0 |
| Jigsaw | 6 | 5 | 0 | 0 | 0.417 | 0 | 0 |
| | Average number of vehicles per delivery for all surveyed retailers | | | | 15.86 | 15.47 | 3.89 |
| | Average number of vehicles per delivery per retailer | | | | 0.43 | 0.42 | 0.11 |
| | Total number of vehicles per delivery for the population | | | | 46.29 | 45.16 | 11.37 |
| | Total number of vehicles (considering coordination of deliveries | | | | 30.55 | 29.80 | 7.50 |

*Appendix 26 – Number of vehicles per delivery for the population in study*