

## Appraising Freight Tram Schemes: A Case Study of Barcelona

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Urban goods distribution has gained in importance in recent years since its optimization not only has the potential to increase productivity and operational efficiency but also to achieve broader goals related to the reduction of externalities including congestion, accidents, noise, air pollution and CO<sub>2</sub> emissions. The focus of this paper is to explore the costs and benefits related to freight trams and appraise, by means of a cost benefit analysis a hypothetical freight tram scheme in the centre of Barcelona, to identify the factors that critically influence the potential success or failure of such schemes and to examine through sensitivity testing ways of improving performance. Thus, this paper aims to enhance our understanding of the potential for freight trams to contribute to mitigating a range of transport externalities.

Two freight tram scenarios were developed for detailed investigation: the first for retail deliveries and the second for domestic waste collection. Cost benefit analysis (CBA) was carried out based on the best available public domain information and with clearly specified assumptions. The waste tram scenario yields a high Net Present Value (NPV) and rapid return on investment due to the low set up costs and significant operating cost savings. On the other hand, in the initial specification, the retail delivery tram has a very negative NPV due to high initial investment costs and annual costs exceeding annual benefits. Sensitivity tests indicate that both the initial infrastructure costs and the costs and efficiency levels of the consolidation centres are critical to the performance of a freight tram.

*Keywords:* City Logistics, Cost Benefit Analysis, Light Rail Vehicle, Tram.

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### 1. Introduction

Urban goods distribution has gained a higher profile in recent years since its optimization not only has the potential to increase productivity and operational efficiency but also to achieve broader goals related to the reduction of externalities including congestion, accidents, noise, air pollution and CO<sub>2</sub> emissions.

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Freight transport is critical in modern urban areas, as they could not exist without a sustained and reliable flow of goods to, from and within them (Ogden, 1992) and the sector is very effective in meeting the needs of modern urban economies (Dablanc, 2008). In addition, it has a positive impact on the economy and is essential to sustain inhabitants' life style (Browne *et al.*, 2007). However, urban deliveries are a major contributor to problems in urban areas including congestion, air pollution, carbon emissions, energy consumption and safety issues (OECD, 2003). These impacts are likely to get worse given current trends such as the growing number of commercial vehicles, implementation of just in time deliveries, expansion of E-commerce and the growing urbanization of countries (Benjelloun *et al.*, 2008).

The challenge is then to reduce the impacts of urban goods deliveries without compromising economic, social and cultural activities (Benjelloun *et al.*, 2010). However, many cities, especially in Europe, have not yet found adequate solutions to optimise the movement of goods (Behrends *et al.*, 2008) and imaginative, innovative solutions integrating policy and technological aspects to tackle the growing impacts of urban good deliveries are required.

A potential solution that has not been fully explored to improve urban freight deliveries is to use the tram network to deliver goods. Robinson & Mortimer (2004a) note the potential that urban rail has to become a real solution for urban deliveries.

Freight tram schemes have the potential to reduce commercial road vehicle kilometres and therefore reduce congestion, accidents, air pollution, noise levels and road maintenance costs. In addition, they could help to facilitate movement towards green logistics by integrating key elements including: larger warehouses, new information systems, flow consolidation, freight consolidation and standardized vehicles (Piecnyk *et al.*, 2010) and could be integrated with Urban Consolidation Centres (UCCs), where modal shift can occur, leading to improved sales and profitability, improved reliability, better vehicle/driver utilisation, reduced traffic and environmental impacts and improved customer satisfaction (Allen *et al.*, 2010, 2012). Moreover, where passenger tram infrastructure is underutilized a freight tram can exploit this opportunity. Conversely, freight trams share the drawback of all fixed link modes in lacking flexibility; in some cases they may be in competition with passenger services for capacity; infrastructure investment may be necessary and a door to door service will involve additional steps in the supply chain (Robinson & Mortimer, 2004a).

Current literature on the topic is then largely focussed on suggesting new concepts to improve city logistics or describing the effects of a freight tram in operation. However, there has been little appraisal of freight tram schemes to provide insight into the conditions required to make them feasible. This paper aims to fill this gap by identifying the key costs and benefits that should be accounted for when appraising freight tram schemes and their impact on potential performance. Two types of freight tram operation, namely urban deliveries and domestic waste collection, are examined, contributing to a better understanding of the key success factors of freight tram schemes. Sensitivity tests are used to explore ways in which performance might be improved and to find initial feasible implementations from which a whole scheme can be built. These initial implementations can make freight tram projects more attractive by cutting initial investment and familiarizing the stakeholders with the new concept.

The paper is organised as follows. Section 2 reviews recent European freight tram experiences, identifies studies involving hypothetical freight tram schemes and outlines a range of costs and benefits and different scenarios under which freight trams can operate. The context, current infrastructure and scenarios definition may be found in Section 3. Section 4 describes the survey, including survey design, implementation, qualitative findings and key scenario design characteristics. Section 5 estimates the key supply and demand features required to appraise the scheme drawing upon the survey findings and the literature. The cost benefit analysis is reported

in section 6. Section 7 provides the results and discussion. Finally, in section 8, conclusions are drawn.

## 2. Recent European freight tram experiences and framework definition

Even though trams were used on earlier times to move freight in urban areas, the evidence on the performance of modern freight tram systems is limited. Examples in Europe include:

*CarGo Tram, Dresden, Germany.* CarGo Tram was launched by Volkswagen (VW) in cooperation with Dresdener Verkehrsbetriebe (DVB) (the public transport operator in Dresden) and the Government becoming operational in November 2000. The sole purpose of the project is to supply the VW “transparent” factory in Dresden city centre. The tram system was a requirement by the Municipality to allow the construction of the VW factory in the city centre (DVB, 2010). Two 60 metre long trams each with 60 tonne capacity run 16 hours a day, six days a week, under a 15 year contract. The system is reported to be both profitable and competitive with road (BESTUFS, 2005). The main difficulty was in finding a manufacturer able to produce just two specialised tram units, which cost €3.5 million (BESTUFS, 2005).

*CargoTram and E-tram, Zurich, Switzerland.* Cargo Tram was launched by the tram operator (Verkehrsbetriebe Zürich,VBZ) and the company in charge of recycling in the city (Entsorgung + Recycling Zürich, ERZ). The tram was inaugurated in 2003 to collect bulky items, glass and metal products. In 2006, another service was launched, the E-tram, focused on the recycling of electrical and electronic equipment (VBZ, 2010). This solution was adopted because it was noted that traditional waste collection trucks needed three times more time than the CargoTram to move across the city and 37,500l of diesel could be saved annually (Neuhold, 2005). Cargo Tram is cheaper to run, faster, and cleaner than traditional trucks and carries a non-time sensitive and low value commodity, factors that have made Cargo Tram feasible (Robinson & Mortimer 2004b). There are nine collection points spread across the city. In 2003 a total of 272 tonnes were collected in 35 rides increasing to 785 tonnes in 94 collecting rides in 2004. Each ride costs on average €3,200 in 2005 and 5,020 km of truck operation were saved leading to a reduction of 4.9 tonnes of CO<sub>2</sub> (Neuhold, 2005).

*GüterBim, Vienna, Austria.* GüterBim was launched by the Austrian Ministry for Transport and Innovations together with Vienna Transport Authority (Wiener Linien), the Vienna light rail operator (Wiener Lokalbahnen), Vienna Consult and Tina Vienna. Two demonstration projects took place, Güterbim from August 2004 to July 2005, and Güterbim Telematik, from January 2006 to June 2007 aiming to develop an intermodal, interoperable and telematics platform for the operation of the freight tram, involving the stakeholders and integrating it into supply chains to optimise the use of resources (Tina Vienna, 2009). After the test, the operator Wiener Linien decided not to continue with the implementation of the project. It seems there were financial and political issues, as neither the partners nor the developers wanted to make a long-term commitment, making the freight trams unaffordable.

*CityCargo, Amsterdam, Netherlands.* Launched as a pilot project in 2007, combining freight trams with small electric vehicles for the final delivery. However, in 2009, Citycargo applied for bankruptcy as it proved to be impossible to raise the required capital (Issenman *et al.*, 2010).

*Pilot project, Paris, France.* It was recently announced that Paris will have empty freight trams running as a pilot project to test whether the network is able to cope with mixed traffic (Madden, 2011). The project goal is to set up an experimental freight tram scheme in Paris within three years (APUR, 2011) and test whether it is possible to deliver goods to shops at the city centre using the existing tramway infrastructure (Alcaraz, 2012).

The limited experience of freight tram operation to date suggests that only projects focused on solving a particular issue and with stakeholder support have succeeded. In Dresden this involved a key commercial stakeholder with volume deliveries that utilises the infrastructure effectively. In Zurich cooperation between the tram operator and waste collection company has devised a low cost workable solution to bulky waste collection. When attempting general deliveries major challenges include the commitment of the stakeholders involved, the initial investment in rolling stock equipment and the need for political backing.

In the same line, Muñuzuri *et al.* (2005) suggest several solutions to improve city logistics including rail/tram use and remark upon the need to engage all the stakeholders in the process. More recently, Issenmann *et al.* (2010) explored the issues involved in integrating the passenger transit network with urban deliveries focusing on underground services in Paris. A conceptual model of a zero emissions scheme based on freight trams and electric vehicles for the city of Gothenburg is presented in Arvidsson (2010) using obsolete passenger trams to deliver the goods. Motraghi *et al.* (2012), present an event-based simulation to explore the impacts of introducing rail deliveries into the existing Metro rail system in Newcastle upon Tyne, concluding that rail deliveries are possible and may generate new business opportunities and a better utilisation of existing resources. Alessandri *et al.* (2012) explore the sustainability of urban rail deliveries and propose a multi-model urban distribution centre (MUDC) scheme for Rome. This would use conventional rail to carry goods from an outer intermodal terminal to the MUDC. They assess the scheme from the social point of view (emission and fuel consumption reduction) and the operator point of view (operator costs), concluding that social benefits, due to reduced externalities, would be achieved but the scheme may not be profitable to the operator. In addition, it is reported that SAMADA, a private company in Paris that has implemented rail deliveries plus compressed natural gas trucks for the final delivery, has increased the transport cost per pallet by 33%, but is expected to be more competitive than competing transport modes when new charging schemes where all modes are charged by the externalities they produce are introduced in the region.

To date there has been a lack of systematic analysis of the potential and real costs and benefits of freight tram schemes and thus limited understanding of the sensitivity of performance to variation in specific factors and there is no established analytical framework for the assessment of freight trams. Here we utilise a social cost benefit appraisal to examine performance.

Intuitively and based on experience to date we see that the success of a freight tram scheme will depend on the existing relationships between the following three elements: (1) existing infrastructure, (2) demand generators and (3) cross-docking facilities. The perfect city in which to introduce a freight tram would have an extended tram network that goes through commercial areas, typically located at the city centres and also provide access to major road or rail facilities to make the consolidation process more attractive.

Cross-docking facilities are defined as the physical location where the mode shift from current commercial vehicles to the freight trams takes place. These can take the form of Urban Consolidation Centres (UCCs) as described in Allen *et al.* (2010, 2012). The presence of existing road/rail links and UCCs will considerably reduce the required infrastructure investment costs.

Demand could come from single or multiple industrial users (as in Dresden) but this is less likely in urban centres where the prime contenders will be retail premises and waste collection (food and other products requiring specialist storage and transportation facilities are excluded from this analysis). These two types of operation are the most commonly found in the existing literature.

Table 1 identifies the range of potential costs and benefits from the introduction of freight trams for urban retail deliveries and waste collection respectively.

**Table 1. Range of potential costs and benefits**

<b>COSTS</b>	<b>Urban deliveries</b>	<b>Waste collection</b>
Capital Investment:		
Infrastructure	x	x
Rolling stock	x	x
Operational Costs:		
Freight Tram Operation	x	x
Cross-Docking/UCCs	x	
<b>BENEFITS</b>		
Externalities due to mode shift:		
Infrastructure damage	x	x
Noise	x	x
Accidents	x	x
Congestion	x	x
Air pollution	x	x
CO <sub>2</sub> emissions	x	x
Freight tram operation:		
Commercial vehicles operating costs	x	x
*Implementing Consolidation Facilities:		
Value added activities	x	
Stockholding facilities	x	
Reverse Logistics	x	

\* Relative to the assumptions made regarding cross-docking facilities

The costs can be grouped into 1) capital investment: including initial infrastructure needs such as new tracks and/or cross-docking facilities and rolling stock acquisition and 2) operational costs: of the freight tram and/or cross-docking facilities.

The benefits are classified into three groups. 1) Benefits from the reduced externalities due to the mode shift from standard commercial vehicles to freight trams such as infrastructure damage, accidents, noise, air pollution and carbon savings (Piecnyk *et al.*, 2010), 2) the benefits related to the operation of the freight tram, including current commercial vehicles operating savings and 3) the benefits involving the implementation of the UCCs (i.e. value added activities, stockholding facilities, reverse logistics (Allen *et al.*, 2010, 2012)) if those are implemented. Table 1 presents a general case where UCCs instead of cross-docking facilities are included since, as will be shown in the case study, UCCs have a significant impact in the appraisal of the overall scheme.

Note that some of the costs and benefits may be site specific and would depend on the current city logistics, regulations, demand generators, stakeholders involved, existing supply chain and the assumptions made during the analysis, for instance, on the type of freight tram operation (public, private, public-private partnership) or the existence and operation of urban consolidation facilities. It is also recognised that the trams will themselves generate externalities in the form of noise for example, but on balance these are likely to be offset by savings from road traffic.

Details on the estimation and monetisation of each cost and benefit are shown when implementing the above framework to the Barcelona case study.

### 3. Barcelona context and freight tram scenarios

In common with other cities, Barcelona is affected by changes in delivery patterns and consumer behaviour that contribute to the following challenges. Barcelona is failing to satisfy Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe because of the high levels of NO<sub>2</sub> and PM<sub>10</sub> (Ajuntament de Barcelona, 2010a). Barcelona generates 475,000 freight trips daily, resulting in nearly 72,000 freight vehicles accessing the city daily, a figure that has been growing at a pace of 3.2% annually (Generalitat de Catalunya, PTO, 2008). There is an imbalance in road use as 27.5% of the roads carry 82% of the general traffic and nearly 13% of the network is in a saturated condition (Ajuntament de Barcelona, 2010a). The city has diverse and dispersed commercial activity with 88% of establishments being street shops with only 2% located in shopping centres. However, 25% of the inhabitants prefer to buy fashion related items in shopping centres (Ajuntament de Barcelona, 2008).

The freight tram scenarios are determined based on the analysis of the (1) existing infrastructure, (2) demand generators and (3) cross-docking facilities for the city of Barcelona. These are discussed below and illustrated in Figure 1.

(1) The Barcelona tram system is divided into two main routes: Trambaix and Trambesòs, which operate at the both ends of the La Diagonal (main street in Barcelona that crosses the city from end to end diagonally) but are not joined together. For the purposes of this study we assume that the planned extension to link the two through La Diagonal (currently on hold due to economic environment and political changes in the Municipality and regional Government) will be built. The initial financial analysis of the project can be found in ATM (2010a).

(2) The following potential demand generators for deliveries and waste collection have been identified:

- *Shopping centres:* L'Illa Diagonal, Pedralbes Centre, Diagonal Mar and Les Glòries.
- *Large retail stores:* El Corte Inglés Diagonal, El Corte Inglés Francesc Macià.
- *Waste treatment plants:* Ecoparc.

(3) Currently, Barcelona does not have cross-docking or consolidation facilities close to the tram lines. Therefore, as La Diagonal is 11 km long, it is likely that two facilities will be needed, one located on the *Trambesòs* side of the city with access from the A2 motorway and the other on the *Trambaix* side with access from the B-10 motorway as shown in Figure 1.

Drawing on previous experience with freight trams in Europe and the specific characteristics of Barcelona two scenarios are proposed:

*Scenario 1:* Use of freight trams for deliveries to four shopping centres namely L'Illa Diagonal, Pedralbes Centre, Les Glòries and Diagonal Mar. The large retail stores are excluded from the analysis since they already have a logistic platform near Barcelona with consolidation and night deliveries implemented, making the freight tram scheme less attractive.

*Scenario 2:* Use of freight tram for waste collection from residential properties along the tram line to the Ecoparc.



Figure 1. Barcelona potential freight tram scheme

## 4. Survey

Having developed a basic analytical framework in Table 1, which identified the range of potential costs and benefits arising from freight tram operation, data is required to populate the framework. A common issue in urban freight analysis is the lack of data availability due to the private nature of urban logistics and the lack of a standardized methodology for data collection (Taniguchi *et al.*, 2005). In addition, most data collection efforts are city-specific occasional surveys (Browne *et al.*, 2007). Existing studies in Barcelona (Robusté, 2003 and Generalitat de Catalunya, 2010) do not yield suitable information, and as a result, two surveys were carried out with the aim to build a category model able to forecast trip rates per establishment type: a face-to-face establishment survey and an observational vehicle count. This data underpins the subsequent cost benefit analysis and is used to estimate the key supply and demand parameters such as trip rates, number of freight trams required, loads, kilometres saved by current commercial vehicles or urban consolidation needs.

### 4.1 Survey design

An establishment survey is carried out because it allows us to gather information about the delivery/collection processes and the main issues affecting the shop organization, identifying the advantages and disadvantages of the existing supply chain. The approach can also address loading and unloading activity, frequencies, ordering and stockholding arrangements and supply chain management. Of course some respondents might not have enough information regarding vehicle types, methods of goods movement or the origin of the vehicles and goods (Allen *et al.*, 2008), but, even though the respondent might not have all the information required to answer the

questionnaire, it is always known who is answering, avoiding one of the major issues of company surveys: knowing who is really answering the questionnaire.

A simple random sampling strategy was implemented, giving all establishments located inside the shopping centre the same probability of inclusion in the survey. Restaurants, jewellers and services were not included in the sample because they have special delivery systems, security concerns in answering the questionnaire or do not require a large amount of goods.

The questionnaire has four main sections. The first section is focused on understanding the characteristics of the establishments. Questions regarding the sector, number of employees per shift and shop and stockholding surface can be found. The second section contains questions that help to understand deliveries and the logistic structure of the establishments including the commonly used vehicle type, deliveries timing, packaging used or average load and environmental features of the vehicle fleet. The third section focuses on waste collection establishing the types of common waste, frequency of collection and responsibility for waste collection.

The last section explores the options and the willingness to introduce changes in the current delivery system. Issues covered include: night deliveries, the relationship between cost and environmental issues, the aspects that are most valued in the current delivery system and the assessment hypothetical scenarios of freight vehicles restrictions to significantly reduce commercial vehicle environmental impacts through La Diagonal. The alternatives offered included: 1) Day time freight tram operations plus small electric vehicles for the final delivery from the parking side tracks to the logistic platform at the shopping centre, 2) Night time freight tram operations plus small electric vehicles for the final delivery from current tram network to the logistic platform at the shopping centre, 3) Substitution of the current petrol vehicles by electric ones, 4) Consolidation centres located at the outskirts of the city and then, use current freight vehicles for the final delivery and 5) The use of consolidation centres to consolidate and integrate deliveries, followed by freight tram distribution and small electric vehicles for the final delivery. All the alternatives included a cost scenario, which could be the same as now, higher or lower. Questions explored willingness to accept the scheme and how the establishments respond to cost increases or decreases.

The survey was conducted with establishments at L'Illa Diagonal, Diagonal Mar and Pedralbes Center on July 2010, soon after the centre opened in the morning a time with low customer volume (Ajuntament de Barcelona, 2008) which may increase the responsiveness of the store managers.

Les Glòries management did not give permission, and therefore it could not be surveyed. However, due to the nature of the shopping centres, mostly having the same retail chains, it will be assumed that the average results obtained from the other shopping centres also apply to Les Glòries and it is included in the later analysis.

The vehicle counts were performed at L'Illa Diagonal shopping centre during the morning (10.30-12.45), the afternoon (14.00-15.00) and the evening (16.15-18.00) on a Tuesday and a Thursday. These differentiated between vans, trucks, articulated trucks and other kind of vehicles. The purpose of the counts is to validate the trip rates obtained through the establishment survey, and therefore were only performed at L'Illa Diagonal, from where survey data was available and was considered to be representative.

#### *4.2 Survey implementation and qualitative findings*

The sample size was 51 (19% of the total establishments and a reasonable match to the current distribution of establishments by sector was obtained).

The average number of trips per establishment per week is 2.94 and this will be used since the sample size is not enough to disaggregate further (i.e. per establishment type). There is a fairly even distribution of deliveries from Monday to Thursday, with 10am to 1pm being the most popular time window. There are fewer deliveries on Fridays as this is a heavy selling day. Most deliveries arrive by van (51.0%) followed by rigid trucks (23.3%) and 27% of delivery trips are unique in serving only one establishment (warehouse-establishment-warehouse pattern), hereafter referred as unique trips. The most common waste is cardboard and currently the shopping centre arranges waste disposal by a specialist company. There would then be potential for the tram to carry waste on the return journey.

The attribute that respondent's value most from a transport company is reliability, they are fairly satisfied with the existing system and generally averse to change. Concerning the response towards the hypothetical scenarios, the most commonly preferred option (98%) was a simple switch from petrol/diesel vehicles to electric vehicles when costs decrease or remain equal, but if logistic costs increase, the other alternatives looked more attractive. There was a reluctance to consider using a tram delivery system or night deliveries. Reasons given include an aversion to an additional transfer and the related feeling that it is a retrograde step since more stages are added into the current logistic chain.

The number of unique trips (27%) suggests potential savings from consolidation and as most establishments rejected night deliveries, the freight scheme will initially be designed for daytime operation. In addition, since the shopping centres manage waste collection, reverse logistics can then be implemented.

#### 4.3 Key scenario design features

Here we define some of the key operational characteristics of the schemes.

The first consideration is whether deliveries are made during the day or at night. A potential limiting factor on night time deliveries would be noise. However, in Barcelona, as reported by Ajuntament de Barcelona (2007) noise levels produced by the current passenger trams are below road traffic at all time periods (day, evening and night), which may allow night time deliveries by freight tram under the assumption that loading and unloading operations are also performed within the noise emissions regulations. Daytime deliveries require higher infrastructure investment, since freight trams would have to operate under mixed traffic conditions, needing to park up without disturbing passenger trams while performing loading and unloading operations. So, short side tracks would be built perpendicular to current tram network for this purpose. On the other hand, implementing night time deliveries mean increasing the distance that the final handling equipment would travel and may generate further legal and safety issues, moreover the survey respondents did not favour night time deliveries.

Another decision to take is the definition of the cross-docking facilities, where the modal switch from road vehicles to freight trams would take place. As pointed out earlier, Barcelona does not have facilities that can serve this purpose nearby current tram infrastructure. Given the range of retailers and the number of unique deliveries some kind of consolidation centre is indicated. Thus instead of considering a traditional cross-docking facility, we propose implementing the concept of UCC described in Allen *et al.* (2010, 2012), which will serve not only as a consolidation facility but also will provide a range of value-added logistic and pre-retail activities. These could include: pricing, ticketing, quality inspection and introducing security alarms which would mean more sales space in-store, reduced unpacking time, better inventory control, better schedule planning and released time to provide improved customer service for the establishments (Allen *et al.*, 2010, 2012). In addition, UCCs are intended to reduce stockholding space available in the establishments or in the logistic levels of the shopping centres, which increases retail space and potentially, revenues (Allen *et al.*, 2012).

The definition of the UCCs as in Allen *et al.* (2010, 2012) provides the most suitable scenario to make the freight tram scheme profitable, since a range of benefits that may not be accounted for under other assumptions exist. To better understand the impact of the UCCs, their costs and benefits components are disaggregated in the cost benefit analysis.

To avoid the need to make assumptions regarding the ownership and the business model used to operate the UCCs, it has been considered that the consolidation facilities will be rented and operated by a third company, therefore leading to an annual cost instead of an initial investment.

## 5. Key supply and demand features estimates

First, the total number of trips generated by the shopping centres is computed using survey data and is used to estimate the distance travelled by current commercial vehicles that could be saved if the freight tram is operating, under the assumption that all road deliveries must be shifted to the freight tram. The trip rate is validated using the vehicle counts undertaken at L'Illa Diagonal.

Second, the number of freight trams and loads hauled is estimated using average lading factors and survey data. Spanish data was only available for heavy trucks in intercity operations, conditions that would underestimate the total number of vehicles required, and therefore urban freight data from the Department for Transport (2010) and from AEA Technology (2010) regarding heavy goods vehicles (HGV) and light good vehicles (LGV) respectively from UK is used.

Third, UCCs surface are estimated using L'Illa Diagonal shopping centre data as a reference and assuming a linear relationship between the surface requirements and the number of establishments. Finally, parameters involving the waste collection scenario are derived from current Barcelona Municipality regulations and local waste collection statistics.

### 5.1 Trips and distance travelled

Given 342 establishments and an average of 2.94 trips per week per establishment, a total of 1005 trips per week are generated by the shopping centres. This means 52,260 trips per year, 35,432 by vans and 16,828 by trucks.

For unique trips (27%) we estimate the distance travelled by each vehicle from the proposed location of the UCC to the corresponding shopping centre and hence the distance that will be saved. UCC1 will supply L'illa Diagonal and Pedralbes centre, and UCC2 Diagonal Mar and Les Glòries, as this gives the shortest routes in terms of travel time (and hence a conservative estimate of any saving). The distances were measured using Google Maps and are shown in Table 2. Including outward and return trips the weekly savings are 4,377km.

For multiple delivery trips (73%) it is known that, on average, each has four legs (Robusté, 2003) before the return trip. However, Origin/Destination data is not available and it is not known whether the multiple trips are between shopping centres or not, resulting in the trip to the UCC substituting for anything from one to four legs of an existing trip. Given the strategic location of the UCCs even the worst of these outcomes would not result in increased mileage. We make the simplifying and conservative assumption that for every four existing multiple trips the distance saved will be the same as for one unique trip without considering the return trip. Table 2 shows the resulting savings per week for unique and multiple trip deliveries, amounting to a total of 5,816 km per week or 302,442 km per year.

**Table 2. Distance Travelled by Unique and Multiple Deliveries per Week**

Shopping Centre	Total number of stores	Analysed stores number (%)	Unique Trips per week	Multiple Trips per week	Distance to UCC1 (km)	Distance to UCC2 (km)	Unique trips distance (km/week)	Multiple trips distance (km/week)
L'illa Diagonal	164	122 (36)	99	260	12.7	10.1	2,515	826
Pedralbes	59	41 (12)	33	87	11.6	10.8	766	252
Diagonal Mar	187	99 (29)	80	211	18.9	3.2	512	169
Les Glòries	166	80 (23)	65	171	17.2	4.5	585	192
<b>Total</b>	<b>576</b>	<b>342 (100)</b>	<b>277</b>	<b>729</b>	-	-	<b>4,377</b>	<b>1,439</b>

### 5.2 Tram requirements and loads

To estimate the total load to be carried it is necessary to know the number of vehicles, lading factors and payloads. The daily load has been derived using the above data on numbers of road vehicle trips and the van/truck split. Payloads are assumed to be one tonne for a medium van and 7.5 tonnes for an average truck.

The lading factor (tonne·km hauled/max tonne·km) is derived from the Department for Transport (2010) for trucks and AEA Technology (2010) for vans and is adjusted for vehicle shares, obtaining an average lading factor of 0.33 and a daily freight movement of 86 tonnes.

Since the maximum capacity of the freight tram is 35 tonnes (Regué, 2009), three freight tram trips will be needed daily. However, due to shopping centre distribution, four daily trips are considered, two from each UCC. Assuming that the deliveries do not need to be made at the same time, two freight trams will suffice to supply the shopping centres with the goods required to ensure greater reliability and allowing more flexibility than could be achieved with a single freight tram.

The average distance travelled by the tram per trip is the distance between UCC1 and the farthest shopping centre (Illa Diagonal) and the average route distance between UCC2 and Les Glòries and Diagonal Mar, since different trams routes are taken to supply those shopping centres. Including return trips this gives a total of 81.16 tram kilometres a day.

### 5.3 UCC features

L'Illa Diagonal requires 21,000 m<sup>2</sup> of logistic surface (L'Illa Diagonal, personal communication, June 15, 2010) therefore, since UCC1 is supplying L'Illa Diagonal and Pedralbes Centre, and assuming a linear relationship between the surface requirements and the number of establishments, UCC1 requires 28,000 m<sup>2</sup>. Applying the same reasoning to Diagonal Mar and Les Glòries, UCC2 should be 30,800 m<sup>2</sup>.

However, implementing scheduled supplier deliveries, automation and taking into account that the height available can be trebled; the required surface can be reduced considerably. For the analysis, a reduction of 70% has been considered under the assumption that height could be trebled, given that the current logistic centre is in the parking facilities of the shopping centre with standard height, and the expected performance gains. Therefore, the surface of UCC1 is 11,220 m<sup>2</sup> and UCC2 12,325 m<sup>2</sup>.

#### 5.4 Residential waste collection

The Barcelona Municipality requires that all households are less than 100 metres from a waste container. Therefore, the catchment area of the waste tram is 6.58km<sup>2</sup>, being the track length (32.9km) times 200m, to cover both sides of the track. Only the 40% of this area that is residential is considered further since the area near the depots is industrial.

The Area Metropolitana de Barcelona, Entitat del Medi Ambient (2010), estimates average waste per person per year to be 349kg of general waste and 56kg organic waste. Barcelona population density is 15,817 people per km<sup>2</sup> (Ajuntament de Barcelona, 2010b). Total daily waste from the residential catchment area is then around 46 tonnes. The minimum number of waste trams required is two due to capacity and time constraints, since waste collection is time consuming and must be completed between 1am and 5am when passenger trams do not operate.

The distance travelled by each waste tram is estimated to be the length of the current network, 32.9km, at most, accounting for a return trip. The next step is to consider the potential saving in waste truck kilometres. The city has 328 waste collection trucks (Ajuntament de Barcelona, 2010c). Assuming a linear relationship between the number of trucks and the tonnes of waste collected, the number of trucks collecting household waste is 250, (the other trucks deal with cardboard, glass and plastic) with an annual collection capacity of 2,626 tonnes/year truck. Since waste collected in the catchment area is known, seven waste collection trucks can be replaced.

The trucks are based at the Ecoparc and measuring the distance from the Ecoparc to the centroid of the zone each truck serves, an average route of 20.5 km a day per truck is obtained. As a result, the distance saved by trucks is 52,400 km per year.

## 6. Cost Benefit Analysis

Once the key parameters for both freight tram scenarios are determined, the costs and benefits can be monetised. However, some assumptions concerning data availability apply.

The externalities, carbon emissions and air pollution are monetised using data from the UK literature, since similar values in the Spanish literature could not be found. The main sources are DEFRA (2006, 2008) and Piecyk *et al.* (2010). The issues of using UK values are that an exchange rate from pounds to euros is needed and that the data may not be transferrable to the Spanish case. To deal with those issues, a conservative approach is taken. The exchange rate used is 1.17 €/£, an average value for the years 2008 and 2009, which is conservative estimate, since historically, the exchange rate has been fluctuating around higher values. Regarding the externalities, it can be argued that they are also underestimated, since the Spanish commercial vehicle fleet is older than the UK fleet (Ministerio de Fomento, 2012 and Department for Transport, 2012).

The benefits concerning the UCCs are accounted as productivity gains, assuming that employees at UCCs can perform the same activities as in-store but more efficiently due to economies of scale and trained personnel, resulting in a net benefit. An initial assumption on productivity gains of 50% is made, and this is tested in the later sensitivity analysis.

The appraisal is performed using a standard cost benefit analysis, as described in Department for Transport (2011). A project life of 25 years is assumed, as after this, the trams may need replacing. A discount rate of 3.5% (Department for Transport, 2011) is applied. Willingness to pay for environmental savings is expected to increase by 2% a year, as suggested by DEFRA (2008) and operating costs by 1% a year.

The measures of economic worth used are the Net Present Value (NPV), the Benefit Cost Ratio (BCR) and the Payback period. The NPV is computed using Eq. 1, where: N is the project cycle life,  $B_i$  the benefits for year i,  $C_i$  the cost for year i, and r the discount rate. The BCR is computed using Eq. 2 and the Payback is the number of years required to generate enough net benefits to recover the initial investment.

$$NPV = \sum_{i=0}^N \frac{B_i - C_i}{(1+r)^i} \quad \text{Eq. 1}$$

$$BCR = \frac{NPV}{C_0} \quad \text{Eq. 2}$$

To measure the impact of each of the costs and benefits, the 1<sup>st</sup> year flows are computed and compared between the different scenarios.

Sensitivity tests are also used to find initial feasible implementations from which the whole scheme can be built. To do so, different cases are tested, for instance introducing night deliveries, using a single freight tram, increasing UCCs productivity, doubling in-store stockholding benefit and implementing a shared use of the UCCs. Some of the cases can be combined together to understand the joint impact of the measures.

The detailed computation of the costs and benefits included in the analysis are detailed below.

### 6.1 Freight tram operating costs

Data in ATM (2010b) are used to provide an estimate of operating costs (including energy, staff and maintenance costs) of €10.48 per vehicle kilometre for passenger trams in Barcelona. This is in line with an earlier estimate (2005) for Barcelona by Lussich Obes (2005) of €7.30 per vehicle kilometre. Here, the more recent and higher figure of €10.48 is used. This may be an overestimation, as freight tram operations are expected to be quicker with fewer stops, but on the other hand, loading and unloading operations are more time consuming and the average load is expected to be higher.

Waste collection operating costs are assumed to be 40% higher as the tram needs to stop frequently and take on waste containers, activity that is more time and energy consuming. The resulting operating costs are €534,000 and €352,000 per year for retail deliveries and waste collection respectively (as the retail scenario requires more kilometres to be run).

### 6.2 Infrastructure and rolling stock costs

The cost of new track is based on those for Trambesòs project (ATM, 2003), uplifted to 2009 values using the index of construction cost for civil works (Idescat, 2010). This gives a cost per metre of €9,829. The length of new track is estimated to be 1.04 km for retail deliveries and 0.10 km for waste collection giving costs of €10,223,000 and €983,000 respectively. The cost of a single freight tram is €1,800,000 (Regué, 2009) and as two trams are required for each scenario this gives vehicle costs of €3,600,000 in each case.

### 6.3 UCC Rent and operating costs

The construction and operational costs of a UCC are derived from the average monthly rental cost for industrial properties in the area where the shopping centres are located. The figure used is 4.47 €/m<sup>2</sup> per month (Forcadell, 2009). The annual rent is then €1,263,000 based on the areas of both UCCs previously estimated.

Another aspect that needs to be considered is UCCs staff costs. Two shifts with ten employees are required, based on similar size industries with an average cost per employee of €34,354 per year including the National Health Tax (Ajuntament de Barcelona, 2010b). This gives annual staff costs of €1,374,000.

#### 6.4 Vehicle operating cost savings

ACOTRAM, software developed by the Ministerio de Fomento (2010) to estimate transportation costs, was used to estimate the vehicle operating costs. The annual costs of running a van and a truck similar to those used here are €0.89 and €0.80 per km respectively including fuel, amortization, staff and insurance. Since the distance saved by vehicle type has already been calculated, the total operating cost savings of the freight vehicles may be estimated as €268,000.

Concerning the operating cost savings for the waste collection scenario, the assumption made is that the costs are proportional to the tonnes of waste collected. Total costs are provided by Barcelona Municipality budget (Ajuntament de Barcelona, 2010c), €92,840,438 year, and the estimated share of waste collected by the freight scheme is 1.95%, yielding to a saving of €1,815,000 per year.

#### 6.5 Air pollution and carbon savings

Freight vehicle emission factors are taken from AEA (2007) and weighted by share of trucks and vans. For waste collection only truck emissions are relevant whereas for retail deliveries a weighting is applied by vehicle share.

Monetary values are applied to: chronic mortality hospital admissions and building soiling for PM<sub>10</sub>; the impact on materials caused by SO<sub>2</sub> (DEFRA, 2008) and deaths due to ozone levels and hospital admissions for VOCs (DEFRA, 2006). The CO<sub>2</sub> value is based on mitigation costs (Department of Energy and Climate Change, 2009). All values are adjusted to 2009 prices according to Spanish GDP growth and the exchange rate used is 1.17 €/£.

Kilograms saved and its respective monetised value for each pollutant can be observed in Table 3. The savings are €13,200 per year for retail deliveries and €4,200 per year for waste collection, with CO<sub>2</sub> providing around two thirds of the benefit in both cases. PM<sub>10</sub> is also a large contributor to the benefit even though its savings (in kg) are one of the lowest. As was pointed out earlier, Barcelona is not meeting the Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe because of NO<sub>2</sub> and PM<sub>10</sub> levels, which could be reduced by the implementation of the suggested scheme.

**Table 3. Air pollution and Carbon Savings**

Pollutant	Retail Deliveries		Waste collection	
	kg	€	kg	€
CO <sub>2</sub>	146217.5	8773.1	47934.8	2876.1
NO <sub>x</sub>	679.2	763.3	290.2	326.1
PM <sub>10</sub>	34.9	3626.9	10.0	1033.8
VOC's	66.3	3.1	24.6	1.2
SO <sub>2</sub>	1.4	2.7	0.5	1.0
<b>Totals</b>		<b>€13,200</b>		<b>€4,200</b>

### *6.6 Infrastructure damage, noise, accidents and congestion reduction benefits*

Values per vehicle kilometre for infrastructure damage, noise, accidents and congestion are obtained from Piecyk *et al.* (2010) and uplifted to 2009 values. In both scenarios, congestion reduction accounts for approximately 80% of the total benefit, followed by accident cost savings (12%), infrastructure savings (7%) and noise reduction (2%). The total benefit per year is €118,100 for retail deliveries and €34,900 for waste collection.

### *6.7 UCC Added value*

To value the activities to be undertaken at the UCCs, the time spent by the establishments to place the items on the shelves, price them and put the alarm on is evaluated. The following assumptions and comments apply.

It is assumed that each trip made accounts for one delivery therefore new items need to be placed. On average, two hours per trip are needed for each establishment to carry out value added activities, based on information from survey respondents. Considering the cost per hour per employee for the company is €15.78 per hour (taxes included) (Ajuntament de Barcelona, 2010b) and assuming productivity increases by 50% due to economies of scale, trained personnel and automation at UCCs, the benefit that the value added activities generate is €825,000 per year.

### *6.8 In-Store stockholding surface reduction benefit*

The implementation of the value added activities in the UCC would enable reductions in both the stockholding surface on the premises since goods will be ready to place on shelves and the logistic areas of the shopping centres. Here an initial 50% surface reduction is assumed on the in-store stockholding surface, and is later tested for sensitivity.

An average stockholding surface of 14.75m<sup>2</sup> per establishment is deduced from the survey findings. As the number of establishments is 342 this gives a total stockholding surface of 5043m<sup>2</sup>. According to data provided by the surveyed shopping centres, renting a premise costs on average 11 €/m<sup>2</sup> per month depending on the shopping centre, location of the premise and establishment type. The resulting benefit for the shopping centres is €333,000 per year.

Another potential source of revenues lies in the scope to increase of car parking spaces, due to the reduction of logistic facilities in parking levels. However, this benefit has not been included in the analysis due to a lack of information.

### *6.9 Reverse logistics*

The most common waste, as concluded from the survey, is cardboard, followed by plastic, both of which can be piled up in containers and then hauled on a freight tram. It is assumed that at present three trucks a week are needed at each shopping centre, to collect full loads of cardboard, plastic and general waste respectively. Each trip is unique, since the truck is picking up a container from the shopping centre and then heading to waste management facilities. The distance saved will be that from the respective UCC to the shopping centre. Operating costs of the current waste trucks are estimated using ACOTRAM. Externalities are valued by the procedure discussed above but in this case for trucks only. Freight tram operating costs are as defined in section 6.1. Under these assumptions, the kilometres saved by waste trucks are 9,984km, which leads to annual savings of €6,600 for infrastructure damage, noise, accidents and congestion externalities, €800 for air pollution and carbon and €8,800 for operating costs.

## 7. Cost benefit analysis results and discussion

Table 4 shows the cost and benefits flows for the first year of operation, the Net Present Value (NPV), the Benefit Cost Ratio (BCR) and the Payback obtained for each scenario. The percentages indicate, share of initial investment; share of 1<sup>st</sup> year operating costs and share of 1<sup>st</sup> year benefits respectively.

**Table 4. Costs and Benefits for the 1st Year of Operation and NPV**

COSTS	Retail deliveries		Waste Collection	
	€	%	€	%
<i>Initial Investment:</i>	13,823,000	100.0	4,583,000	100.0
Track	10,223,000	74.0	983,000	21.4
Rolling stock	3,600,000	26.0	3,600,000	78.6
<i>Operational Cost 1<sup>st</sup> Year:</i>	3,171,000	100.0	352,000	100.0
Tram Operation	534,000	16.8	352,000	100.0
UCC rent	1,263,000	39.8	NA	NA
UCC operation	1,374,000	43.3	NA	NA
<b>BENEFITS 1<sup>st</sup> Year</b>	<b>€</b>	<b>%</b>	<b>€</b>	<b>%</b>
<i>Externalities due to mode shift:</i>	131,300	8.4	39,200	2.1
Infrastructure damage	6,200	0.4	3,200	0.2
Noise	2,200	0.1	800	0.0
Accidents	12,600	0.8	4,200	0.2
Congestion	97,100	6.2	26,700	1.4
Air pollution	4,400	0.3	1,400	0.1
Carbon	8,800	0.6	2,900	0.2
<i>Freight Tram Operation:</i>	268,000	17.0	1,815,000	97.9
Operating savings	268,000	17.0	1,815,000	97.9
<i>Implementing Consolidation Facilities:</i>	1,174,200	74.6	NA	NA
Value added activities	825,000	52.4	NA	NA
Stockholding facilities	333,000	21.2	NA	NA
Reverse Logistics	16,200	1.0	NA	NA
<b>TOTAL Benefits 1<sup>st</sup> Year</b>	<b>1,573,500</b>	<b>100.0</b>	<b>1,854,200</b>	<b>100.0</b>
<b>Total Benefits-Total Costs 1<sup>st</sup> Year</b>	<b>-1,597,500</b>	<b>NA</b>	<b>1,502,200</b>	<b>NA</b>
<b>NPV</b>	<b>-43,170,000</b>	<b>NA</b>	<b>23,931,000</b>	<b>NA</b>
<b>Benefit Cost Ratio (BCR)</b>	<b>-3.12</b>		<b>5.22</b>	
<b>Payback (years)</b>	<b>Never</b>		<b>4</b>	

The costs between scenarios are quite different due to the varying new track requirements and UCC related costs and benefits. As a result, the initial investment required for retail deliveries is three times higher than for waste collection and the annual costs are nine times higher.

In terms of benefits, the largest benefit for retail deliveries is the value added activities performed at the UCCs followed by stockholding facilities benefit, which implies that the design of the UCC is a key aspect for the success of the scheme. In addition, it should be noted that the annual costs of implementing UCCs (rent+operation) is greater than the annual benefits they generate, leading to an annual deficit of €1,462,000. Some benefits related to the UCCs have not been accounted for

due to lack of data availability such as: increasing retail space or parking availability by reducing logistic areas of the shopping centres, efficiency gains due to better vehicle/driver utilisation or smoother city traffic due to reduced kerbside operations. Nevertheless, these are not expected to be sufficient to offset the remaining annual cost deficit.

For waste collection operating cost savings are almost wholly dominant accounting for 97.9% of the annual benefits. Air pollution and other externalities savings are relatively low in both cases because the kilometres saved and the trucks taken off the roads are low. The high NPV for waste collection (€23,931,000) is due to the low initial investment required and large operating cost savings, which result in a BCR of 5.22 and an expected return on investment within four years. A sensitivity test, assuming a 50% reduction in the operational savings, has been performed, showing that the NPV is still positive, €6,750,000 with a BCR of 1.47. In order to become economically infeasible, a 70% reduction is needed.

The main reasons for the negative NPV of -€43,170,000 for retail deliveries are the high initial investment costs, especially the track, which accounts for 74% of the initial investment and the fact that annual costs exceed annual benefits. Indeed, the cost of operating freight trams exceeds the operational savings derived from the commercial vehicles that are no longer used. To change this would require sufficient demand to justify larger freight tram schemes, serving more shopping centres, retail stores or commercial districts taking advantage of the economies of scale that trams can offer. For instance, in the current design two freight trams are needed, making only two trips per day, indicating that there would be potential to serve more demand if exist.

Given this result sensitivity tests were undertaken for retail deliveries to determine under what conditions the scheme might be feasible. The following were tested and are reported in Table 5:

(1) *Night deliveries*: night deliveries reduce the initial investment sharply since parking tracks at the shopping centres would be no longer needed. As a result the initial investment falls to €6,058,000, yielding to an 18.0% improvement in the NPV. The freight volume is assumed to be the same as for the base retail deliveries scenario.

(2) *Only one freight tram is used*: using only one freight tram is another way to cut initial investment even though flexibility and reliability is reduced. However, in the early stages of the project, one tram may be used to prove the concept cutting initial investment to €12,023,000 and improving NPV by 4.2%.

(3) *UCCs improved productivity by 75% instead of the assumed 50%*: if the productivity at UCCs improved due to expertise and large scale operations, the NPV improves by 18.1%.

(4) *Doubling stockholding surface benefits*: when accounting for stockholding surface benefits the potential revenue generated by the increase in parking spaces and reduction of logistic facilities provided by the shopping centres was not accounted for. Considering those added benefits to be of the same order as the in-store stockholding benefits the NPV improves by 14.6%.

(5) *Sharing UCCs costs with other forms of distribution*: UCCs could also be used by other retailers who are not within the catchment area of the tram network but could benefit from goods consolidation. González (2002) suggested a similar idea by proposing building underground logistic platforms at main corners of Barcelona to serve textile wholesalers. Potential users could be associations of commercial establishments that do not have enough resources to operate their own consolidation centre but they could outsource the service. Assuming that 25% of costs could be met in this way yields to a 13.8% improvement in the NPV.

(6) *Combination of measures*: combining all the above measures, the NPV is still negative at €-13,516,000. It is clear that the factors with greatest impact on the NPV are the initial investment, the optimization of UCC use and the stockholding surface reduction.

**Table 5. Sensitivity tests under different hypotheses for retail deliveries**

HYPOTHESES	€	%
0) NPV Base case	-37,512,000	100.0
1) NPV Night Deliveries	-29,747,000	-20.7
2) NPV one freight tram only	-35,712,000	-4.8
3) NPV 75% UCC productivity	-29,704,000	-20.8
4) NPV Doubling stockholding space benefit	-31,210,000	-16.8
5) NPV 25% costs of UCC shared	-31,534,000	-15.9
6.1) NPV 1)+2)+3)+4)	-19,500,000	-54.8
6.2) NPV 3)+4)+5)	-23,082,000	-46.5
6.3) NPV 1)+3)+5)	-21,619,000	-49.9
6.4) NPV 1)+3)+4)+5)	-15,316,000	-64.5
6.5) NPV 1)+2)+3)+4)+5)	-13,516,000	-68.7

Unrealistic assumptions would be required to obtain a positive NPV for retail deliveries with two UCCs. However, given the tram extension plans and the characteristics of the freight tram scheme, where the distance between UCC2 and the shopping centres is small, a pilot project could be launched with only the construction of UCC1 serving l'Illa Diagonal and Pedralbes Centre operated by a single freight tram at night together with the waste collection scheme, which will result in a NPV of €8,791,000 (-15,140,000+23,931,000). The joint operation of both scenarios would require the involvement of the Municipality that could cross-subsidise the urban deliveries with the benefits obtained from the waste collection as well as the active participation of the shopping centre management and tram operator. If sensitivity analysis is performed to the pilot project, by: 1) Sharing 50% of UCC costs, 2) Increasing productivity to 75% and 3) Doubling stockholding surface benefits, a positive NPV of €214,000 is obtained for the pilot retail deliveries scheme, that when combined with waste collection, yields to an aggregate NPV of €24,145,000 (214,000+23,931,000).

Note, however, that all costs and benefits do not apply to the same entity or organization. For instance, freight tram operation costs affect the operator of the scheme, whereas stockholding benefits only have an impact on the shopping centre, which may lead to organizational challenges. Allen *et al.* 2012 suggest that organizational challenges are reduced for UCCs serving large sites with a unique landlord, since the landlord can enforce UCCs usage and charge their services through the rent. This case study comes close to this, with a small number of shopping centre landlords. This challenge is limited when appraising the waste collection scenario, since there is only one major stakeholder, the Local Authority. As a result, the different distribution of financial costs and benefits may pose a barrier for the scheme acceptability.

Another aspect to consider when appraising the scheme is the potential new usages and/or extensions of current tram network over time. It should be borne in mind that the project life is 25 years, and within this timeframe several improvements to the Barcelona tram network are proposed (ATM, 2010a). There are two suggested extensions of particular interest: 1) Besòs side along B10 motorway and 2) Besòs side towards city centre. The first project would allow UCC2 to be located farther out from the city centre, the retail delivery tram would then yield greater savings in road freight vehicle mileage. The second project increases the catchment area, serving the city centre, with narrow streets, pedestrian areas and high levels of commercial activity, conditions that can make freight tram deliveries and waste collection even more attractive.

Sensitivity tests indicate that retail deliveries by tram would be more economically attractive if night deliveries were possible and the costs of the consolidation centres could be shared with other forms of final distribution in the urban centre. Waste tram operation could also play a role in familiarising potential users with the service and demonstrating reliability, which could then make a freight tram more acceptable.

## 8. Discussion and conclusions

The paper takes a systematic approach, based on identifying scenarios, key costs and benefits and appraising the scheme through a cost benefit analysis to assess a hypothetical freight tram scheme in Barcelona. The case study results show that freight tram operation for urban retail deliveries is not economically attractive if the tram has to bear all the costs of the UCC and requires additional track. Additionally survey findings suggest that retailers would not support such a scheme at present even in a city that appears to be an excellent candidate for freight trams, given that it already has infrastructure in place and demand generators. This result is in line with recent European freight tram experience.

Cost Benefit Analysis highlights the main reasons for the economic unsustainability of a freight tram scheme here, apart from the infrastructure cost, are: 1) the annual tram operation costs exceed the annual operating savings of current commercial vehicles plus the benefits of the externalities due to the mode shift, meaning that the do-nothing scenario is preferred and 2) the annual cost of renting and operating the UCCs is greater than the benefits that they produce.

The first issue, involving freight tram operating costs, may occur because of the economies of scale that the freight trams can offer are not being exploited, implying that a minimum demand needs to be served to make it feasible. In the case study, the number of commercial vehicles substituted is limited, and the associated savings in operating costs and externalities do not outweigh the tram operating costs. It is expected that if the freight tram scheme were to serve more demand or new charging schemes were introduced where all modes are charged by the externalities they produce, the benefit would be higher. This observation may explain the reasons for the failure of other schemes, such as CityCargo in Amsterdam, where the minimum demand needed to make the project attractive to take advantage of economies of scale and compensate for the infrastructure investment and supply chain changes may not be reached.

Regarding the second issue, even though it has not been tested in the case study, it is believed that other assumptions regarding the ownership and operation of the UCCs would lead to similar results, as some costs will simply be transferred from annual flows to initial investments, or if simpler consolidation approaches are taken, some of the benefits will not be present. As discussed before, there are some benefits reported in Allen *et al.* (2012) for the UCCs that have not been accounted for, but it is not expected that they are enough to reverse the current result. An evaluation of UCCs is made in Zunder *et al.* (2011) and Allen *et al.* (2012). The first claims that UCCs are not feasible under liberal markets unless they are targeting the construction sector. The second argues that in the cases of a single landlord that can properly enforce the use of the UCCs, benefits could be obtained. This case study approaches these circumstances with a small number of shopping centres. However, it is also stated that high goods throughput is required to generate sufficient benefits (eg. efficiency gains, reduced externalities, improved reliability, etc.) to compensate for the costs of operating the UCCs, a throughput level that may not be reached in the suggested Barcelona freight tram scheme as the results seem to show.

On the other hand, domestic waste collection by tram does appear to have the potential to yield net benefits in cities with existing tram networks, mainly because it cuts the traditional waste collection operation costs and the organisational challenges are more manageable. .

Future research should be focused on exploring those demand and throughput thresholds that would make a freight tram scheme feasible and incorporating into the framework UCCs benefits that have been omitted from this analysis due to a lack of evidence. In addition, ways to overcome current organisational barriers and what would be the best business model under which the scheme should operate could be investigated. Finally, a broader analysis including different competing solutions and scenarios, which could be based on potential technological adverts and urban freight sector trends, should be undertaken, providing a better insight on the effects of freight trams in the longer term.

In conclusion, a different approach to appraise freight tram schemes by means of a cost benefit analysis has been implemented, which provides insight on the reasons for their failure and success that are in line with recent European experiences. Freight tram schemes can only be feasible if they take advantage of economies of scale, serving a minimum demand and have highly efficient UCCs, or exploit niche markets where current operational costs are high and little or no additional infrastructure is required.

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