Exploring Scenarios for the Introduction of Freight Trams in Barcelona

Robert Regue
PhD Student, Transportation Systems Engineering Program
Department of Civil & Environmental Engineering
Institute of Transportation Studies
University of California, Irvine, CA 92697-3600 USA
TEL: (949) 824-5989
FAX: (949) 824-8385
E-MAIL: rreguegr@uci.edu
Corresponding author

Abigail L. Bristow
Transport Studies Group
School of Civil and Building Engineering
Loughborough University
Loughborough LE11 3TU
TEL: +44(0)1509 223781
FAX: +44(0)1509 223981
E-MAIL: a.l.bristow@lboro.ac.uk

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ABSTRACT

Urban goods distribution has gained in importance in recent years since its optimization not only has the potential to increase productivity and efficiency of the operations but also to achieve broader goals related to the reduction of environmental impacts such as noise, air pollution and CO₂ emissions. The focus of this paper is to explore the financial feasibility of a hypothetical freight tram scheme in Barcelona and examine the extent to which a scheme based largely on existing infrastructure could have a role in mitigating such effects.

Two different freight tram scenarios are developed for detailed investigation: scenario 1 for deliveries and scenario 2 for waste collection. Cost benefit analysis was carried out based on the best available public domain information and with clearly specified assumptions.

A waste tram scenario yields high Net Present Value (NPV) and rapid return on investment due to the low initial costs and significant operating cost savings. On the other hand, in the initial specification the delivery tram has a very negative NPV due to high initial investment costs and annual costs exceeding annual benefits. A number of modifications were explored indicating 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.

These results are in line with previous freight tram projects, where only those with a specific objective and few stakeholders have succeeded, suggesting that for urban deliveries systems organisational challenges may pose the largest barrier to its implementation.

Keywords: city logistics, tram, cost benefit analysis
1. INTRODUCTION

Urban goods distribution has gained in importance in recent years since its optimization not only has the potential to increase productivity and efficiency of the operations but also to achieve broader goals related to the reduction of environmental impacts such as noise, air pollution and CO₂ emissions. Overall, improving city logistics does not involve a simple solution, instead imaginative/innovative solutions integrating policy and technological aspects to tackle the growing impacts of urban good deliveries are required. Many cities, especially in Europe, have not yet found adequate solutions to optimise the urban movement of goods (1).

A potential solution that has not been fully explored is the use of the tram network to deliver goods. Robinson & Mortimer (2) note the potential that urban rail has to become a real solution for urban deliveries. Muñuzurri *et al.* (3) suggest several solutions to improve city logistics including rail/tram use and remark upon the need to engage all the stakeholders in the process. Issenmann *et al.* (4) suggest integrating the passenger transit network with urban deliveries focusing on underground services in Paris.

This paper reports the findings of a scoping study exploring the feasibility of a freight tram scheme in Barcelona (5) with the aim to determine under which circumstances and to what extent a freight tram scheme, based on largely existing infrastructure, can have a role on mitigating the impacts of urban good deliveries. Freight tram scenarios are developed and appraised through a cost benefit analysis.

The use of trams to deliver goods and/or collect waste clearly has potential. The main advantages the tram can offer are based on optimizing the last step of the urban logistics supply chain by using existing infrastructure and reducing environmental impacts in the city centre. However, new steps are added into the logistic chain, which may offset the benefits gained by the implementation of the freight tram scheme.

Evidence on freight tram systems is limited, examples in Europe include:

- **CarGo Tram, Dresden, Germany.** CarGo Tram was launched by Volkswagen (VW) in cooperation with DVB (Public transport operator in Dresden) and the Government. It became operational in November 2000. The sole purpose of the project is to supply the VW “transparent” factory in Dresden city centre (6). Two 60 metre long trams each with 60 tons capacity run 16 hours a day 6 days a week under a 15 year contract. The system is reported to be both profitable and competitive with road (7). The main difficulty was in finding a manufacturer able to produce just two specialised tram units, which cost €3.5 million (7).

- **CargoTram and E-tram, Zurich, Switzerland.** Cargo Tram was launched by the tram operator (VBZ) and the company in charge of recycling in the city (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 (8). This solution was adopted because it was noted that traditional waste collection trucks needed three times more time to move across the city within the peak hour. Cargo Tram is cheaper to run, faster, clean and carries a non-time sensitive and low value commodity and these factors have made Cargo Tram feasible (2). There are 9 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 cost on average €3,200 in 2005 and 5,020 km of truck operation was saved leading to a reduction of 4.9 tonnes of CO₂ (9).

- **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 the supply chains to optimise the use of the resources (10). After the test, the operator Wiener Linien decided not to continue with the implementation of the project. The reasons given were financial and political, as the partners and the developers did not want to make a long term commitment, making the freight trams unaffordable and there was a feeling of lack of political backing.

- 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 (4).

- Monoprix deliveries in Paris, France. The project was launched in 2004 by Monoprix and implemented in 2007 after a feasibility study (11). Freight travels by train to halle de Bercy inside Paris and goods are then delivered to 90 stores using 26 NGV trucks (4). It is claimed that 700,000km of truck operation were saved in 2009 and emissions reduced by 50% (4). In addition, it has been 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 (12).

The limited experience of freight tram operation suggests that only projects focused on solving a particular issue and with stakeholder support have succeeded. In Dresden and Paris this involved a key commercial stakeholder with volume deliveries that utilise the infrastructure effectively. In Zurich cooperation between the tram operator and waste collection company has devised 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.

This paper aims to provide further insight into the conditions required to make a freight tram scheme feasible. This is achieved through a case study of Barcelona, the context, tram systems and surveys of retailers to explore potential use may be found in Section 2. Section 3 examines key scheme features and section 4 the potential cost and benefits and the evidence and assumptions underpinning the cost benefit analysis (CBA). Section 5 presents a CBA for each scenario, including sensitivity tests for the delivery scenario and finally, in section 6, conclusions are drawn.

2. CASE STUDY CONTEXT AND SURVEY

2.1 Barcelona Context and Freight Tram Scenarios

Barcelona, in common with other cities, is affected by changes in delivery patterns and consumer behaviour that contribute to the following developments. Barcelona is failing to satisfy Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe because of the high levels of NO2 and PM10 (13). 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 (14). 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 (13). 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 (15). All of these factors influence the liveability and economic prosperity of the city. Current urban logistics have not effectively tackled these issues.
A freight tram scheme has the potential to improve air quality in the city centre and reduce commercial vehicle kilometres, maintenance costs and noise levels. It 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 (16). A freight tram can be integrated with Urban Consolidation Centres (UCCs), leading to improved sales and profitability, reduced traffic and environmental impacts and improved customer satisfaction (17). Passenger tram infrastructure may be underutilized especially at night and a freight tram can exploit this opportunity.

A freight tram scheme has three main requirements: (1) infrastructure, (2) demand generators and (3) consolidation facilities. 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 but are not joined together. For the purposes of this study we assume that the planned scheme to link the two through La Diagonal (currently on hold) will be built.

(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) Urban Consolidation Centres (UCCs), are facilities where the modal switch from road vehicles to freight trams would take place alongside a range of value added logistic and retail operations. These could include: pricing, ticketing, quality inspection and introducing security alarms. This would mean more sales space in-store, reduced unloading time, better inventory control, better schedule planning and released time to provide improved customer service for the establishments. In addition, UCCs are intended to reduce stockholding space available in the establishments or in the logistic levels of the shopping centres.

As La Diagonal is 11 km long, it is likely that two UCCs will be needed, one located on the Besòs side of the city with access from the A2 motorway and the other on the Llobregat side with access from the B-10 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**: Freight tram for deliveries to four shopping centres namely L’Il·la Diagonal, Pedralbes Centre, Les Glòries and Diagonal Mar (the large retail stores are excluded as they already have a logistic platform near Barcelona).

- **Scenario 2**: Freight tram for waste collection from residential properties to the Ecoparc.

### 2.2 Surveys

Before the estimation of costs and benefits it is necessary to quantify the number and nature of trips generated by each establishment. Existing studies ((18) and (19)) do not yield suitable information on trip rates. Therefore two surveys were carried out with the aim to build a category model able to forecast trip rates per establishment type. Firstly, a series of observations were made to determine freight vehicle flows in l’Il·la Diagonal shopping centre at different times of the day on two different days. These differentiated between vans, trucks, articulated trucks and other kind of vehicles. The counts are used to validate the establishment survey results. The results indicate an average of 31 vehicles per hour in the morning peak and 12 vehicles per hour during the afternoon peak.

Secondly, face-to-face interviews aimed to provide data concerning delivery patterns, equipment used, trip rates and willingness to accept supply changes and cost increase due to environmental benefits was carried out. The survey was conducted with establishments at L’Il·la Diagonal, Diagonal Mar and Pedralbes Center on July 2010. Les Glòries was not surveyed since permission was not given. The sampling strategy was simple random sampling. The sample size was 51 (19% of the total establishments and a reasonable match to the current distribution of establishments by sector). Restaurants, jewellers and services were not included in the sample population because they have special delivery systems, security concerns in answering the questionnaire or do not require large amount of goods.
The survey findings are now discussed briefly. The average number of trips per establishment per week is 2.94 and this will be used in the analysis as there is not sufficient information to disaggregate further. 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. The most common waste is cardboard and currently the shopping centre provides the facilities to dispose of waste, which is collected by a specialist company. There would then be potential for the tram to carry waste on the return journey. The attribute that respondents value most from a transport company is reliability, they are fairly satisfied with the existing system and generally averse to change. When offered a set of options including: day time freight tram and small electric vehicles for the final delivery, night time freight tram and small electric vehicles for the final delivery, substitution of the current petrol vehicles by electric ones, consolidation centres located at the outskirts of the city and then, use current freight vehicles for the final delivery and the use of consolidation centres to consolidate and integrate deliveries, followed by freight tram distribution and small electric vehicles for the final delivery, the preferred option was a simple switch from petrol/diesel vehicles to electric vehicles. There was a reluctance to consider using a tram delivery system or night deliveries. Reasons given include an aversion on additional transfer and the related feeling that it is a retrograde step since more stages are added into the logistic chain.

These findings are used to estimate the total number of trips generated by the shopping centres. The number of unique trips suggests potential savings from consolidation. As most establishments rejected night deliveries, the freight scheme will initially be designed for daytime operation. Therefore the freight tram will require parking space during the day while performing loading and unloading operations. So, short sections will be built perpendicular to current network to guarantee access to shopping centres without interfering with passenger tram operations. In addition, since the shopping centres manage waste collection, reverse logistics can then be implemented.

3. KEY SUPPLY AND DEMAND FEATURES
Here detailed operational aspects of the proposed scenarios are discussed.

3.1 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 1. As a result 4,377km are saved per week, accounting for the return trip.

For multiple delivery trips (73%) it is known that, on average, each vehicle makes 4 trips (18) 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 1 to 4 legs of an existing trip. Given the strategic location of the
We make the simplifying and conservative assumption that for every 4 existing multiple trips the distance saved will be the same as for one unique trip without considering the return trip. Table 1 shows the resulting saving per week amounting to 302,442 km per year.

### Table 1 Scenario 1. Distance Travelled by Unique Deliveries per Week

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

### 3.2 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 1 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 UK data on urban conditions from the Department for Transport (20) for trucks and AEA Technology (21) for vans. Spanish data was only available for heavy trucks in intercity operations, conditions that would underestimate the total number of vehicles required. Adjusting for vehicle shares the average lading factor is 0.33 and 86 tonnes are moved each day.

Since the maximum capacity of the freight tram is 35 tonnes (22), 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 one tram.

The average distance travelled by the tram per trip is the distance between UCC1 and the farther shopping centre (Illa Diagonal) and the average route distance between UCC2 and the shopping centres. Including return trips this gives a total of 81.16 tram kilometres a day.

### 3.3 UCC Features

To evaluate UCCs surface needs, data provided by l’Illa Diagonal is used. The shopping centre requires 21,000 m² of logistic surface, therefore, since UCC1 is supplying L’Illa Diagonal and Pedralbes Centre, assuming a linear relationship between the surface requirements and the number of establishments, UCC1 requires 28,000 m². Applying the same reasoning to Diagonal Mar and Les Glòries, UCC2 should be 30,800 m².
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. Therefore, the surface of UCC1 is 11,220 m² and UCC2 12,325 m².

3.4 Residential Waste Collection and Waste Trams
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 6.58km², 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.

The Area Metropolitana de Barcelona, Entitat del Medi Ambient, (23), estimates average waste per person per year to be 349.28kg of general waste and 55.5kg organic waste. Barcelona population density is 15,817 people per km² (24). Total daily waste from the residential catchment area is then 46.17 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 (25). 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, 7 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 52,378 km/year.

4. COSTS & BENEFITS
Having determined the key parameters for both freight tram scenarios, the cost and benefits that are analysed are detailed below.

4.1 Freight Tram Operating Costs
Data in ATM (26) 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 7.30€/veh·km (27). The 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 average load is expected to be higher.

For the waste collection scenario 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 €533,754 and €352,463 per year for scenarios 1 and 2 respectively.

4.2 Infrastructure and Rolling Stock Costs
The cost of new track is based on those for Trambesòs project (28), uplifting the values to 2009 by the construction cost for civil works (29), resulting in €9829 per meter. The length of new
track is estimated to be 1.04 km and 0.10 km for scenarios 1 and 2 respectively giving costs of €10,222,519 and €982,935. The cost of a single freight tram is €1,800,185 (22) and as 2 trams are required for each scenario this gives vehicle costs of €3,600,371 in each case.

4.3 UCCs Rent and Operating Costs
The construction and use costs of a UCC are derived from the average monthly rental cost for industrial properties in the area where the shopping centres are located. Therefore, the land and construction costs are already accounted for and assumptions concerning the ownership of the building do not need to be made. The figure used is 4.47 €/m² per month (30). The annual rent is then €1,262,954 based on the areas of both UCCs.

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 (24). This gives annual staff costs of €1,374,128.

4.4 Vehicle Operating Cost Savings
ACOTRAM (31) 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 €/veh-km and 0.80 €/veh-km respectively including fuel, amortization, staff and insurance. Since the distance saved has already been calculated, the total operating cost savings of the freight vehicles may be estimated as €268,156.

Concerning the operational 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 (25), €92,840,438 year, and the estimated share of waste collected by the freight scheme is 1.95%, yielding to a saving of €1,814,872 per year.

4.5 Air Pollution and Carbon Savings
Freight vehicle emissions are taken from AEA (32) and weighted by share of trucks and vans. For scenario 2 the emissions per km factors only include truck emissions whereas for scenario 1 they have been weighted by the vehicle shares.

The pollutant values used here include: the effects of chronic mortality, increase of hospital admissions and building soiling for PM$_{10}$; the impact on materials caused by SO$_2$ (33) and deaths due to ozone levels and hospital admissions for VOCs (33). The CO$_2$ value is based on mitigation costs (35). All values are adjusted to 2009 prices according to Spanish GDP growth. The exchange rate used is 1.17 €/£, an average value of past two years. This value is conservative, since historically, the exchange rate has been fluctuating around higher values.

The savings are €13,169 per year for scenario 1 and €4,238 per year for scenario 2, with CO$_2$ providing around two thirds of the benefit.

4.6 Infrastructure Damage, Noise, Accidents and Congestion Reduction Benefits
Values per vehicle kilometre for infrastructure, noise accidents and congestion are obtained from Piecyk et al. (16) and uplifted to 2009 values. In both scenarios the main benefit is from congestion reduction. The total benefit per year is €118,152 for scenario 1 and €34,868 for scenario 2.
4.7 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, 2 hours per trip are needed for each establishment to carry out value added activities, based on the feedback given for the respondents when conducting the survey. Considering the cost per hour per employee for the company €15.78 employee/hour (taxes included) (24) and a productivity increase of 50% due to economies of scale, trained personnel and automation at UCCs, the benefit that the value added activities generate is €824,746 per year.

4.8 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 a 50% surface reduction is assumed.

The average stockholding surface is deduced from the survey resulting on 14.75 m$^2$ per establishment. As the number of establishments is 342, the total stockholding surface is 5043 m$^2$.

According to data provided by the surveyed shopping centres, renting a premise costs on average 11 €/m$^2$ per month depending on the shopping centre, location of the premise and establishment type. The resulting benefit for the shopping centres is €332,826 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.

4.9 Reverse logistics
The most common waste, as concluded from the survey, is cardboard, followed by plastic, waste that 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, a full load of cardboard, plastic and general waste. 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 same procedure as commercial vehicles but for trucks only. Freight tram operating costs are as defined in section 4.1. Under these assumptions, the kilometres saved by waste trucks are 9,984 km.

The saving in externalities are €6,646, air pollution and carbon €808 and operating costs €8,824 per year.

4.10 Revenues
It is assumed that the company operating the freight tram scheme will charge a similar price as the current freight operators. Thus, first year revenues are expected to be €268,160 including reverse logistics.

5. COST BENEFIT ANALYSIS (CBA)
Table 2 shows the cost and benefits flows for the first year of operation and the Net Present Value (NPV) obtained for each scenario under different hypotheses detailed below.
### TABLE 2 Cost & Benefit Disaggregation for Each Scenario During the 1st Year of Operation and NPV Results Under Different Hypotheses

<table>
<thead>
<tr>
<th>COSTS</th>
<th>Scenario 1: deliveries</th>
<th>Scenario 2: waste</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>€</td>
<td>%</td>
</tr>
<tr>
<td>Track</td>
<td>10,222,520</td>
<td>74.0</td>
</tr>
<tr>
<td>Rolling stock</td>
<td>3,600,371</td>
<td>26.0</td>
</tr>
<tr>
<td><strong>Initial Investment</strong></td>
<td><strong>13,822,891</strong></td>
<td><strong>100.0</strong></td>
</tr>
<tr>
<td>Tram Operation</td>
<td>533,754</td>
<td>16.8</td>
</tr>
<tr>
<td>UCC rent</td>
<td>1262,9534</td>
<td>39.8</td>
</tr>
<tr>
<td>UCC operation</td>
<td>1374,128</td>
<td>43.3</td>
</tr>
<tr>
<td><strong>TOTAL Costs 1st Year</strong></td>
<td><strong>3,170,836</strong></td>
<td><strong>100.0</strong></td>
</tr>
<tr>
<td>BENEFITS</td>
<td>€</td>
<td>%</td>
</tr>
<tr>
<td>Infrastructure damage</td>
<td>6,221</td>
<td>0.3</td>
</tr>
<tr>
<td>Noise</td>
<td>2,193</td>
<td>0.1</td>
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<tr>
<td>Accidents</td>
<td>12,601</td>
<td>0.7</td>
</tr>
<tr>
<td>Congestion</td>
<td>97,136</td>
<td>5.3</td>
</tr>
<tr>
<td>Air pollution</td>
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<tr>
<td>Carbon</td>
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<td>Operating savings</td>
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<td>14.6</td>
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<tr>
<td>Revenues</td>
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<tr>
<td>Value added activities</td>
<td>824,746</td>
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<td>Stockholding facilities</td>
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<tr>
<td>Reverse Logistics</td>
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<tr>
<td><strong>TOTAL Benefits 1st Year</strong></td>
<td><strong>1,841,490</strong></td>
<td><strong>100.0</strong></td>
</tr>
<tr>
<td>Total Benefits - Total Costs 1st Year</td>
<td>-1,329,346</td>
<td>NA</td>
</tr>
<tr>
<td>NPVs</td>
<td>€</td>
<td>%</td>
</tr>
<tr>
<td>0) NPV Base case</td>
<td>-37,512,022</td>
<td>100.0</td>
</tr>
<tr>
<td>1) NPV Night Deliveries</td>
<td>-29,746,8389</td>
<td>-20.7</td>
</tr>
<tr>
<td>2) NPV one freight tram only</td>
<td>-29,704,153</td>
<td>-20.8</td>
</tr>
<tr>
<td>3) NPV 75% UCC productivity</td>
<td>-29,704,153</td>
<td>-20.8</td>
</tr>
<tr>
<td>4) NPV Doubling stockholding space benefit</td>
<td>-31,210,291</td>
<td>-16.8</td>
</tr>
<tr>
<td>5) NPV 25% costs of UCC shared</td>
<td>-31,533,833</td>
<td>-15.9</td>
</tr>
<tr>
<td>6.1) NPV 1)+2)+3)+4)</td>
<td>-13,837,053</td>
<td>-63.1</td>
</tr>
<tr>
<td>6.2) NPV 3)+4)+5)</td>
<td>-17,424,233</td>
<td>-53.6</td>
</tr>
<tr>
<td>6.3) NPV 1)+3)+5)</td>
<td>-15,960,781</td>
<td>-57.5</td>
</tr>
<tr>
<td>6.4) NPV 1)+3)+4)+5)</td>
<td>-9,659,050</td>
<td>-74.3</td>
</tr>
<tr>
<td>6.5) NPV 1)+2)+3)+4)+5)</td>
<td>-7,858,864</td>
<td>-79.0</td>
</tr>
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</table>
The costs between scenarios are quite different due to the varying new track requirements and UCC related costs. As a result, the initial investment required for scenario 1 is 3 times greater than for scenario 2 and annual costs are 9 times greater.

In terms of benefits, the largest benefit for scenario 1 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 scenario 2, operating cost savings account for 97.9% of the annual benefits. Air pollution and externalities savings are relatively low in both cases because the kilometres saved and the trucks taken out of the roads are low.

In the CBA, a project life of 25 years is assumed, as after this the trams may need replacing. A discount rate of 3.5% (the rate in use for public projects in the UK) is applied. Prices are expected to increase in real terms by 2% a year, as suggested by DEFRA to account for willingness to pay increases and operating costs by 1% a year. As a result, NPV is €37,512,022 for scenario 1 and €23,931,047 for scenario 2.

The high NPV for scenario 2 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 of 4 years.

The main reasons for the negative NPV for scenario 1 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. Given this result sensitivity testing is undertaken for scenario 1 to determine under what conditions the scheme would be feasible. The following were tested and are reported in Table 2:

- (1) Night deliveries: allowing night deliveries would reduce the initial investment sharply since parking tracks at the shopping centres would be no longer needed since trams can safely park in the existing track. As a result, initial investment becomes €6,057,708, yielding to a 20.7% improvement in the NPV. This change, however, increases the distance that the final handling equipment should travel and may generate further legal and safety issues. It has been assumed the freight volume is the same as for normal 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, on the early stages of the project, one tram may be used to prove the concept cutting initial investment to €12,022,705 and improving NPV by 4.8%.

- (3) UCCs improved productivity to 75% instead of the assumed 50%: if the productivity at UCCs were to improve up to 75% in the future, due to expertise and large scale operations, the NPV improves by 20.8%.

- (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 the same order as the renting benefits the NPV improves by 16.8%.

- (5) Sharing UCCs costs with other forms of distribution: UCCs could also be used as a consolidation centres for other retailers that are not within the catchment area of the tram network but are willing to consolidate their goods. González (35) suggested a similar idea by 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 15.9% improvement in the NPV.
Combination of measures: combining all the above measures, the NPV is still negative at €-7,858,864. 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. Unrealistic assumptions would be required to obtain a positive NPV for a freight tram with two UCCs. 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 €11,091,532 (-12,839,515+23,931,047). If sensitivity analysis is performed to the pilot project, by sharing 25% of UCC costs, increasing productivity to 75% and doubling stockholding surface benefits, a positive NPV of €133,741 is obtained for urban deliveries, that combined with waste collection, yields to an aggregate NPV of €24,064,788.

Note, however, that all costs and benefits do not apply to the same entity, which yields to organizational challenges.

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 born in mind that the project life is 25 years, and within this timeframe several improvements to the Barcelona tram network are proposed (37). There are 2 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, reducing freight vehicles mileage considerably. 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.

6. CONCLUSIONS

In conclusion freight tram operation for urban deliveries is not economically attractive if the tram has to bear all the costs of the UCC and requires additional track. Waste tram collection does appear to have the potential to yield net benefits in cities with existing tram networks. The Barcelona case study shows that even a city that appears to be an excellent candidate for freight trams, given that it already has in place the main elements, freight tram deliveries are not financially feasible. 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. A freight 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. These results are in line with previous freight tram projects, where only those with a specific objective and few stakeholders have succeeded, suggesting that for urban deliveries systems organisational challenges may pose the largest barrier to its implementation.

7. REFERENCES


34. DEFRA. *Damage Costs for Air Pollution.* London, 2006.

