



Using rail to make urban freight distribution more sustainable

Adriano Alessandrini¹, Paolo Delle Site¹, Francesco Filippi^{1*},
Marco Valerio Salucci¹

¹ CTL Centre for Transport and Logistics, University of Rome “La Sapienza”

Abstract

Rail is today a minimally used modality in urban freight distribution. To reap the benefits of this more sustainable transport mode a few experiences in Europe have attempted to introduce innovative freight distribution schemes where rail is used. One of such schemes uses rail for the urban penetration leg. After having been consolidated in a centre located outside the urban area, goods are transported by shuttle trains to a centre located inside the central area (the multi-modal urban distribution centre – MUDC) and there are transferred to low-pollution road vehicles to reach their final destination. Other schemes use tramways.

The paper provides a review of rail-based schemes which have been introduced in European cities. An in-depth assessment is provided of the scheme based on the use of a MUDC. The case study relates to the distribution of fish food in Rome. The environmental and energy benefits obtainable from the shift from the current road-only scheme to the MUDC scheme are estimated in physical and monetary units. An estimate is provided of the maximum public contribution that would still make the scheme beneficial for society as a whole, obtained as the difference between the social costs of the road-only scheme and those of the MUDC scheme. Also, an assessment is provided of the profitability of the scheme from the operators' viewpoint.

Keywords: Urban freight distribution, sustainable transport, rail transport, multi-modal urban distribution centre.

1. Introduction

The organisation of urban freight distribution is based almost universally on the use of road vehicles. As a consequence, urban freight distribution must confront high levels of traffic congestion, lack of parking spaces, lack of appropriate loading and unloading areas, which affect its efficiency. Urban freight traffic has significant impacts in terms of energy consumption and pollutant emissions, especially of PM due to the predominant use of diesel vehicles. European surveys show that the share of emissions

* Corresponding author: Francesco Filippi (francesco.filippi@uniroma1.it)

of freight vehicles is between 20% and 30% of total urban traffic emissions depending on the local situation (Schoemaker et al., 2006). The share of freight traffic on total urban traffic is in the range of 14% of vehicle-kilometres, 19% of energy use, and 21% of CO₂ emissions (Schoemaker et al., 2006). Furthermore, urban freight traffic is more polluting than long-distance freight traffic as fuel consumption increases sharply if vehicles make frequent stops.

In an attempt to improve the efficiency of freight distribution in cities and achieve environmental sustainability municipalities have adopted policies specifically targeted to freight traffic. Most commonly these policies consist in access restriction schemes which prevent certain categories of vehicles from entering sensitive areas. These are, typically, city centres, where several challenges are met simultaneously: the lack of space, the protection of citizens' health and the protection of the built environment. Restrictions are usually differentiated by time of day, by vehicle size, and by type of operations (own account versus third account). Increasingly, differentiation based on the environmental performance of the vehicles is introduced. Differentiated access restriction schemes aim to contain the interference with other traffic and, at the same time, create incentives for adopting third account operations and renewing the vehicle fleet (Comi et al., 2008).

Besides these traditional schemes, there are few examples of implementation of innovative schemes. These include pricing schemes, which create incentives for efficient and more environmentally sustainable behaviour on the side of the operators via a range of mechanisms (better routing and vehicle utilisation, shift to third account and less polluting vehicles), and urban distribution centres (UDC), which pursue system efficiency in the form of vehicle utilisation enhancement via the mechanism of load consolidation.

The paper deals with the potential for use in urban freight distribution of schemes based on the use of rail. The use of rail is a key element of the strategy for the achievement of the objective of decoupling economic growth from the negative side-effects of the transport activities. This objective is at the centre of the European transport policy according to the mid-term review of the European Commission's transport policy White Paper (CEC, 2007). Road traffic is a primary source of these negative side-effects which include greenhouse gas emissions, local pollution, noise and accidents. In contrast, rail can offer the use of more sustainable energy sources for traction, better energy efficiency, less accidents.

Rail has been dominant in freight transport as long as the road infrastructure and services did not achieve the levels of development of the last decades. Rail is currently used mainly to transport large quantities of low value or non-time sensitive goods or goods unusual for size or weight. The mode share of rail transport in Europe in the freight sector declined to less than 15% in tonne-kilometres in last decades (Maes and Vanelslander, 2010). Transport policy at European and national level has included the revitalisation of railways in the agenda and several initiatives have followed. In the freight sector, the policy focus has restricted to long-distance traffic.

Rail is nowadays an under-used modality in urban freight distribution. The main hindrances to the use of rail transport for urban freight distribution have been identified in (Robinson and Mortimer, 2004):

- limited physical flexibility;
- competition with passenger services for line capacity;
- perception of costs of rail infrastructure and related systems as being high.

In Italy the major player of rail freight services has adopted a policy of progressive discontinuation of goods yards located in city centres. This has been the consequence of both the competition with road transport, which lends itself much better for the last mile because of its flexibility and ability to offer a door-to-door service, and of the preference assigned to the supply of block-trains with the concurrent discontinuation of the single wagon load market.

A few experiences in European cities have demonstrated that rail can still play a role in freight distribution. In these experiences innovative schemes are introduced. Three classes of schemes can be identified. One refers to the use of rail for the urban penetration leg. Goods are consolidated in a centre located outside the urban area, are transported from this on shuttle trains to a distribution centre located inside the central area of the city (multi-modal urban distribution centres - MUDC), and are finally transferred from rail to green, i.e. low-pollution, road vehicles to reach their final destination. These will be referred to hereafter as MUDC schemes because the MUDC is their key element. The second class refers to the use of tramways and the third to the use of underground infrastructures. From the policy viewpoint it is desirable to assess the benefits and the practical feasibility of these schemes. Literature with assessment evidence is still scant.

The paper first provides an international review of innovative rail-based schemes according to the three classes mentioned above. The paper then provides an in-depth assessment of the scheme based on the MUDC concept. The assessment considers the case study of the distribution of fish food in the city of Rome. The current road-only distribution scheme and the innovative rail-based scheme which uses a MUDC coupled with green vehicles are described. The assessment considers the viewpoint of the society and that of the operators. The environmental and energy benefits which can be obtained from the shift from the current scheme to the MUDC scheme are estimated in physical and monetary units. An estimate of the monetary incentive which can be paid by the government is provided. The profitability of the MUDC scheme from the operators' viewpoint is assessed. In the conclusions, scenarios for future developments are outlined.

2. Review of innovative rail-based schemes

2.1 Multi-modal Urban Distribution Centre - MUDC

The most significant example is the scheme developed by SAMADA, the logistical subsidiary of Monoprix (a large French supermarket chain) established to supply Monoprix convenience stores in the centre and suburb of Paris. This scheme is operational since 2007 (after three years of surveys, studies and calls for tenders) and consists in using the rail in combination with Natural Gas Vehicles (NGV) to transport goods from the two warehouses in Combs-la-Ville and Lieusaint (Seine et Marne) out of Paris to Monoprix stores in Paris. The typology of goods ranges from textile and beauty products to soft drinks, which are consolidated in pallets in the two warehouses (Maes and Vanelslander, 2010). From the rail track siding the warehouses, which allows direct transshipment to the wagons, the pallets are loaded onto a rail shuttle, consisting of about 20 wagons, which each day from Monday to Friday runs about 30 kilometres of

the line D of the RER to link the two warehouses to the market Gabriel Lamé of the station of Bercy (12th Paris administrative district in the south east area). The goods are then loaded onto NGVs and delivered to the Monoprix stores (Monoprix, 2008). The wagons are loaded between 1 p.m. and 6.30 p.m. The shuttle leaves at 8 p.m. and arrives in one hour at the station of Bercy. The trucks deliver the goods the day after (Maes and Vanelslander, 2010).

The fleet of trucks of Monoprix consisted of 20 vehicles in 2007 and 26 in 2008. The served stores were 60 in 2007, 80 at the end of 2008, almost 90 in 2009. 120,000 tonnes of goods (210,000 pallets) are transported using this scheme, which is 30% of the total of the goods delivered to Paris by Monoprix (Maes and Vanelslander, 2010). Furthermore, in order to ensure the availability of natural gas for trucks, a NGV public station was inaugurated in October 2008, near the vast area reserved to Monoprix in the market Gabriel Lamé of the station of Bercy (Monoprix, 2008).

In order to make the scheme operational, SAMADA had to build the connections between the two warehouses and the railway network, and arrange an agreement with SNCF (French National Railways company) for the shuttle service and for the use of the 3,700 m² platform in Bercy, near Gare de Lyon. (Issenmann et al., 2010).

This scheme has contributed to alleviate most negative impacts concerning urban freight distribution in the Paris region. The total distance run by trucks in Ile de France has been reduced by 700,000 km/year with consequent improvement in traffic congestion on the road network surrounding Paris (Issenmann et al., 2010). Improvement in polluting emissions has also been achieved saving 70,000 litres of fuel which meant a reduction in CO₂ and NO_x emissions by respectively 340,000 tonnes and 25 tonnes. The use of NGV for the last mile distribution also contributed to improve negative impacts usually generated by freight traffic. The vehicles are equipped with anti-noise devices and automatic gearboxes. According to the restriction imposed by the municipality of Paris, these trucks are less than 29 m² on ground with positive impacts in terms of improved safety and vehicle handling in the narrow streets of the city centre, but negative impacts in terms of the number of trips necessary to deliver the goods (Maes and Vanelslander, 2010).

However, this scheme generates additional costs compared to the conventional scheme (only using trucks) due to the use of rail transport, the operation of the depot at Bercy Station, the additional transshipment and the use of NGV. The cost per pallet using the new scheme is 17.61 €, while the cost per pallet using the conventional scheme is 13.25 € (Maes and Vanelslander, 2010). Therefore it appears that the new scheme is less profitable from a company viewpoint, which only considers internal costs, but Monoprix is confident that in future, when the modes will be effectively charged for the externalities they produce through fair pricing schemes, the new scheme will become more profitable than the conventional one.

In the city of Berlin, in April 2005 a private railway company (DHL) started a daily container train service from Unna to the BEHALA logistics centre in Berlin-Westhafen for Karstadt GmbH, a German department store chain. The service involved the transport of 40 swap bodies per day to supply Berlin Karstadt department stores. BEHALA Westhafen is a trimodal (road, water and rail) distribution centre located at the edge of the city of Berlin and provides services for the distribution of goods in the capital region Berlin Brandenburg (TELLUS, 2005).

In the city of Rome, Omnia Logistica provided the group La Rinascente with a door-to-door-service between its supplier in Emilia Romagna and its department stores in Rome. The scheme involved road transport from the supplier to the Interporto (intermodal freight centre) of Bologna, a rail shuttle service (leaving three times a week) from the Interporto of Bologna to the Scalo San Lorenzo rail freight terminal in the central area of Rome, the distribution of goods to the department stores in Rome using conventional diesel trucks. The goods, which consisted in water, textile, home and leisure products, were consolidated in pallets and roll containers. In 2005, the total number (pallets plus roll containers) transported ranged from a minimum of about 1,800 per month to a maximum of 5,800 per month (data made available by Omnia Logistica).

2.2 Tramways

Schemes using tram systems for urban freight distribution have been investigated and tested in a number of European cities, and, in few cases, permanently implemented.

In the city of Dresden, CarGo Tram is operational since March 2001. This tram service has been conceived within the Volkswagen's initiative called Transparent Factory, which involved the construction of a manufacturing plant near the city centre to make the production of cars visible to the public. Volkswagen and the PT provider of Dresden (DVB AG) have decided to link the cargo transport centre of Dresden (Dresdner Güterverkehrszentrum, GVZ) to the factory with a tram service in order to avoid impacts due to the additional goods flows in the city centre. Except for car frames, all components are supplied just in time using this tram service. The two ad hoc built trains are 60 m long and each has a capacity up to 214 m³ and 60 tonnes. Each trip of the CarGo Tram prevents three trucks from going through the city centre with consequent benefits in terms of polluting emissions and traffic congestion. CarGo Tram uses the same infrastructure used for passenger transport. It was only necessary to create the links between the tram network and the GVZ and between the tram network and the factory. The coordinated scheduling of passenger tram services and the CarGo Tram trips permits the smooth operation of the system (www.dvb.de/en/The-DVB-AG/Facts-and-Figures/CarGoTram).

Following the example of Dresden, a proposal to apply the scheme to a similar context in Turin (Italy) has been put forward, suggesting a service linking the Nizza deposit to the Lingotto exhibition centre of FIAT using the existing tram infrastructure (Moro, 2008).

In the city of Zurich, ERZ, the company responsible for the city waste disposal and recycling, has involved VBZ, the city tram company, in the implementation of a tram service (called Cargotram) to collect bulky refuse around the city in order to allow residents to easily dispose of them. Even though ERZ allows residents to leave for free their bulky refuse at one of the two proper ERZ yards or to have them collected at home with fee, some hundred tonnes of bulky refuse were illegally dumped every year. The implementation only took two months and cost about 20,000 €, thanks to the use of existing surplus vehicles combined with standard parts. Two standard refuse containers have been adapted on two four-wheeled flat wagons. These two wagons are pulled by a tram used for this purpose and painted differently from passenger trams in order to easily identify it. Cargotram runs four times a month and each time starts from a different pick-up point. Residents can leave their bulky items from 3 p.m. to 7 p.m. The tram terminus is in Werdhölzli next to an ERZ waste disposal yard. The pilot phase

started on April 2003 and became permanent on November 2003. Subsequently new further destinations have been added, and in January 2006, following the success of Cargotram, an E-Tram has been introduced for collecting electrical and electronic goods (www.proaktiva.ch/tram/zurich/cargotram_index.html).

The city of Vienna has tested in May 2005 the prototype of its cargo tram whose use, however, has been restricted to the movement of supplies between tram depots. In the Netherlands, different cities are planning the implementation of freight tram services. The company City Cargo Amsterdam (CCA) was created in April 2005 to develop a business model for this service. A pilot project was successfully carried out in March 2007. This pilot consisted in two empty cargo trams running on the network for one month to assess possible interference with passenger tram services. This pilot showed that it was possible to insert freight tram services in the traffic of passengers during off-peak hours. Unfortunately, in January 2009, CCA got bankrupt (less than half of the 150 M€ required for the project were raised) and the project was put to an end (Issenmann et al., 2010; www.proaktiva.ch/tram/zurich/newslog/newsitem.php?year=2009&item=080109).

2.3 Underground infrastructures

Underground freight distribution is considered a promising and sustainable solution because it can reduce environmental, congestion and space problems. However, initiatives for studying this solution have never reached the demonstration phase. In Amsterdam, a study for incorporating freight transport in the existing metro system used for transporting passengers has been proposed and carried out by the municipality and GVB, the local public transport company, but concerns about operational and maintenance issues have induced to stop this initiative (Robinson and Mortimer, 2004).

3. A MUDC scheme for Rome

3.1 The current scheme

Fresh Food Center S.p.A. (FFC) provides logistics services for the distribution of fresh food for supermarket chains (SMA, Auchan, Cityper) in central Italy and, in particular, in Rome. Its main offices and logistics platform are in the area of Santa Palomba which is located 30 kilometres south of Rome. FFC can rely on 48,000 square metres of refrigerated warehouse with suitable equipment to meet the needs of the different types of food product, whether in transit or stored on shelves. For the distribution FFC makes use of insulated trucks and devices to control and record temperatures. In 2009, 80,600 tonnes of pre-packed white and red meat, various kinds of cold meat, cheese and gastronomy have been handled and transported, as well as 20,150 tonnes of industrial ice cream and frozen food, 80,000 tonnes of fruits and vegetables, and 7,100 tonnes of fish food (http://www.freshfoodcenter.com/home/?page_id=47).

FFC is the main distributor of fish food within the region. Fish food arrives at the logistics platform in Santa Palomba between 6 a.m and 12 noon (fish arrival phase in Figure 1). Between 8 a.m. and 5 p.m. it is kept in specific warehouses for ventilation and placed in appropriate boxes according to its destination (preparation phase in Figure

1). The next day between 4 a.m. to 6 a.m. these boxes are loaded onto vehicles, which leave the platform at 6 a.m. for delivery. Each delivery takes on average about 4.5 h, of which 2.5 spent travelling and 2 spent at stops, queuing before unloading and unloading.



Fig. (1): Schedule of fish handling.
Source: Fresh Food Center

FFC vehicles operating the fish food delivery service have been monitored by the Centre for Transport and Logistics (CTL) of the university of Rome “La Sapienza” to collect information on logistics variables and on emissions and fuel consumption. In a first campaign, carried out in November 2005, a 6.5 tonnes (8 pallet) truck (Iveco 65E12) was monitored for about two weeks in its daily delivery of fish food from Santa Palomba to several supermarkets in the Roman urban and extra-urban area. In a second campaign, carried out in June 2006, a 12 tonnes vehicle (Iveco 120E18) was monitored for 5 days. The acquisition tool (described in Alessandrini et al. 2006) consisted of a laptop computer, a specific OBD (on-board diagnostics) hardware interface to connect the computer to the vehicle, a GPS and software programmes to manage communication and data collection.

The analysis of the information collected has highlighted interesting differences between urban and inter-urban routes (having taken the GRA, Grande Raccordo Anulare, as boundary cordon between the two) in terms of both logistics variables and of emissions and fuel consumption.

The logistics variables are the number and weight of delivered items, the time spent at each stop, and the arrival time (computed starting when the vehicle left the logistics platform in Santa Palomba). On the basis of this information, an average unloading time per item delivered of 40 seconds and the average number of items delivered has been estimated for each stop. Vehicles spent 72 to 80% of trip time on road (the remaining time was spent queuing and unloading at stops) in inter-urban routes with an average speed of 35 km/h (having discounted time spent at stops), and only 55-65% in urban routes with an average speed of 15 km/h.

The comparison between the emissions and the fuel consumption in urban and inter-urban routes is in Figure 2. Data refer to Eurocargo 120E18.

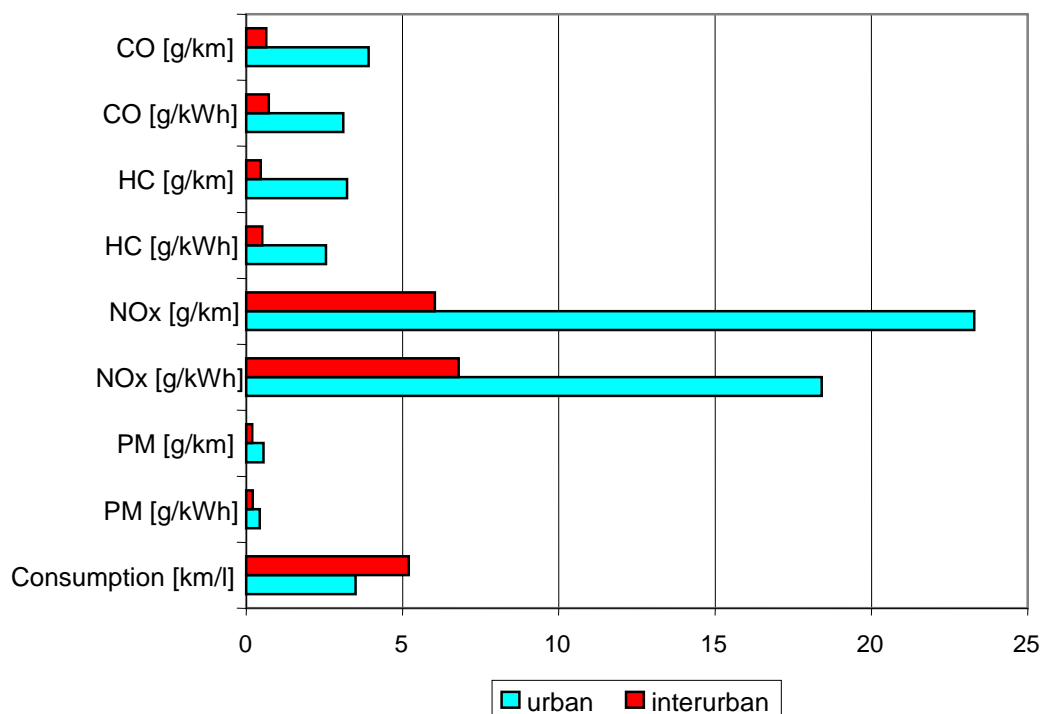


Fig. (2): Comparison between urban and inter-urban vehicle emissions and consumption.
Source: Centre for Transport and Logistics, university of Rome "La Sapienza"

NO_x emissions, which are highly significant for large diesel engines, reached the level of more than 23 g/km on urban routes and 6 g/km on inter-urban routes. In terms of g/kWh the level reached in inter-urban routes is approximately the one set by the European legislation (for Euro 2 heavy duty vehicles the limit is set to 7 g/kWh), while in inter-urban routes is 18 g/kWh which is significantly beyond. The main reason for such low environmental performances on urban routes is that these freight vehicle engines are specifically designed for outer city operations, and, consequently, operate out of the optimal torque-speed ranges when travelling inside cities. To achieve good environmental performances in cities vehicles should be specifically designed for that, but they would no longer be able to efficiently work on inter-urban routes. In terms of energy, the average power and fuel consumption measured during the campaigns in the urban routes (respectively 10-20 kW and 3.5 km/litre) is relatively low compared to the 30-35 kW and 5.2 km/litre required on average on inter-urban routes.

3.2 The proposed scheme

The scheme is conceived for the distribution of fish food from the Santa Palomba platform to destinations located inside the urban area of Rome (delimited by the GRA cordon). The scheme centres around the use of a MUDC in Scalo San Lorenzo, an existing rail freight terminal located in the eastern inner area of the city of Rome. Shuttle trains are used to transport fish food from the existing rail terminal of Pomezia Santa Palomba, located near the FFC platform, to the MUDC located in Scalo San Lorenzo. In the MUDC the fish food is transferred to road vehicles which are used to reach the final destinations. The MUDC concept is illustrated in Figure 3.

The scheme allows to divert freight traffic from road to rail along the penetration into Rome, which suffers from serious congestion problems in the morning hours due to commuters' car traffic. As the capacity of the railway node in Rome is saturated by passenger rail traffic in daytime, the train shuttle between the two terminals needs to operate during the night. The layout of the existing railway infrastructure in the Rome node makes the direct connection between the Santa Palomba terminal and Scalo San Lorenzo not possible. Therefore, trains need first to reach the stop at Tiburtina Station and then reverse direction to Scalo San Lorenzo.

Ideally the MUDC concept is implemented by using specially designed intermodal transport units (ITUs). Conventional standard ITUs would not be suitable because the smallest ITUs (the container 1C and the swap-body C625) are more than 6 metres long and 2.5 metres wide with an overall weight between 14 and 20 tonnes and cannot be handled using the small pick-up/delivery vehicles typically used in cities. Therefore, it is necessary to introduce new smaller ITUs which can be easily transferred (using horizontal and automatic transshipment equipment) to special innovative vehicles for urban service. Practically, in the case here it is possible to transport the pallets with the boxes of fish food using refrigerator cars for the train leg and then transfer them into refrigerated small trucks.

The scheme can provide the most beneficial effects if low-pollution trucks are used for the final delivery inside the urban area. Diesel-electric hybrid vehicles are considered. While hybrid cars have become commercial products, hybrid buses and hybrid trucks still remain niche products developed for specific applications. The European project HOST (Orecchini et al. 2005) has developed the concept of a multipurpose vehicle for urban transport services (Alessandrini et al. 2009) featuring a hybrid power-train, which has been designed according to a bottom up methodology (Pede et al. 2006). The vehicle is designed (in terms of size, power, weight) specifically for urban use. A prototype of this power train has been tested and evaluated to measure the emission and consumption factors in the actual traffic conditions of Rome (Alessandrini et al. 2010).

Besides hybrid vehicles, alternative fuelling and fully electric vehicles and can be considered. The study presented in this paper, however, has been focused on hybrid vehicles. Alternative fuelling vehicles are normal vehicles, designed for inter-urban trips, which suffer from the same inefficiencies of diesel vehicles in cities; furthermore despite saving other emissions (mainly NO_x and PM), CO₂ emissions and fuel consumption are higher than diesel vehicles. Fully electric vehicles do still have a problem of range; after 12 hours charging present batteries allow not more than a 40 km range. In the near future, when different batteries will be available, fully electric vehicles can be the best choice for this application.

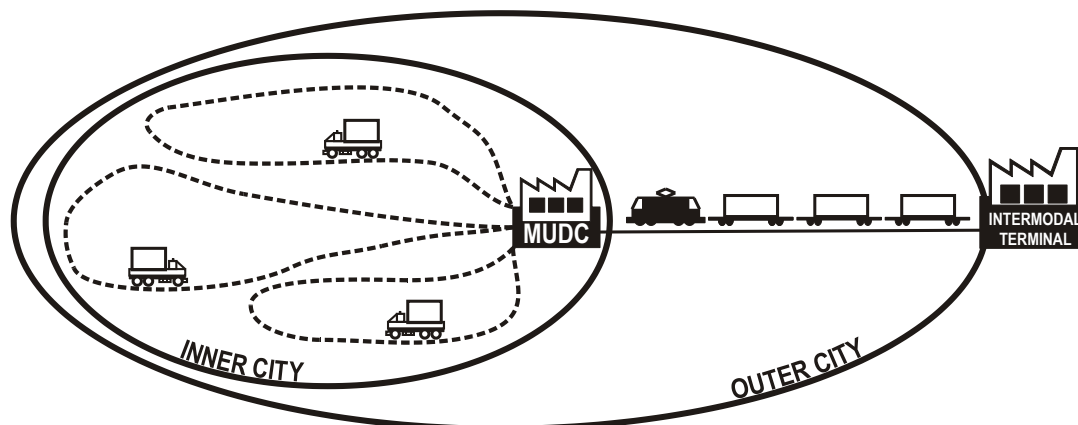


Fig. (3): The MUDC scheme for urban freight distribution.
 Source: Centre for Transport and Logistics, university of Rome “La Sapienza”.

4. Assessment of the proposed MUDC scheme in Rome

4.1 Scenarios and simulations

The following scenarios are considered:

- reference scenario,
- design scenario with conventional vehicles,
- design scenario with green vehicles.

In the reference scenario the fish food is delivered according to the road-only scheme currently provided by FFC. Conventional diesel vehicles are used. In the two design scenarios the MUDC scheme is adopted according to the specifications described in the previous section. In the design scenario with conventional vehicles the final delivery from the MUDC is performed with the use of the conventional vehicles that are currently used by FFC. This scenario provides the assessment of the benefits which can be obtained from the use of rail only. In the design scenario with green vehicles the final delivery from the MUDC is performed with the use of hybrid vehicles. This scenario provides the assessment of the additional benefits which can be obtained from coupling the rail shuttle service with the use of low-pollution vehicles inside the urban area.

The quantitative analysis considers the daily delivery of a total of 2.2 tonnes of fish food which is currently organised in 4 separate tours for a total of 287 kilometres and 18 supermarkets served. The information on the tours came from the monitoring campaign which has been described in the previous section. In the design scenarios the organisation of the deliveries into 4 separate tours is maintained. Based on the deliveries at each destination, this implies vehicles with a capacity of 4 pallets which is equivalent to 160 boxes of fish food.

When the design scenarios are considered the origin of the tours changes from the Santa Palomba platform to the MUDC in Scalo San Lorenzo and each tour has to be regenerated. To this aim the TransCAD transportation planning software has been used. TransCAD offers a vehicle routing program which is able to consider multiple vehicles, mixed pick-up and delivery, multiple time windows at stops and vehicle type constraints at stops. In the case here four time-efficient routes have been generated separately

having considered a single vehicle per route. The inputs provided include link travel times (a speed of 15 km/h based on the monitoring campaign is assumed), time spent at each stop, quantity delivered at each stop, opening hours at the MUDC and at each stop. The four tours generated, shown in Figure 4, have a total length of 110 kilometres.

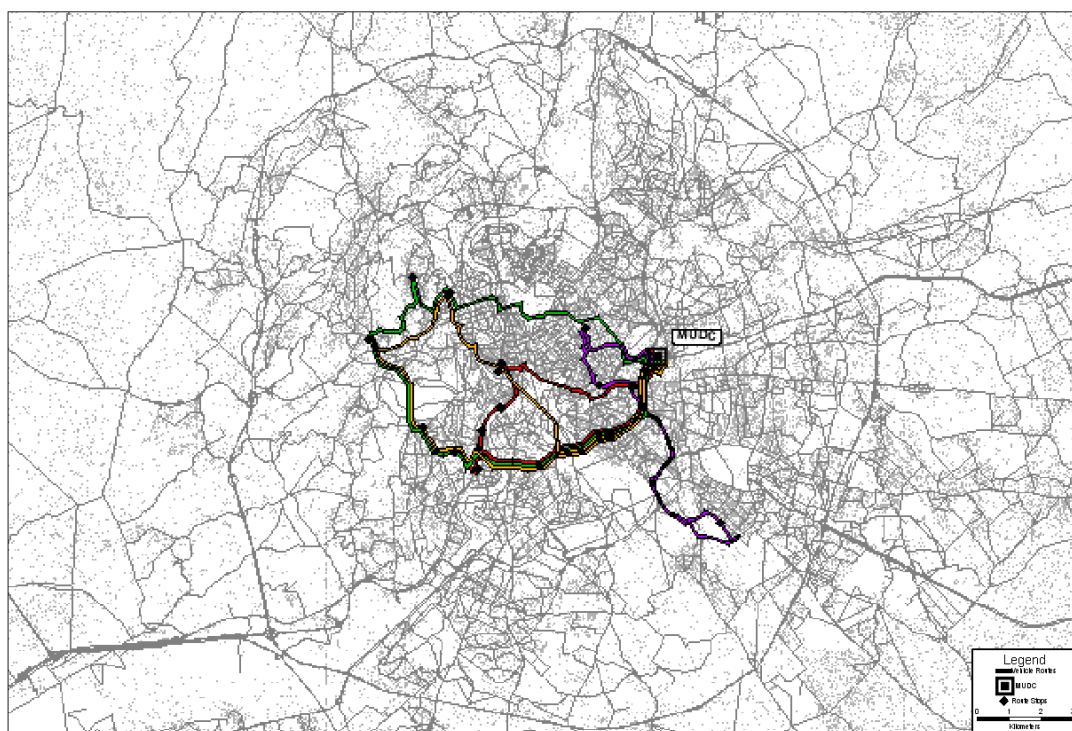


Fig. (4): The four simulated routes.
Source: Centre for Transport and Logistics, university of Rome “La Sapienza”

4.2 Assessment from the social viewpoint

Under this viewpoint the social costs of the emissions and of consumption are considered. The emission and consumption factors (Table 1) used for assessing the performances of conventional vehicles are those experimentally measured during the monitoring campaigns carried out in 2005 and 2006, while for hybrid vehicles are those obtained testing the HOST prototype in the same working conditions measured for the conventional vehicles in Rome. Table 1 shows that hybrid vehicles consume 50% less fuel than a conventional vehicle, emit about 50% less CO₂, emit 30 times less NO_x and 50 times less PM.

Table 1: Emission and consumption factors for conventional and hybrid vehicles.

| | conventional vehicles in urban areas | conventional vehicles in inter-urban areas | hybrid vehicles in urban areas |
|---------------------------|---|---|-----------------------------------|
| CO ₂ [g/km] | 728 | 497 | 359 |
| CO [g/km] | 3.97 | 0.55 | 0.03 |
| HC [g/km] | 3.23 | 0.47 | 0.01 |
| NO _x [g/km] | 23.25 | 6.02 | 0.75 |
| PM [g/km] | 0.47 | 0.23 | 0.01 |
| consumption [km/litre] | 3.51 | 5.23 | 7.3 |

Source: Centre for Transport and Logistics, university of Rome "La Sapienza"

The total emissions and consumptions of the road legs of the three scenarios are obtained by multiplying these emission factors for the total kilometres travelled in the respective routes. To calculate the total emissions and energy consumptions of the two design scenarios it is necessary to add the contribution of the rail leg. Emission and energy consumption of railway transport have been calculated using the methodology proposed by the European project MEET (MEET Consortium, 1999), which calculates the electric energy spent per tonne of transported goods and then calculates the emissions released when producing electricity.

Table 2 shows the results of the comparison between the emissions in the reference scenario and those in the two design scenarios. The comparison is in terms of percentage reduction. The most significant reduction is obtained for CO₂ emissions, which is above 50% with the conventional vehicles and 77% with hybrid vehicles. Table 2 also shows that the use of hybrid vehicles allows to achieve reductions of the other pollutant emissions of almost 100%. However, the use of conventional vehicles for the final delivery also allows to achieve appreciable reductions.

Table 2 does not show figures on fuel consumption reduction because the electric energy consumption of train in the two design scenarios cannot be directly add to truck fuel consumption. In the reference scenario the overall diesel fuel consumption is 67.3 litres. The overall fuel consumption for performing the delivery service in the four simulated tours of the design scenarios is 31.4 litres using conventional diesel vehicles, and 15.1 litres using hybrid vehicles. The electric energy produced to move the train in the design scenarios is 30.2 kWh.

Table 2: Comparison between the design scenarios and the reference scenario in terms of percentage reduction of emissions

| | design scenario with conventional vehicles | design scenario with hybrid vehicles |
|-----------------|--|--|
| CO ₂ | 54 % | 77 % |
| CO | 28 % | 99 % |
| HC | 24 % | 95 % |
| NO _x | 34 % | 96 % |
| PM | 42 % | 94 % |

Source: Centre for Transport and Logistics, university of Rome "La Sapienza"

It is worth pointing out that electric energy generation in Italy is mostly made with heavy oils whose sulphur content is not negligible (sulphur is now almost absent in diesel fuel). Consequently, SO₂ emissions, which are negligible for the road legs, amount to 106 g in the rail leg.

To assess the social costs associated to each scenario, the emissions have been monetised using the information in the European Commission's handbook on the estimation of external costs in the transport sector (Maibach et al. 2008). Table 3 shows the unit monetary values of the different kind of emissions drawn from the mentioned document. The values are those recommended by the handbook for Italy. As the handbook does not provide a value for CO this kind of emissions is left out of the subsequent calculations. Fuel monetisation has been made considering a price of 1.24 €/litre, while electric energy has been monetised considering a price of 0.12 €/kWh.

Table 3: Emission social costs: unit monetary values.

| | In urban areas (€/tonne) | In inter-urban areas (€/tonne) |
|-----------------|--------------------------|--------------------------------|
| CO ₂ | 25 | 25 |
| HC | 1,100 | 1,100 |
| NO _x | 5,700 | 5,700 |
| PM | 148,600 | 27,100 |
| SO ₂ | 6,100 | 6,100 |

Source: Maibach et al. 2008.

Table 4 summarises the results of the monetisation of polluting emissions and energy consumption. The values refer to the tonne of fish food transported. In all scenarios the main contribution to social cost is given by fuel (energy) consumption which represents a share between 60% and 70 % of total cost in the case of conventional diesel vehicles and a share of 90 % in the case of hybrid vehicles. NO_x is the single most important emission. However, its incidence decreases from 18%-22% for conventional vehicles to 2.6% for hybrid vehicles.

Table 4 also shows that the design scenario with the MUDC coupled with conventional vehicles for the final delivery can reduce the social cost of emissions from nearly 40 €/tonne to 25 €/tonne with a saving of 15 € per transported tonne. The use of hybrid vehicles for the final delivery would reduce the remaining 25 €/tonne to 2 €/tonne, saving further 23 €/tonne. However, emission costs are low compared to fuel costs.

Table 4: Social costs in the different scenarios and cost savings of the two design scenarios on the reference scenario.

| | reference scenario | design scenario with conventional vehicles | savings | design scenario with green vehicles | savings |
|-----------------|--------------------|--|---------|-------------------------------------|---------|
| | €/tonne | €/tonne | | €/tonne | |
| CO ₂ | 4.34 | 2.12 | -51% | 1.10 | -75% |
| HC | 0.55 | 0.40 | -28% | 0.01 | -99% |
| NO _x | 22.80 | 14.69 | -36% | 0.56 | -98% |
| PM | 10.17 | 7.73 | -24% | 0.19 | -98% |
| SO ₂ | 0.00 | 0.16 | 100% | 0.16 | 100% |
| energy/fuel | 83.78 | 39.99 | -52% | 19.70 | -76% |
| total | 121.63 | 65.09 | -46% | 21.72 | -82% |

Source: Centre for Transport and Logistics, university of Rome "La Sapienza"

The difference between the total social cost in the reference scenario and in the design scenario provides an estimate of the maximum monetary incentive which the government can pay to encourage operators to adopt the MUDC scheme. Society would still gain if an incentive up to this maximum is paid. The maximum incentive is in the

range of 56 €/tonne if the scheme uses conventional vehicles, of 100 €/tonne if the scheme uses hybrid vehicles.

4.3 Assessment from the viewpoint of the operator

The assessment of the profitability of the MUDC scheme from the operators' viewpoint calls for the estimation of the operating costs in the reference and in the design scenarios. Lower operating costs in the design scenario would be indicative of the preference of the operators for the MUDC scheme.

The calculation of actual operating costs for providing road transport services depends on a number of variables. These costs often are not made publicly available by operators for competition reasons. This is even truer in the case of the costs of rail transport services.

Table 5 shows the road transport operating costs per kilometre and per tonne for the three considered scenarios. The operating costs per kilometre of conventional and hybrid vehicles have been calculated using data from the magazine *Tuttotrasporti* and from the online ACI (the Italian Automotive Club) application (available at <http://www.aci.it/index.php?id=1850>). The operating costs include costs relating to amortisation, maintenance, taxes and insurance, fuel as well as driver's wage. Compared to conventional vehicles, maintenance and amortisation costs of hybrid vehicles have been increased by 50% on the basis of relevant available information and fuel cost decreased by 50% on the basis of the results of the monitoring campaigns described above.

Table 5: Road operating costs of the different scenarios

| | daily distance travelled (km) | operating costs per kilometre (€/km) | operating costs per tonne (€/tonne) |
|---|----------------------------------|---|--|
| reference scenario | 287 | 1.14* | 150.19 |
| design scenario with conventional vehicles | 110 | 2.13* | 107.66 |
| design scenario with green vehicles | 110 | 1.92* | 96.91 |

* *Source: calculations of the authors on the basis of data from the magazine *Tuttotrasporti* of September 2010 and from the website www.aci.it of the Italian Automotive Club.

From these data it is possible to calculate the difference between the total cost of the service in the reference scenario and the share of the costs related to the road legs in the two design scenarios. This difference, shown in Table 6, represents the maximum amount which can be paid for the costs related to rail transport and modal transfer operations in the two design scenarios. Up to this maximum the MUDC scheme would still be more profitable, i.e. less costly, for the operators than the road-only scheme. The maximum amount increases in the case the government pays the operators the incentive according to the social cost savings estimated in the previous section.

Table 6: Maximum amount of rail and modal transfer costs to have MUDC scheme profitability

| | design scenario with conventional vehicles | design scenario with green vehicles |
|-----------------------------------|---|--|
| without incentives (€/tonne). | 42.53 | 53.28 |
| if incentives are paid (€/tonne). | 98.53 | 153.28 |

Source: Centre for Transport and Logistics, university of Rome "La Sapienza"

Considering that the rail and modal transfer costs are the same for the two design scenarios, the profitability of the MUDC scheme is always easier to achieve using hybrid vehicles rather than conventional vehicles, because the use of hybrid and smaller vehicles generates lower road transport operating costs with or without incentives. The profitability threshold reaches, if incentives are paid, 153 €/tonne versus 99 €/tonne of the combination of rail and conventional vehicles.

5. Conclusions

Current trends, with the discontinuation of the single wagon load market, are indicative that conventional rail is likely to play no role in the future in urban freight distribution. A few experiences suggest that rail could still play a role. The idea is to use rail for the urban penetration leg of the trip. Goods are transported by shuttle trains to a MUDC located in the central area and from there are distributed to final destinations using green vehicles.

The SAMADA experience in Paris demonstrates that the MUDC scheme provides environmental benefits but it is not profitable from the operators' viewpoint in the current market conditions. The paper here has provided an ex-ante assessment for a MUDC scheme for the delivery of fish food in Rome. Both the use of conventional and of hybrid vehicles have been considered for the final delivery. The environmental and energy benefits have been quantified in physical and energy units. The assessment provides evidence of the relative importance in terms of social costs of the energy consumption and of the different emissions. Energy consumption costs are the highest share (70%) of total social costs. Also, an estimate of the monetary incentive which the government may pay and an assessment of the profitability from the operators' viewpoint have been provided.

The results of the Rome case study suggest that the achievement of environmental and energy benefits is granted. The operators' viewpoint assessment has provided the maximum amount of the costs of the train and of the modal transfer operations which makes the MUDC scheme still profitable on the road-only scheme. This amount is in the range of 50 €/tonne if hybrid vehicles are used, 40 €/tonne if conventional vehicles are used. The actual cost of the train and modal transfer operations depends on a range of factors including the distance, the efficiency of the modal transfer operations, the quantities transported. It is possible to obtain scale economies because the higher the payload of the shuttle train the lower the cost per tonne transported.

Government should support MUDC schemes in the light of their social profitability. The support may take the form of the promotion of pilot projects along the lines of the European Commission's MARCO POLO programme which grants subsidies to services using sustainable transport modes in their start-up phase. If the scheme would not turn out sustainable from the operators' financial viewpoint it is necessary to make provision to guarantee that a permanent incentive is paid by the government.

The analysis carried out for the Rome case study has provided an estimate of the incentive based on the environmental and energy benefits. Social costs relating to traffic congestion and road accident reductions have not been included. It is reasonable to think that the use of rail transport is likely to produce positive impacts also on these two

categories of social costs, which would add to its beneficial effects and consequently to the amount of incentives.

The resources for the incentive might come from the road sector in the form of a redistribution if freight road pricing were put in place. The pricing schemes might normally charge freight vehicles for entering the central area while grant vehicles of the MUDC an exemption. The scheme might charge vehicles differently, typically based on their environmental performance. The revenues from the charges paid by the less virtuous vehicles might be redistributed as incentive to vehicles of the MUDC.

Moreover, it is possible to shift the choice using the price lever itself without incentive: this may occur if the road-only option would be rendered sufficiently unattractive with significant charges. The justification of the currently unprofitable SAMADA scheme lies, according to their developers, exactly on the expectation that in the future road transport will be subject to pricing.

Public authorities need to be made aware of the beneficial effects of using the rail infrastructure for urban freight distribution, because there are significant pressures to reallocate urban rail infrastructure areas to other uses, and once rail infrastructure is dismantled, it is very costly and consequently very unlikely its rebuilding.

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