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A Focus on Railway Shift in Urban Freight Transport: Scenarios and Applications

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Abstract: This research germinates from the statement that cities need to solve the impacts caused by freight transport to improve their sustainability by implementing a set of city logistic measures. Urban freight distribution through environmentally friendly vehicle measures is one of the main sustainable actions being implemented worldwide, with a significant potential to reduce the congestion and pollution levels according to the assessment performed around the world. In this context, this paper aims to explore the use of railways for urban freight transport and then focuses on the potential of shifting from a road to railway system, which uses an advanced demand modelling framework specified and calibrated according to the results of surveys carried out in the study area. Subsequently, the potential benefits of introducing this urban freight transport through the metro system in Rome (Italy) are investigated, showing significant positive effects, both in terms of operational and external costs.

Keywords: rail; shifting; urban freight; city logistics; feasibility analysis; freight transport; urban goods movements

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1. Introduction

The movement of goods within urban areas is vital since cities are the centre of economic and social life. Freight movements in cities often put considerable strain on urban transport infrastructure and impose high social costs. Cities are now on their way to become more sustainable and liveable [1]. Planners, researchers, and authorities are providing initiatives and policies to achieve these main goals [2–4]. An efficient transport system is necessary for sustaining economic, environment, and social prosperity. The explicit consideration of urban goods movements have the potential to contribute towards achieving the goals of urban transport. The objectives of city planning, and in particular the city transport system one, are to enable goods movements at the desired levels of efficiency. It is increasingly becoming recognised as an integral component of urban transport planning.

So, many different types of freight are transported and delivered in cities. These logistic activities engender additional vehicle movements within the city. Three main trends affect urban freight distribution. Firstly, forecasts indicate that the transport of freight will even grow in the future. As a result, the (road transport) issues mentioned here are likely to increase as well, making urban freight distribution an even more interesting research subject, given the challenges ahead. Secondly, the growing population and urbanisation will lead to extra transport movements in cities [5]. Thirdly, an increased general awareness of the environment exists [6].

Therefore, urban freight transport (UFT) plays a key role in satisfying city users' needs (e.g., citizens, visitors), but freight vehicles establish an unsustainable impact that could be classified into the following:

- environment, i.e., air pollution, noise, greenhouse gas, etc. [7–9];
- society, i.e., a combination of different types of vehicles on the road that increase the risk of accidents;
- economy, i.e., congestion, raise logistic costs, and hence the price of products; in addition, costs for delivering an increase causing non-optimised deliveries (both in terms of internal and external costs) [10].

Then, although there is a growing interest in freight vehicle movements from a local administration point of view, only recently have cities been pushed to take into due consideration the effects of urban goods movements on the liveability and sustainability of a city. Additionally, to solve the relevant lack of sustainability goals in city planning, the United Nation promoted Agenda 2030 [11,12] and identified 17 Sustainable Development Goals (SDGs). SDG 11 (*make cities and human settlements inclusive, safe, resilient and sustainable*) refers to cities. In this context, the European Commission has promoted the concept of sustainable urban mobility and has supported guidelines for developing Sustainable Urban Mobility Plans (SUMPs) [13–17]. According to the SUMPs approach, the guidelines for developing and implementing Sustainable Urban Logistics Plans (SULPs) were defined within a research project named ENCLOSE (energy efficiency in city logistics services for small- and mid-sized European historic towns) [18]. Furthermore, uncertainty should be included in modelling scenarios because plans are prone to rapid obsolescence and lack adaptation to new circumstances. Accordingly, Triple Access Planning for Uncertain Futures (TAP, 2021) is an interesting idea that can enhance the resilience of SUMPs by addressing both the mobility of people and things [19].

Importantly, sustainable development objectives can be pursued by means of measures that are sometimes conflicting and generate impacts that depend on the acceptance of stakeholders as well as external factors [20–25]. For example, local government (e.g., public authorities) and planners seek to reduce transport impacts to ensure that cities are more attractive for end consumers (e.g., residents and visitors) alike (mainly environmental and social sustainability, entailing a reduction in negative impact). On the other hand, retailers (e.g., producers) and private companies (e.g., carriers) seek to deliver and pick up freight at a lowest cost, performing high-quality transport operations and achieving short lead times to fulfil user expectations (mainly economic sustainability).

This leads to new challenges for operators and planners. However, new trends, as well as the just-in-time phenomenon, a logistic integrated approach which is user-oriented, has a low weight/volume ratio, and urban economy, industrial economy, have an impact on urban travel demand, like an increase in the number of vehicles per day. According to [26], city logistics is "*the process for totally optimising the logistics and transport activities by private companies with support of advanced information systems in urban areas considering the traffic environment, the traffic congestion, the traffic safety and the energy savings within the framework of a market economy*". So, the focus has to be on optimising the process of transport and logistic activities related to goods movements to increase environmental, economic, and social sustainability. To achieve sustainability and liveability for city users, the authorities are implementing some measures for urban freight transport [1] based on the following main strategies:

- reduction in commercial vehicle trips;
- use of light and environmentally friendly vehicles;
- optimisation of loading and unloading operations in order to reduce delivering times and traffic congestion;
- reduction in interferences with the other components of urban mobility (e.g., pedestrians).

Thus, city logistics has to investigate the possible solutions that allow us to reduce externalities and to increase sustainability without damaging city life. In addition, the cost associated with transport operations has decreased, from an incidence on the selling price of 5.9% in 1987 to 2.6% in 2018. So, the implementation of new city logistics initiatives should be based on a detailed assessment in order to avoid an increase in delivery costs and to favour their acceptance, as summarised in Section 2. Then, the main objective of this paper is to investigate the opportunity offered by urban railways to implement the above strategies for freight delivering and to propose a methodology for supporting urban planning decision making. This paper examines the concept of railways, such as the metro, trains, and tram systems.

The remainder of this paper is organised as follows. Section 2 reviews the current literature on the use of railways for urban delivery, while Section 3 presents a developed methodology for supporting the assessment and implementation of a delivery system based on the railways in Rome (Italy). Conclusions and the road ahead are drawn in Section 4.

2. State of the Art

Researchers have worked on the modelling and simulation of railway shifting for urban delivery [27,28]. Montraghi and Marinov [27] do not include a definition of the potential demand, and Regue and Bistrow [28] investigated the issues with the shifting to freight tram operation for urban retail deliveries in Barcelona (which was evaluated as not fully economically attractive), showing the need to take into account land use given that "*. . . most of the publications in this field are based on economic or technical approaches. . .*" [29].

Singh and Gupta [30] developed some scenarios that included a railway network for delivering in Delhi (India). They refer to the daily postal demand of Delhi, and in one of the proposed scenarios, it was observed that there could be a potential reduction in carbon emissions by 97.8% by 2026 and a considerable reduction in fuel consumption.

Trams for delivering are mainly used for movement between cities and countries. However, researchers have also investigated scenarios for designing a tram/train network for delivering as well as for shop restocking [31–36]. However, few of them included demand model forecast methodologies, showing the need for further research in such a field. Table 1 summarises the main real case studies that have a pilot period and continue to run and those that stopped after funding ceased.

Based on the results summarised in Table 1, it emerges that some of the projects funded by public administrations failed to continue after the funding period because they were not able to cover the costs and to attract interest from potential users. Additionally, according to Arvidsson and Browne [37], some relevant barriers can be identified: sharing the lane with other traffic can strongly impact service reliability, large initial investments, and the number of cooperating users with contrasting interests, all barriers in the way of potential users revising their usual operations. Therefore, the implementation of new scenarios should take into due consideration the above factors and should include the assessment of costs and benefits for all potential users, as shown in Section 3. The system to design should be based on a solid and robust demand modelling framework that needs to point out the different stages of demand definition according to the freight distribution process that should be substituted by railways.

Recently, researchers provided some analysis about using the metro or tramways for integrated passenger–freight transport [38] and developed a discrete event simulation in order to evaluate their real operations [27]. Modelling framework was also developed to design a schedule for combining the usual work of the metro with an additional freight service [39–41]. Furthermore, a simulation model of the urban distribution system has been developed to solve the problem of optimising the organisation of small consignments delivered by freight trams [42,43]. Paris (France) was one of these last research cases [44]. Therefore, below, a feasibility analysis of a delivery system based on the metro network is investigated. It identifies the main factors that need to be pointed out and assesses the design of a successful delivery system based on railways.

Table 1. Projects in European Union countries: a synthesis.

	Ongoing Systems (in 2019)				Stopped after Pilot Period [1]	
City, Country	Dresden, Germany	Paris, France	Zurich, Switzerland	Paris, France	Amsterdam, the Netherlands	Vienna, Austria
Project name	CarGo Tram	TramFret	Cargo Tram	Monoprix	CityCargo	GuterBim
Private or public initiatives	Private and Public	Private and Public	Private	Private	Public	Public
Starting date	2001	2009	2003	2007	2007	2004
Estimated cost of implementation	About EUR 3.5 mln	-	About EUR 1.4 mln	-		More than EUR 1.4 mln
Routes	5 km every hour (40 min) and 10 units/day	Daily urban delivery	9 different routes 3–15 km 1 unit/month	30 km, night trip	14 km, night trip	From 3 large logistic centres
	Warehouses factory Volkswagen	Inner-city	Waste collection	90 designated supermarkets	Inner-city goods distribution	Between the main workshop and its satellites
Number of trains	2	1	1	1	2	2
- *Capacity*	60 t/214 m³	-	12 t/48 m³	19 t	30 t	13 t/40 m³
- *Length*	about 60 m	-	about 18 m	-	-	about 19 m
- *Width*	2.2 m	-	2.2 m	-	-	1.5 m
Freight types	Automotive parts and modules	Hobby and housing products	Bulky refuse	Perishable goods	Commercial, parcels, etc.	Spare parts for hospitals
System	B2B	B2B	B2C	B2B	B2B	B2B
Reference(s)	[28,30,37,45–48]	[25,39,45,47]	[29,30,45,46,48]	[30,45,46,48,49]	[25,28,30,45–48]	[28,45]

[1] prototyped transportation systems.

3. Materials and Methods

As said, transportation companies in the European Union and around the world are trying to find "green" solutions for transport. Also, environmentally friendly vehicles (like railways) are expected to produce an average high benefit from the point of view of city users [50]. The benefits for city users can be significant, and retailers are quite indifferent (even if they can have subsequent benefits due to the increased turnover), and the high costs are probably supported by transport and logistic operators (and by retailer transport by their own account) for revising their operations. Therefore, for the success of such measures, an in-depth assessment is needed. As shown in Section 2, one way of doing this is the use of a railway system with or without electronically driven vehicles. Additionally, in order to assure their full implementation, the ex-ante analysis should allow for the investigation of the different aspects connected with such a system. Therefore, below, the methodology used for designing a metro network for urban freight transport in Rome is presented. The key role is played by the analysis of potential freight demand that can be shifted from roads to the metro delivery system.

Rome is a large city with a high number of city users (i.e., residents, employees, tourists) with different spatial distributions. Rome has 15 municipalities with different characteristics and land uses [51]. Furthermore, the concentration of users is in the city centre. This causes many movements in the historical centre and negative traffic impacts [52].

One of the most important characteristics of the historical centre of Rome is the implemented ZTL (Zona a Traffico Limitato, in *Italian*—limited traffic zone). It has specific time windows that vehicles and private cars are able to gain access. ZTL pushed logistics and transport operators to find new sustainable solutions in order to cater to the needs of both inhabitants and city users. On the one hand, ZTL aimed to provide more environmental conditions for the inner area of the city. One of the possible solutions addressed by the municipality has been the implementation of urban delivering that uses the railways during the off-peak hours of passenger transport. Therefore, the methodology summarised in Figure 1 has been developed, which consists of four main stages.

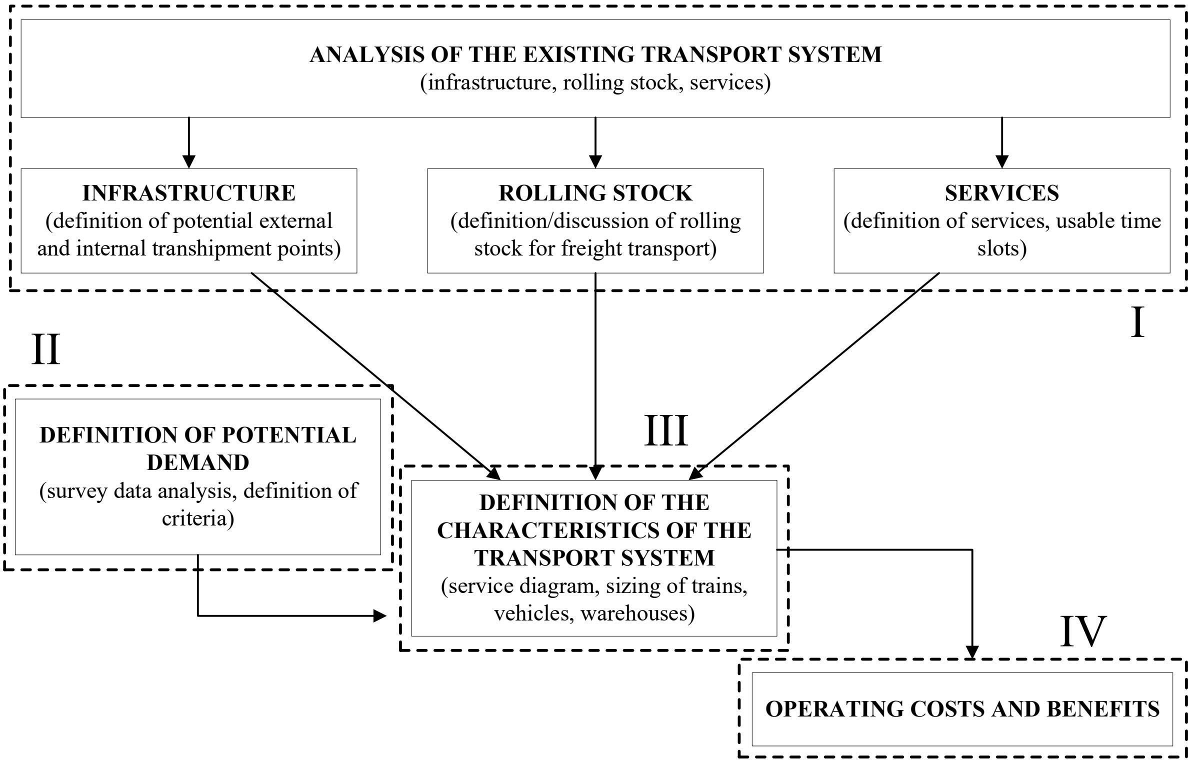


Figure 1. Methodology for the analysis of the technical feasibility.

The first phase (*I*) is an *analysis of the existing transport system*. First, the infrastructure analysis is performed. This is the basis for understanding the existing transportation system. In order to limit the investment costs, the existing infrastructure has to be used and adapted for freight transport, including the identification of the potential external and internal transhipment points. Secondly, the used rolling stock has to be analysed. The designing of freight flow by railway must take into account the use of the existing rolling stock (passenger metro/tram/train through maintenance, renovate, etc.) or changing it for new freight rolling stock. Thirdly, the characteristics of the service for freight delivery need to be analysed. It is relevant to identify in which part of the supply chain the railways substitute road transport and if the service operates for e-parcel deliveries or for shop restocking.

The second phase (*II*) is a *definition of potentially usable demand*. To simulate the designed scenario, the potentially served demand is required. The survey data analysis allows us to investigate the types of freight that should be delivered. Based on it, the future potential demand can be calculated.

The third phase (*III*) is the *definition of the characteristics of the transport system*. In accordance with the previous steps, there is the simulation of the transport system. The number, size of rolling stock, schedule, and other elements of the transport system are considered here.

Finally, the fourth phase (*IV*) is the *calculation of operating cost and benefits*. The analysis before implementation is a step of decision making. Based on the analysis of the costs and benefits, the current and designed scenarios are compared. Therefore, the last step aims to assess and to quantify the ameliorative aspects of the designed scenario, and then to support the decision making. The detailed application of the developed methodology to the real case of Rome is described in the following sections.

3.1. Analysis of the Existing Transport System

This analysis, as said, aims to verify the possibility of using existing railway infrastructures and systems to reduce building and management costs, as well as to exploit the unused railway capacity. It consists of different stages as reported below.

3.1.1. Infrastructure

The analysis of infrastructure allows us to identify the exiting railway terminals within the study area and to verify their potential use as transit points; in particular, it is necessary to verify the following:

- the availability of adequate areas for loading/unloading operations and the warehousing of freight, if necessary;
- the distance between the handling track and the storage area;
- the drop between the platform of the train and the yard in order to reduce the costs of transhipment;
- the presence of appropriate areas for truck manoeuvres;
- the accessibility from/to the main road network.

The schematical implementation of such a delivery system is showed in Figure 2. For this study, the network of metro lines was selected. In Rome, there are three metro lines that connect the most remote areas of the city, concentrating existing connections in the centre. The metro network is available for passenger flow from 05:30 to 23:30 (except on Friday and Saturday when the metro lines work until 1:30). This allows the metro network to be used for freight flows from 00:30 to 05:30 (from Sunday to Thursday).

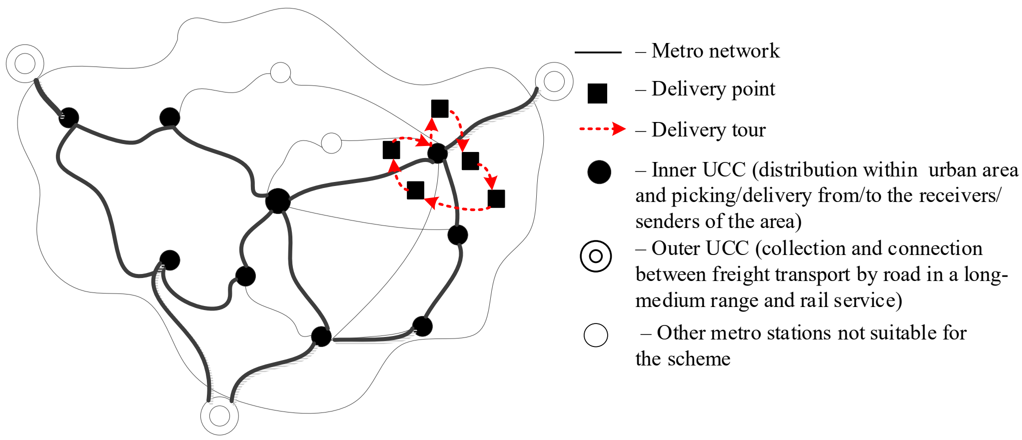


Figure 2. Scheme of service pattern.

3.1.2. Rolling Stock

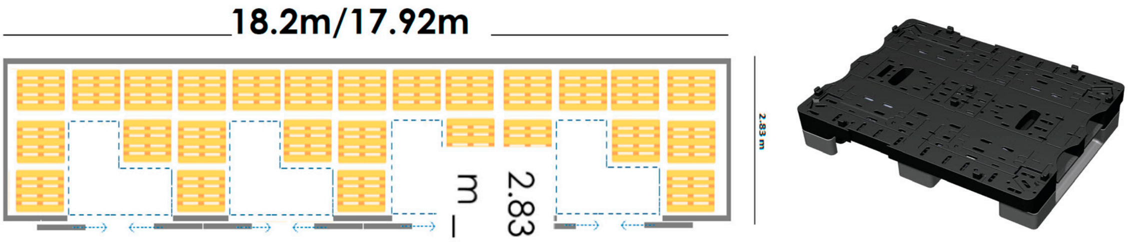
The analysis of the rolling stock characteristics could consider the use of carriages actually used for passenger services which have to be specifically adapted for freight transport; this activity can be summarised in the check of the following:

- load capacity in terms of maximum load per surface unit;
- technical characteristics assuring the possibility to transport-specific loading units (e.g., pallets).

The metro of Rome uses the S/300 type carriage. The main characteristics of the train (Figure 3a) are as follows: the carriage length (18.2 m/17.92 m), width (2.83 m), max train length (108.08 m), height from platform level (2.45 m), and train composition (maximum 6 carriages). Based on this, the available surface for the train is calculated, which is equal to 305.64 m^2. The steps for the conversion of carriages for the transport of freight are as follows:

1. the elimination of all components dedicated to passenger transport;
2. the reinforcement of the platforms for the transport of a weight of at least 1000 kg/m^2;

3. the use of the old carriages following the renewal of the park.



(**a**) (**b**)

Figure 3. Rolling stock: (**a**) carriage and (**b**) pallet with retractable wheels.

Figure 3b also pictures the load unit used for transport operations. In particular, it is important that the equipment allows for the loading and unloading operations to be performed efficiently. It has to be suitable for both train and vehicle. So, the load unit used for transport operations could be a pallet with retractable wheels. The main characteristics are as follows: length (0.8 m), width (0.6 m), and maximum permitted weight (500 kg/m^2). The available surface is 0.48 m^2. In addition, two pallets with wheels are equal to one European pallet. This characteristic allows for making loading and unloading operations quick and easy. It eliminates the handing equipment from the process (e.g., transpallet), given that it can be used directly by the user.

3.1.3. Service

A definition of the potential service in terms of the timetable which assures the use of the residual metro's capacity with respect to the actual passenger services is needed. Based on the metro service time for passengers, the potential service hours (the remaining capacity of the transport dedicated to passengers) are 00:30 a.m.–05:30 a.m. (from Sunday to Thursday). The metro stations within the ZTL (inner area) for freight distribution operations are Flaminio, Piramide, and Termini. These stations, as said, meet the following conditions: availability of an area for the temporary storage of freight and availability of an area to carry out the loading and unloading operations of the freight to be transported to their final destination. On the other hand, the designed schedule for the last mile delivery process should be accepted by retailers. Night delivery is one of the measures used to reduce externalities, but it is important to consider the interests of all the stakeholders involved [53,54].

3.2. Definition of Potential Demand

The design of the features of this freight transport system can be performed on the basis of the application context by estimating the freight demand attracted/generated from the study area zones. An initial magnitude of design variables can be taken with the use of statistical methods for the estimation of the actual demand, while for the forecast freight demand, it could be useful to have a modelling system which has to be calibrated on surveys aiming to investigate the freight distribution structure and its main characteristics [35,55].

Thus, this analysis can be supported by two types of surveys:

- traffic surveys and traffic counts in order to investigate the incidence of commercial traffic and to understand the supply chain followed by the study area operators;
- interviews of potential service users (e.g., retailers) in order to investigate their needs and their organisation.

The survey was carried out through interviews with commercial vehicle drivers. From the data, it was possible to specify the demand modelling framework used for estimating the origin/destination (O/D) matrix and the subsequent potential demand that is possible to shift from roads to the railway. Freight type (s) and time period play key roles in estimating commodity flows; however, for the simplicity of notations, they will be taken as understood unless otherwise stated. Therefore, let Q_{od}^{store} be the average *quantity* flow of freight type s attracted between zone o and zone d within the identified study area in a given time period (e.g., day, time slice, week), which can be estimated as follows [35]:

$$Q_{od}^{store} = Q_{d}^{store} \cdot p[o/d] \quad (1)$$

where

- Q_{od}^{store} is the average quantity flow of freight attracted by zone d and coming from zone o;
- Q_{d}^{store} is the average freight quantity attracted by zone d obtained by an *attraction model*; the *attraction* flow is modelled through a regressive-type model in which the average daily quantity of freight attracted by zone d, Q_{d}^{store}, is estimated as follows,

$$Q_{d}^{store} = \sum_{p=1}^{P} \beta_p \cdot AD_{p,d} + \sum_{j=1}^{N_{ASA}} \beta_j \cdot ASA_{j,d} \quad (2)$$

  with

  - $AD_{p,d}$ is the number of retail employees of type p (e.g., retail employees at foodstuffs shops) in zone d;
  - $ASA_{j,d}$ is the j-th land use variable of zone d (e.g., it could be a dummy variable equal to *1* if the proportion of retail employees to inhabitants in zone d is higher than *35%*);
  - β_p and β_j are parameters to be calibrated.

- $p[o/d]$ is the probability that freight attracted by zone d comes from zone o (e.g., warehouse location zone); it represents the acquisition share obtained by a discrete choice *acquisition model*; this share is obtained through random utility models, as follows

$$p[o/d] = \frac{\exp\left(\sum_{p=1}^{PA} \gamma_{p,o} \cdot AI_{p,o} + \sum_{j=1}^{NC} \gamma_j \cdot C_{j,od}\right)}{\sum_{o\prime=1}^{N} \exp\left(\sum_{p=1}^{PA} \gamma_{p,o\prime} \cdot AI_{p,o\prime} + \sum_{j=1}^{NC} \gamma_j \cdot C_{j,o\prime d}\right)} \quad (3)$$

  with

  - $p[o/d]$ is the probability that the freight attracted by zone d comes from zone o;
  - $AI_{p,o}$ is the generic p attribute measuring the commodity flow production of zone o (e.g., the number of warehouse employees of zone o);
  - $C_{j,od}$ is generic component j of travel cost (e.g., travel distance) between o and d;
  - $\gamma_{p,o}$ and γ_j are the parameters to be calibrated.

The O/D matrix has the origins of all the zones that have a quantity of freight to be delivered within the ZTL area of the municipality of Rome and, as destinations, all the zones of the historic centre to serve. Therefore, it allowed us to identify the zones as follows: origin is all areas in the administrative borders of the municipality of Rome (excluding ZTL; Figure 4a) and destination is all the municipalities that make up the ZTL zone (Figure 4b). Based on the results of the survey, the modelling framework was calibrated and applied to the case study. It emerges that the overall amount of all the deliveries made within the ZTL coming from the areas of the study area is 12,536.69 tons/day [50].

In addition, the freight demand requirements for transport were investigated in order to evaluate their availability to be moved by the designing system. In particular, the following criteria were identified:

- *freight type*:
  - perishable freight that does not require special devices for transport (i.e., cold chain);
  - freight with dimensions that exceed the load capacity of the vehicle;
  - dangerous/flammable/contaminating freight;

- ○ freight that has particular time constraints for distribution;
- ○ freight that has a high intrinsic value.

- *type of senders* that has a constant demand and a regular frequency of deliveries such as wholesale trade, warehouses, and production units.
- *potentially affected areas* that have a minimum distance from the selected terminal station compared to that from the ZTL area in which they must make the delivery and that there is no interchange of freight within unloading stations.

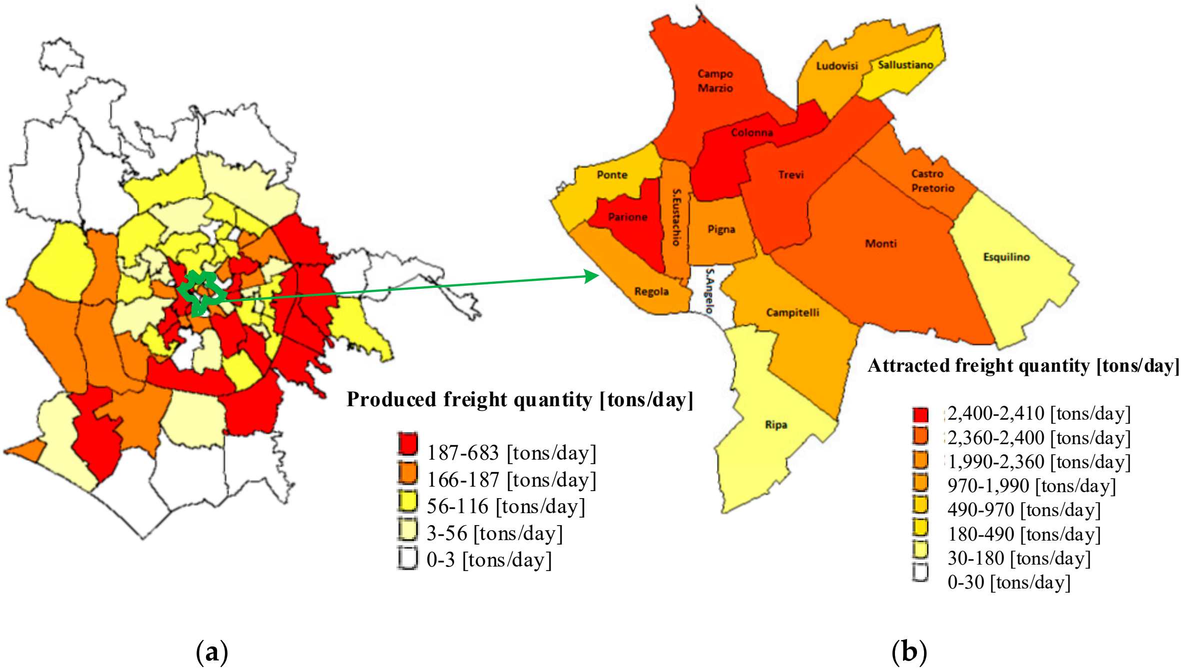


Figure 4. Quantity of produced (**a**) and attracted (**b**) freight.

Based on the potentially usable demand (Figure 4a), the outer terminal stations of the metro are selected as transhipment points for the freight coming from the various zones of the study area (i.e., Anagnina and Rebibbia stations; Figure 5a). They are close to the main road network's infrastructure and have spaces available for storage. Then, the metro stations within the ZTL for freight distribution operations were selected. After a detailed assessment of the metro stations, the stations of Termini, Flaminio, and Piramide were identified (Figure 5b).

Once the stations of the metropolitan lines have been identified on which to converge all the flows of freight coming from the various selected areas, it is necessary to identify within the two metropolitan lines the stations on which to carry out all the operations necessary for the delivery of these freight to their final destination. The main characteristics that the stations in which to carry out the operations just described should have are as follows:

1. location within or on the borders of the area to be served (ZTL);
2. provision of a sufficient area to temporarily store freight while waiting to be loaded onto vehicles for transport to final destination;
3. arrangement of an external area in which to carry out loading operations of the means of transport;
4. equidistance between the stations with respect to the area to be served in order to allow a fair distribution of the quantity to be delivered;
5. no strong impact on city users and, in particular, on tourists flows.

After an analysis based on the criteria just introduced, it was possible to select stations on the two metro lines that possessed these characteristics. The selected stations, as said, are

Termini station (station shared by line A and B), Piramide station on line B, and Flaminio station on line A.

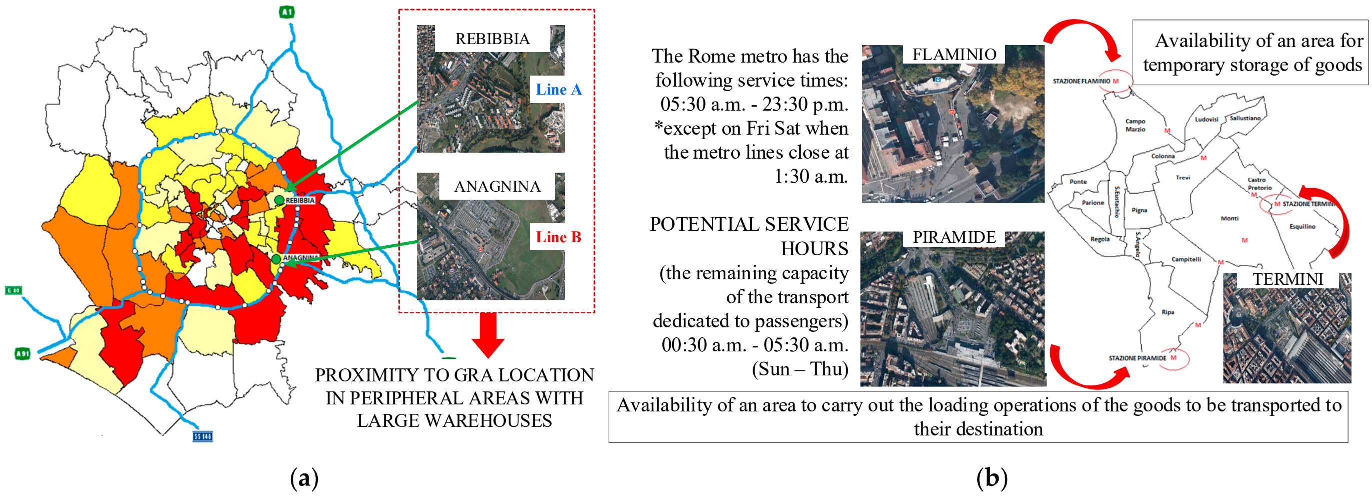


Figure 5. Metro stations identified for delivery operations: origin (**a**) and destination (**b**).

According to the identified stations and potential demand, the demand that can be transported is 2459 t/day, equal to 19.61% of the total quantity of freight that are transported daily within the study area with the origin–destination flows reported in Table 2.

Table 2. Distribution of freight flows among metro stations [tons/day].

Origin–Outer UCC	Termini	Termini–Flaminio	Termini–Piramide	Total for Outer UCC
Anagnina–Termini	559.92	692.87	642.98	**1252.79**
Rebibbia–Termini	563.24			**1206.22**
Total for Inner UCC	**1123.16**	**692.87**	**642.98**	**2459.01**

UCC: urban consolidation centre.

3.3. Definition of the Characteristics of the Transport System

Given the potential freight demand and the potential freight terminals, it is possible to define the operative planning of the new freight metro system. The two terminals were kitted out with handling equipment for transferring the freight from/to train and additional one that allowed the handling in the storage area (fork-lifts and transpallets). The transport system was built and works as showed in a Figure 6:

1. the freight arrives at the outer urban consolidation centres (UCCs);
2. the freight is grouped by type and destination and then stored in warehouses waiting to be loaded onto the trains;
3. once loaded onto the trains, the freight is transported to the unloading stations where it is stored in the warehouses (from 00.30 a.m. to 05.30 a.m.);
4. the freight is then loaded onto the train and sent to the final destination by freight vehicles (e.g., ELGVs, environmentally friendly vehicles).

In addition, once all the freight has been unloaded from the trains, they continue their journey until they reach the nearest "*switch*", located, respectively, in the Ottaviano stations for line A after the Flaminio unloading stop, and in the Piramide station itself.

The following step refers to the calculation of the number of trains needed for delivering the identified freight flows. The quantity of freight to be transported from the outer UCC are, as said, from Anagnina 1252.79 tons/day and from Rebibbia 1206.22 tons/day.

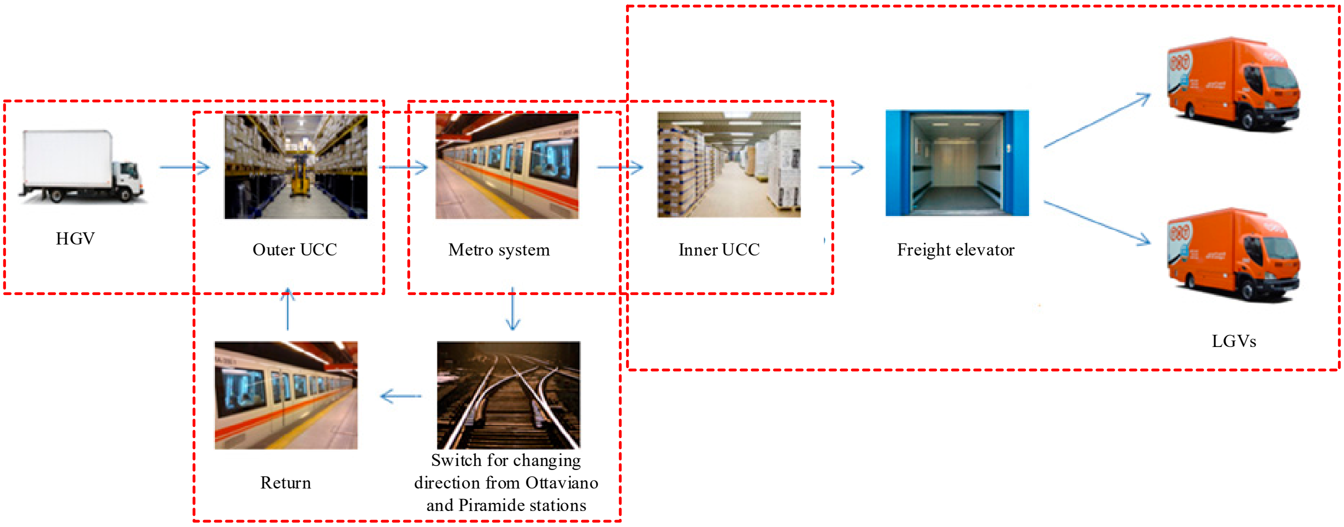


Figure 6. Scheme of the process.

The loading and unloading operations take about 30 min, and the travel time between the stations is 15 min. Based on characteristics of the train, the capacity is 160 tons/train. As an example, the schedule for the route "Anagnina–Termini–Flaminio–Anagnina" is presented in Table 3. The number of required trains, based on the above identified input, is 3 trains/line.

Table 3. Daily schedule for case Anagnina–Termini–Flaminio–Anagnina (time is a.m.).

Operation	Train 1	Train 2	Train 3
1st departure time	00:30	01:00	01:30
Arrival time	01:30	02:00	02:30
Quantity transported, [tons]	160.00	160.00	160.00
Loading operations, [min]	30	30	30
2nd departure time	02:00	02:30	03:00
Arrival time	03:00	03:00	03:00
Quantity transported, [tons]	160.00	160.00	160.00
Loading operations, [min]	30	30	-
3rd departure time	03:00	04:00	
Arrival time	04:30	05:00	
Quantity transported, [tons]	160.00	132.79	
Total quantity transported [tons]		**1252.79**	

From the scheme of the process (Figure 6), it is possible to observe how, once arrived at the unloading stations, the freight is unloaded from the trains. Freight is then transported to the surface using freight elevators. The elevators are available currently for passengers; however, the elevators could also be used for freight in each selected unloading station. The means of transport for distribution in the last mile are waiting for the freight on the surface. Light good vehicles (i.e., gross laden weight of 3.5 tons) were assumed to be used according to the narrow roads of the inner area of the city. A routing–scheduling procedure was implemented in order to optimise the delivery tours. Taking into consideration the demand (Table 2), the number of needed vehicles is calculated based on the assumption of a load factor of 85% and an average delivery tour of 40 min per vehicle. In addition, the schedule for drivers is based on an 8-h working day, which allow us to assume that the number of tours for one vehicle is 12. As a result, the number of vehicles according to the stations is as follows (Table 4): from Termini—3 vehicles, from Flaminio—2 vehicles, and from Piramide—2 vehicles (total is 7 vehicles for the designed scenario).

Table 4. Main features of the designed delivery system.

	Termini	Flaminio	Piramide	Total
Potentially transportable freight, [%]	8.96	5.52	5.13	**19.61**
Number of trains needed	6	3	3	**6**
Daily tours needed for delivering	32	20	18	**70**
Number of light good vehicles	3	2	2	**7**
Size of UCC at terminal stations, [tons/day]	840	520	485	**-**
Number of freight elevators at unloading stations	2	1	1	**4**
Number of employees	3 drivers	2 drivers	2 drivers	**7 drivers + 1 operator**

Finally, the UCC has been designed. It has different functions if it is an outer or inner terminal. According to the transport schedule, the design capacity of the two outer UCCs in Anagnina and Rebibbia is 1500 tons/day.

The inner UCC has to include the capacity that was calculated. The UCC capacity in Termini needs to assure the movement of 840 tons/day. In addition, the number of freight elevators is 2. The UCC in Flaminio should have a capacity of 520 tons/day, 1 freight elevator, and the UCC in Piramide should have a capacity of 470 tons/day, 1 freight elevator. In total, 4 freight elevators should be used. Table 4 summaries the main operation features. In total, the designed scenario makes it possible to transport 19.61% (2500 tons/day) of the freight that must be delivered every day within the ZTL area. The number of trains and vehicles (of 3.5 tons) needed is 6 and 7, respectively. In addition, this scheme needs employers, such as 7 drivers (for the vehicles) and 1 shared operator for managing and controlling the whole delivery process.

3.4. Operating Costs and Benefits

Given the definition of the new freight metro system and its potential demand, the economic appraisal was investigated. The current scenario of the distribution of freight consists of freight light and medium good vehicles (LGVs and MGVs). The current scenario uses LGVs with 1.5 tons of capacity. The externalities due to freight transport are congestion, air pollution, noise pollution, accidentality, greenhouse gases, etc. The current scenario consists of transportation scheme with MGVs such as transport from outer zones to the city centre (ZTL), and LGVs are used for the transhipment of freight in a last mile delivery. The current average lengths of the tour are 20 and 26 km, respectively (Table 5). In addition, the average quantity transported shows us that the load factor in the current scenario is about 50%. The potential service quantity is equal to the demand from Section 3.2 and Table 2. The external costs are given for different types of vehicles and influence the external costs. The estimated external cost is 18,577.54 EUR/day (see Table 5), calculated with all the values mentioned before, and the external costs estimated according to INFRAS [56]. For example, the calculation for LGVs is as follows:

$$(0.328\ €/v - km) \cdot (1545.16\ tons/day) \cdot (20\,km)/(0.763\,tons/v) = 13,285\ €/day$$

In addition, the service production for LGVs is 44,552.45 EUR/day for that which was used as the unit production cost of the service. The total costs (sum of external costs and operational) for the current scenario are more than 81,000 EUR/day.

The shifting to metro (designed scenario) allows us to reduce the externalities and operating costs. The total (operational and external) cost for the designed scenario is 32,635.42 EUR/day (Table 6). The delivery cost from the outer UCC to the inner UCC that uses trains was calculated based on the assumption of the train delivery tour length being 853.25 km per day and the unit production cost of the service being 25 EUR/v-km. The delivery cost from the inner UCCs to the final customer is about 9940.23 EUR/day; calculations were used for the current scenario (external and operational cost). The calculations for the staff and other costs include the salaries of the drivers, one shared operator, and other costs of managing the system (i.e., the equipment to function).

Table 5. Current cost of outsourcing and for producing the service.

Time	LGVs (*Less Than 1.5 t*)	MGVs (*Less Than 3.5 t*)	*Subtotal*	Total [*EUR/day*]
Average delivery tour length, [km]	20	26		
Average quantity transported, [tons/vehicle]	0.763	1.652		
Potential service quantity, [tons/day]	1545.16	913.85	***2459.01***	
External cost, [EUR/v-km]	0.328	0.368		
External cost, [EUR/day]	13,285	5293	***18,577.54***	**81,108.27**
Unit production cost of the service, [EUR/v-km]	1.10	1.25		
Operational costs, [EUR/day]	44,552.45	17,978.28	***62,530.73***	

Table 6. Total costs of the design scenario.

Cost Type	Total Cost [EUR/day]
Delivery from outer UCCs to inner UCCs	21,331.25
Distribution from inner UCCs to the final customer	9940.23
Staff and other	1363.93
Total [EUR/day]	**32,635.41**

4. Conclusions

The world is on the road to becoming more sustainable and liveable. One of the possible ways to reach these goals is to increase the use of railway systems for freight distribution. This measure is gaining popularity and could be achieved. This paper provided a view of this for the city of Rome. The shift to more environmentally friendly vehicles was an objective of this study.

A pre-feasibility study was developed in order to analyse the existing metro system in Rome, including a methodology that allows for the forecast of the potential demand and the delivery tour. Using the existing transport system as a data point, two scenarios (current and designed) were assessed. First, the transport system with an existing scenario has a fixed operating pattern due to the freight vehicle. Second, the designed scenario consists of a multimodal service. The additional trains for freight run during the close period of passenger services. Light goods vehicles are used for the last mile delivery.

It should be noted that this study on the technical feasibility of urban transport of freight by metro within the municipality of Rome was performed with a view to the maximum valorisation of existing structures and vehicles.

Every aspect of the analysis was considered in relation to the realistic potentiality of realisation, always considering a percentage of safety in the data estimate of the times necessary for the operations as well as on the sizing of the structures to be built. The main purpose of these considerations is to highlight a freight distribution process that can be as close to reality as possible.

From a first estimate of the possible results due to the adoption of the proposed transport system, it was possible to quantify in monetary terms the potential cost reduction, understood as an estimate of the costs due to the externalities of traditional transport that the metro transport service can generate.

Based on the data analysed, a reduction in costs due to externalities of over 60% is estimated, as well as a considerable reduction in the number of vehicles circulating within the limited traffic zone of Rome.

In the particular atmosphere that exists today, where energy efficiency and concerns over pollution are growing in importance, by showing that it is possible for railways to compete in urban freight delivery, it could in the long run save money for freight providers and reduce the negative effects on the environment. The analyses showed that the use of the metro for the distribution of freight in urban areas is possible and can bring some benefits to the existing transport system. However, the future advancement of this study needs to develop a more detailed economic assessment, such as a cost–benefit analysis, as well as the analysis of potential freight demand through a forecast based on an advanced modelling framework that allows for the different level of the delivery decision making process to be taken into consideration.

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References

1. Russo, F.; Comi, A. The Role of City Logistics in Pursuing the Goals of Agenda 2030. In Proceedings of the Computational Science and Its Applications (ICCSA 2023 Workshops), Athens, Greece, 3–6 July 2023; Gervasi, O., Murgante, B., Rocha, A.M.A.C., Garau, C., Scorza, F., Karaca, Y., Torre, C.M., Eds.; Lecture Notes in Computer Science. Springer Nature: Cham, Switzerland, 2023; Volume 14106, pp. 335–348. Available online: https://link.springer.com/10.1007/978-3-031-37111-0_24 (accessed on 11 September 2023).
2. De Marco, A.; Mangano, G.; Zenezini, G. Classification and benchmark of City Logistics measures: An empirical analysis. *Int. J. Logist. Res. Appl.* **2018**, *21*, 1–19. [CrossRef]
3. Holguín-Veras, J.; Amaya Leal, J.; Sánchez-Diaz, I.; Browne, M.; Wojtowicz, J. State of the art and practice of urban freight management Part I: Infrastructure, vehicle-related, and traffic operations. *Transp. Res. Part A Policy Pract.* **2020**, *137*, 360–382. [CrossRef]
4. Holguín-Veras, J.; Amaya Leal, J.; Sanchez-Diaz, I.; Browne, M.; Wojtowicz, J. State of the art and practice of urban freight management Part II: Financial approaches, logistics, and demand management. *Transp. Res. Part A Policy Pract.* **2020**, *137*, 383–410. [CrossRef]
5. Ritchie, H.; Rodés-Guirao, L.; Mathieu, E.; Gerber, M.; Ortiz-Ospina, E. Population Growth. 2023. Available online: https://ourworldindata.org/population-growth (accessed on 11 September 2023).
6. UN. Transforming Our World: The 2030 Agenda for Sustainable Development. *United Nations*. 2015. Available online: https://sdgs.un.org/2030agenda (accessed on 11 September 2023).
7. McKinnon, A. Environmentally sustainable city logistics: Minimising urban freight emission. In *Handbook on City Logistics and Urban Freight*; Edward Elgar Publishing Ltd.: Northampton, MA, USA, 2023; pp. 463–481.
8. Waygood, E.O.D.; Chatterton, T.; Avineri, E. Comparing and presenting city-level transportation CO_2 emissions using GIS. *Transp. Res. Part D Transp. Environ.* **2013**, *24*, 127–134. [CrossRef]
9. Taniguchi, E. City Logistics for Sustainable and Liveable Cities. In *Green Logistics and Transportation*; Springer: Berlin/Heidelberg, Germany, 2015; pp. 49–60.
10. Taniguchi, E.; Fwa, T.; Thompson, R. *Urban Transportation and Logistics: Health, Safety, and Security Concerns*; CRC Press: Boca Raton, FL, USA, 2013.
11. Comi, A.; Gruenwald, N.; Danchuk, V.; Kunytska, O.; Vakulenko, K.; Zakrzewska, M. How Cities and Universities Approach the Sustainable Development Goals. In *Handbook of Sustainability Science in the Future*; Leal Filho, W., Azul, A.M., Doni, F., Salvia, A.L., Eds.; Springer International Publishing: Cham, Switzerland, 2023; pp. 1–21. Available online: https://link.springer.com/10.1007/978-3-030-68074-9_155-1 (accessed on 3 April 2023).
12. Ruiz-Mallén, I.; Heras, M. What Sustainability? Higher Education Institutions' Pathways to Reach the Agenda 2030 Goals. *Sustainability* **2020**, *12*, 1290. [CrossRef]
13. SUMP. *Guidelines. Developing and Implementing a Sustainable Urban Mobility Plan*; European Commission: Brussels, Belgium, 2019.
14. Russo, F.; Iiritano, G.; Petrungaro, G.; Trecozzi, M.R. Regional Transportation Plan of the Calabria: The mobility in urban areas. *Transp. Res. Procedia* **2022**, *60*, 156–163. [CrossRef]
15. Kiba-Janiak, M.; Witkowski, J. Sustainable Urban Mobility Plans: How Do They Work? *Sustainability* **2019**, *11*, 4605. [CrossRef]

16. Russo, F.; Pellicanò, D. Planning and sustainable development of: Urban logistics: From international goals to regional realization. *WIT Trans. Ecol. Environ.* **2019**, *238*, 59–72.
17. Russo, F.; Comi, A. Overview of urban freight transport planning and European suggestions. In *Handbook on City Logistics and Urban Freight*; Marcucci, E., Gatta, V., Le Pira, M., Eds.; Edward Elgar Publishing: Northampton, MA, USA, 2023; pp. 225–245. Available online: https://www.elgaronline.com/view/book/9781800370173/book-part-9781800370173-21.xml (accessed on 18 September 2023).
18. Ambrosino, G.; Liberato, A.; Pettinelli, I. Sustainable Urban Logistics Plans (SULP) Guidelines. In Proceedings of the CIVITAS Annual Conference, Ljubljana, Slovenia, 7–9 October 2015.
19. Lyons, G.; Marchau, V.; Paddeu Daniela Rye, T.; Adolphson, M.; Attia, M.; Bozovic, T.; Bylund, J.; Calvert, T.; Chatterjee, K.; Comi, A.; et al. *Triple Access Planning for Uncertain Futures—A Handbook for Practitioners*; University of West England: Bristol, UK, 2024. Available online: https://uwe-repository.worktribe.com/output/11751967/ (accessed on 11 September 2023).
20. Gatta, V.; Marcucci, E.; Delle Site, P.; Le Pira, M.; Carrocci, C.S. Planning with stakeholders: Analysing alternative off-hour delivery solutions via an interactive multi-criteria approach. *Res. Transp. Econ.* **2019**, *73*, 53–62. [CrossRef]
21. Holguín-Veras, J.; Wang, X.C.; Sánchez-Díaz, J.; Campbell, S.; Hodge, S.D.; Jaller, M.; Wojtowicz, J. Fostering unassisted off-hour deliveries: The role of incentives. *Transp. Res. Part A Policy Pract.* **2017**, *102*, 172–187. [CrossRef]
22. Kaszubowski, D. A Method for the Evaluation of Urban Freight Transport Models as a Tool for Improving the Delivery of Sustainable Urban Transport Policy. *Sustainability* **2019**, *11*, 1535. [CrossRef]
23. Katsela, K.; Browme, M. Importance of the Stakeholders' Interaction: Comparative, Longitudinal Study of Two City Logistics Initiatives. *Sustainability* **2019**, *11*, 5844. [CrossRef]
24. Stathopouios, A.; Valeri, E.; Marcucci, E. Stakeholder reactions to urban freight policy innovation. *J. Transp. Geogr.* **2012**, *22*, 34–45. [CrossRef]
25. Van Duin, R.; Wiegmans, B.; Tavasszy, L.; Hendriks, B.; He, Y. Evaluating new participative city logistics concepts: The case of cargo hitching. *Transp. Res. Procedia* **2019**, *39*, 565–575. [CrossRef]
26. Taniguchi, E.; Thompson, R.G. Modeling City Logistics. *Transp. Res. Rec.* **2002**, *1790*, 45–51. [CrossRef]
27. Motraghi, A.; Marinov, M.V. Analysis of urban freight by rail using event based simulation. *Simul. Model. Pract. Theory* **2012**, *25*, 73–89. [CrossRef]
28. Regue, R.; Bristow, A. Appraising freight tram schemes: A case study of Barcelona. *Eur. J. Transp. Infrastruct. Res.* **2013**, *13*, 56–78. [CrossRef]
29. Strale, M. The Cargo Tram: Current Status and Perspectives, the Example of Brussels. *Sustain. Logist.* **2014**, *6*, 245–263.
30. Singh, M.; Gupta, S. Urban rail system for freight distribution in a mega city: Case study of Delhi, India. *Transp. Res. Procedia* **2020**, *48*, 452–466. [CrossRef]
31. Browne, M.; Allen, J.; Woodburn, A.; Piotrowska, M. The Potential for Non-road Modes to Support Environmentally Friendly Urban Logistics. *Procedia-Soc. Behav. Sci.* **2014**, *151*, 29–36. [CrossRef]
32. Dablanc, L. Commercial Goods Transport, Paris, France. Global Report on Human Settlements 2013. 2013. Available online: https://unhabitat.org/sites/default/files/2013/06/GRHS.2013.Case_.Study_.Paris_.France.pdf (accessed on 11 September 2023).
33. De Langhe, K.; Meersman, H.; Sys, C.; Van De Voorde, E.; Vanelslander, T. How to make urban freight transport by tram successful? *J. Shipp. Trade* **2019**, *4*, 13. [CrossRef]
34. Langhe, K. Analysing the role of rail in urban freight distribution. In *Next Generation Supply Chains: Trends and Opportunities*; epubli GmbH: Berlin, Germany, 2014; pp. 223–244.
35. Nuzzolo, A.; Comi, A. Modelling the demand for rail in an urban context: Some methodological aspects. *Eur. Transp. Trasp. Eur.* **2015**, *57*, 3.
36. Nuzzolo, A.; Comi, A.; Crisalli, U. Metropolitan Freight Distribution by Railways: A Methodology to Support the Feasibility Analysis. In *Innovations in City Logistics*; Nova Science Publishers: Hauppauge, NY, USA, 2008.
37. Arvidsson, N.; Browne, M. A review of the success and failure of tram systems to carry urban freight: The implications for a low emission intermodal solution using electric vehicles on trams. *Eur. Transp. Trasp. Eur.* **2013**, *54*, 5.
38. Hu, W.; Dong, J.; Hwang, B.-G.; Ren, R.; Chen, Z. Is mass rapid transit applicable for deep integration of freight-passenger transport? A multi-perspective analysis from urban China. *Transp. Res. Part A* **2022**, *165*, 490–510. [CrossRef]
39. Ozturk, O.; Patrick, J. An optimization model for freight transport using urban rail transit. *Eur. J. Oper. Res.* **2018**, *267*, 1110–1121. [CrossRef]
40. Li, Z.; Shalaby, A.; Roorda, M.J.; Mao, B. Urban rail service design for collaborative passenger and freight transport. *Transp. Res. Part E Logist. Transp. Rev.* **2021**, *147*, 102205. [CrossRef]
41. Di, Z.; Yang, L.; Shi, J.; Zhou, H.; Yang, K.; Gao, Z. Joint optimization of carriage arrangement and flow control in a metro-based underground logistics system. *Transp. Res. Part B Methodol.* **2022**, *159*, 1–23. [CrossRef]
42. Merkisz-Guranowska, A.; Shramenko, N.; Kiciński, M.; Shramenko, V. Simulation Model for Operational Planning of City Cargo Transportation by Trams in Conditions of Stochastic Demand. *Energies* **2023**, *16*, 4076. [CrossRef]
43. Potti, P.; Marinov, M.; Sweeney, E. A Simulation Study on the Potential of Moving Urban Freight by a Cross-City Railway Line. *Sustainability* **2019**, *11*, 6088. [CrossRef]
44. Behiri, W.; Belmokhtar-Berraf, S.; Chu, C. Urban freight transport using passenger rail network: Scientific issues and quantitative analysis. *Transp. Res. Part E Logist. Transp. Rev.* **2018**, *115*, 227–245. [CrossRef]

45. Cleophas, C.; Cottrill, C.; Ehmke, J.F.; Tierney, K. Collaborative urban transportation: Recent advances in theory and practice. *Eur. J. Oper. Res.* **2019**, *273*, 801–816. [CrossRef]
46. Marinov, M.; Giubilei, F.; Gerhardt, M.; Özkan, T.; Stergiou, E.; Papadopol, M.; Cabecinha, L. Urban freight movement by rail. *J. Transp. Lit.* **2013**, *7*, 87–116. [CrossRef]
47. Mazzarino, M.; Rubini, L. Smart Urban Planning: Evaluating Urban Logistics Performance of Innovative Solutions and Sustainable Policies in the Venice Lagoon—The Results of a Case Study. *Sustainability* **2019**, *11*, 4580. [CrossRef]
48. Motraghi, A. Rail research projects: Case studies. *Res. Transp. Econ.* **2013**, *41*, 76–83. [CrossRef]
49. Delaître, L.; De Barbeyrac, C. Improving an Urban Distribution Centre, the French Case of Samada Monoprix. *Procedia-Soc. Behav. Sci.* **2012**, *39*, 753–769. [CrossRef]
50. Russo, F.; Comi, A. Investigating the Effects of City Logistics Measures on the Economy of the City. *Sustainability* **2020**, *12*, 1439. [CrossRef]
51. Comi, A.; Persia, L.; Nuzzolo, A.; Polimeni, A. Exploring Temporal and Spatial Structure of Urban Road Accidents: Some Empirical Evidences from Rome. In *Data Analytics: Paving the Way to Sustainable Urban Mobility*; Nathanail, E.G., Karakikes, I.D., Eds.; Advances in Intelligent Systems and Computing; Springer International Publishing: Cham, Switzerland, 2019; Volume 879, pp. 147–155. Available online: http://link.springer.com/10.1007/978-3-030-02305-8_18 (accessed on 11 July 2023).
52. Nuzzolo, A.; Comi, A. Urban freight transport policies in Rome: Lessons learned and the road ahead. *J. Urban. Int. Res. Placemaking Urban Sustain.* **2015**, *8*, 133–147. [CrossRef]
53. Felch, V.; Karl, D.; Asdecker, B.; Niedermaier, A.; Sucky, E. Reconfiguration of the Last Mile: Consumer Acceptance of Alternative Delivery Concepts. In *Logistics Management*; Bierwirth, C., Kirschstein, T., Sackmann, D., Eds.; Lecture Notes in Logistics; Springer International Publishing: Cham, Switzerland, 2019; pp. 157–171. Available online: http://link.springer.com/10.1007/978-3-030-29821-0_11 (accessed on 20 February 2024).
54. Stathopoulos, A.; Valeri, E.; Marcucci, E.; Marcucci, E.; Gatti, V.; Nuzzolo, A. Urban Freight Policy Innovation for Rome's LTZ: A Stakeholder Perspective. In *City Distribution and Urban Freight Transport*; Edward Elgar Publishing: Northampton, MA, USA, 2011; p. 14398. Available online: http://www.elgaronline.com/view/9780857932747.00011.xml (accessed on 14 December 2021).
55. Comi, A.; Delle Site, P. Estimating and forecasting urban freight origin–destination flows. In *Handbook on City Logistics and Urban Freight*; Marcucci, E., Gatta, V., Le Pira, M., Eds.; Edward Elgar Publishing: Northampton, MA, USA, 2023; pp. 78–97. Available online: https://www.elgaronline.com/view/book/9781800370173/book-part-9781800370173-12.xml (accessed on 18 September 2023).
56. European Commission; CE Delft; Directorate-General for Mobility and Transport (European Commission); INFRAS; TRT. Directorate-General for Mobility and Transport. In *Handbook on the External Costs of Transport: Version 2019*; Publications Office: Luxembourg, 2019. Available online: https://data.europa.eu/doi/10.2832/27212 (accessed on 18 September 2023).