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THE SPATIAL DIMENSION OF CYCLE LOGISTIC

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ABSTRACT

US Cycle logistics is emerging as a promising alternative in urban freight transport. Compared to fossil fuelled vans, the use of cycles for delivering goods within urban areas offers advantages in terms of environmental friendliness, economic efficiency, flexibility, and liveability of urban neighbourhood. At the same time, cycle logistics has to face limits in terms of weight and volume of goods that can be delivered, distances that can be covered, and spatial urban structures that can be served. This latter issue has till now received less attention in the scientific literature: it is generally recognized that cycle logistics performs at its best in inner urban areas, but no systematic study has been realized to identify specific spatial requisites for the effectiveness of cycle logistics. This paper provides a brief review of the main issues that emerge from the literature over cycle logistics, and contributes to stimulate the debate over the spatial dimension of cycle logistics: it presents a classification of cycle logistics schemes, on the basis of their integration with other urban logistic facilities and of the spatial structure of delivery operations. A three-level classification is proposed, depending on the type of goods consolidation: only distribution without consolidation, consolidation in a fixed urban consolidation centre, or consolidation in a mobile depot; for each level, operational examples and case studies are provided. This systematizing typology could support both public and private operators in decisions about the organization of cycle logistics facilities, such as the location of urban consolidation centres or the composition of cycle fleets.

KEYWORDS:
Cycle Logistics; City Logistics; Urban Freight Transport; Cycles; Urban Spatial Structure; Goods Consolidation.

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自行车物流的空间维度

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摘要

自行车物流正在兴起成为城市货物运输的一种前景光明的替代选项。与使用化石燃料的货车相比，在城市地区使用自行车进行送货具备环保、经济效益、灵活性以及城市街区宜居性等方面的优势。与此同时，自行车物流必须面临所能运输的商品重量和数量、覆盖距离以及所服务的城市空间结构等方面的限制。其中后一个问题现在尚未引起学术界的关注：人们通常认为自行车物流在内城区域能实现最佳表现，但仿不存在系统性的研究，从而识别针对自行车物流实效性的具体空间要件。本文简要回顾了自行车物流文献所出现的主要问题，并推动激发围绕自行车物流空间维度的争论：本文根据自行车物流方案与其他城市物流设施的融合以及送货操作的空间结构，提出了针对自行车物流方案的分类。本文根据商品并货的类型，提出了一个三级分类：只有配送，没有并货；在固定的城市合并中心进行合并；或者在移动式仓库进行合并。本文针对每个层面都提供了操作示例和案例分析。这个系统化的分类可以支持公共和私人运营者做出关于自行车物流设施组织的决策，如城市合并中心的位置或者自行车队的构成。

关键词：
自行车物流、城市物流、城市货物运输、自行车、城市空间结构、并货

1 INTRODUCTION

Among the challenges that cities are facing and will face in the forthcoming decades, there is urban mobility, which accounts for 40% of all CO_2 emissions of road transport and up to 70% of other pollutants (Commission of the European Communities, 2007). Urban freight transport plays an important part within urban mobility, in terms of energy use, CO_2 and other pollutants emissions[1], and congestion (Jorna & Mallens, 2013). This sector itself is facing challenges related to the increasing demand for delivery of goods, fuelled by the growing trend of e-commerce.

Since urban freight transport is mainly done by vehicles that rely on fossil fuels at the moment[2], it causes impacts in cities such as pollution, noise, congestion and traffic accidents, decreasing the quality of life in urban areas (McKinnon, Cullinane, Browne & Whiteing, 2010). These social, environmental and economic impacts imply the need for more sustainable alternatives to the use of vans, cars and trucks.

One possible solution in order to contribute to more effective and environmentally friendly city logistics is "cycle logistics", or the use of cycles for delivering goods and services for personal and third part purposes within urban areas, concurring to reduce fossil fuelled trips and congestion, and to increase the quality of life in cities. Among the main advantages of cycle logistics there is undoubtedly its environmental friendliness: limiting CO_2 emissions and other emissions that are harmful to health (such as NO_X, PM_{10}, $PM_{2.5}$, PM_1) over the whole life cycle, deliveries by cycle reduce the environmental impact of urban logistics (Allen, Browne, Woodburn & Leonardi, 2012; Maes & Vanelslander, 2012). The reduction of emissions can be related to the use of cycles instead of cars both for personal purposes, and for commercial purposes (Koning & Conway, 2014; Wrighton, 2014). As well as the environmental advantages, other success factors of cycle logistics are linked to other aspects, such as economic efficiency, flexibility, liveability of the urban environment. These aspects will be discussed in more detail in paragraph 2.

The debate over cycle logistics is quite recent and it has been quickly growing during the last decade, especially outside the scientific literature, through articles on newspapers, dedicated conferences and fairs to which mostly firms and consulting companies take part. Furthermore, envisaging the importance of this issue and its strategic relevance in order to meet the EU development targets – CO2-free urban freight deliveries by 2030 (Commission of the European Communities, 2011) –, several research projects have been financed by EU programs in order to study and promote the development of cycle logistics[3]. Likewise, even if it is less rich than the general debate, the scientific literature on this topic is young and growing. Especially during the last five years, articles and papers are increasing. The wideness of perspectives from which this issue is considered and the variety of definitions and terms that are used to describe the use of cycles for delivering goods and services playing its part, the literature let emerge that the scientific debate is still in its embryonic stage. To date, a lack of structured research on cycle logistics can be noticed (Gruber, Kihm &

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1 30% of urban transport CO_2 emissions, over 50% of the NO_x emissions and about 40% of the particulate matter emissions are due to urban freight transport (Wrighton & Reiter 2016). These impacts are resulting in urban areas in problems that include premature mortality, disability, aggravation of respiratory and cardiovascular disease, and sleep disturbance (Browne, Allen, Nemoto, Patier & Visser, 2012).

2 Albeit some studies have evidenced the importance of light, electric or hybrid vehicles in order to reduce environmental impacts (Browne et al., 2012; Faccio & Gamberi, 2015; van Duin, Tavasszy & Quak, 2013, Wygonik & Goodchild, 2011), it is currently difficult to quantify their benefits, chiefly because of the lack of interest by local authorities (so that they have been mainly promoted as spot initiatives), and because of the shortage of data (Russo & Comi, 2016). Fossil fuels are still the premier sources of energy adopted for freight transport.

3 E.g: Cyclelogistics, Cyclelogistics Ahead and Pro-e-bike, all co-funded by the Intelligent Energy Europe Programme of the European Union; SMILE, co-funded by the MED Programme, under the European Regional Development Fund; CITYLOG, co-funded by the European Commission DG-TREN in the 7th Framework Programme. These projects consider cycle logistics with different aims and points of view, and some of them are still ongoing (Cyclelogistics Ahead and Pro-e-bike). Considering that cycle logistics is a quite recent issue and that probably other EU projects on this issue are forthcoming, a compared analysis of their contribution and outcomes, that nowadays would be untimely, will be of interest in order to foster and support the debate.

Lenz, 2014; Lenz & Riehle, 2013; Schliwa, Armitage, Aziz, Evans & Rhoades, 2015; Zacharias & Zhang, 2015) and most of the literature is focused on specific case studies, with few comparisons and integrated reflections. Albeit a general idea on cycle logistics can emerge from the literature and from conference presentations, it is more complex to get shared and detailed information on specific aspects, mainly because of the variety and poor homogeneity of topics that are analysed. Furthermore, some issues are still underexplored or handled quite superficially. Among these issues there is the spatial dimension of cycle logistics, i.e. how it can be integrated in different urban logistic systems and in different urban systems. Even if some studies exist on this aspect (Leonardi, Browne & Allen, 2012, Gruber, Ehrler & Lenz, 2013; Gruber et al., 2014), in our point of view this is a crucial aspect that should be duly taken into account in order to assess the effectiveness of cycle logistics schemes and operations.

In order to contribute to the development of the debate over cycle logistics, and to stimulate reflections over the spatial dimension of cycle logistics, this paper is structured as follows: in paragraph 2 we briefly present the main topics and issues that emerge from the literature over cycle logistics; paragraph 3 is devoted to systematise and illustrate a typology of cycle logistics schemes, with a focus on their spatial implications; in paragraph 4 we propose some issues for the discussion over the development of cycle logistics, fostering more attention on its spatial dimension and on its integration in the logistic chain.

1 CYCLE LOGISTICS: KEY ISSUES IN THE DEBATE

As the debate let emerge, cycle logistics is establishing as a promising solution for last mile and inner urban deliveries and a realistic alternative to motorised transportation in urban areas, mainly because of factors such as the rising awareness on environmental issues and concerns related to urban freight transport. Deliveries by trucks and vans have a severe negative impact on urban local environment and citizens' health, interfere with traffic flows, may cause congestion and overcharge urban infrastructures (Menge & Hebes, 2015). To date, trucks and vans are the dominant mode of freight transport in urban areas, and most of these vehicles are transporting light weight goods that could be easily carried by cycle (Jorna & Mallens, 2013). Even if a precise percentage of the substitution potential of deliveries do not emerge from the literature – since it depends on several factors such as the distance travelled, the urban structure, etc. –, some authors suggest that more than 25% of all goods and 50% of light goods could be dispatched by cycle in European cities (Gruber et al., 2013; Lenz & Riehle, 2013; Wrighton & Reiter, 2016), while less optimistic ones consider that the penetration rate will not exceed the threshold of 10% (Melo, Baptista & Costa, 2014).

As some authors suggest, the largest obstacle to the diffusion of deliveries by cycle is still the general lack of acknowledgement of their advantages amongst users, customers and policy makers (Gruber et al., 2014; Lenz & Riehle, 2013; Schliwa et al. 2015). According to Menge and Hebes (2015), the main stakeholders involved with this innovation in urban logistics are:

- Senders, that can be private or public;
- Receivers, private or public;
- Logistics service providers, that can be large companies diversifying their offer, start ups or a combination of them;
- Drivers, employees of a company or self-employed;
- Society, that plays a role especially with regard to the balance between the need of as cheap and quick as possible deliveries and the request for safe and "green" deliveries;
- Public authorities, that should balance interests between different needs and requests and can introduce push-and-pull measures.
- Banks and insurance companies, financing or insuring innovative solutions and startups in this field.

Albeit cycle logistics is receiving a rapidly growing interest[4], especially during the last decade, and it is widely acknowledged in the debate as an innovative solution for facing the main criticalities of urban logistics, it must be noticed that delivering by cycle is not properly a new activity and in no way a new idea (Goldman & Gorham, 2006, Lia, Nocerino, Bresciani, Colorni & Luè, 2014). At the beginning of the last century, cycles were the most common and accepted means of urban freight transport, until the rapid spread of automobiles during the '50s and '60s. And during the '70s and '80s, a renaissance of bike messengers began, especially for companies' internal transport. The digital revolution challenged again the sector at the beginning of this century, since many small-sized goods such as documents, photographs or tickets no longer needed to be delivered physically, as they could be sent by email (Gruber et al. 2013).

Therefore, cycle logistics should not be considered as a new nor by itself a particularly innovative phenomenon. However, considering more widely the evolution of urban logistics and the needs of a more and more wide range of actors, a distinction must be made: the return to the use of cycles for urban logistics should not be considered as a jump back into the past, but as a rebirth in a contemporary and innovative way of lifestyles and business models that stem from the acknowledgement of the potentialities and advantages of the two wheels.

Furthermore, the main companies that are active in this sector combine tradition and innovation using cycles designed ad hoc and software specifically developed in order to manage the service and to monitor routes and emissions. This is why cycle logistics is considered as an innovative response to the criticalities related to urban logistics (Gevaers, Van de Voorde & Vanelslander, 2014; Menge & Hebes, 2015). Besides the unquestioned environmental advantages of cycle logistics, the other main success factors for cycle logistics can be related to the following aspects:

- Economic efficiency: purchase and maintenance costs are lower than those of a commercial van, cycles have no fuel costs and also for e-bikes energy consumption is very low. Also insurance is much cheaper. As a cost modelling simulation of last-mile deliveries attests (Gevaers et al., 2014), the cost for last mile deliveries by cycle in densely populated areas is almost a half of that of deliveries by motorised vehicles. Therefore combining delivering savings with much lower purchasing price and running costs, cycles can be in all respects considered as a cost-saving solution for urban delivery (Wrighton & Reiter, 2016).
- Flexibility: cycles can easily work around congestion and are unlikely to get stuck in traffic, have access to some dedicated lanes and to areas with restrictions due to environmental or congestion issues (Leonardi et al., 2012; Schliwa et al., 2015). Furthermore, they have no parking restrictions and access to bike paths and pedestrian areas.
- Liveability of the urban environment: cycle logistics also improve the quality and liveability of the urban environment, since it reduces noise emissions, it generates less soil consumption on the road and for parking vehicles, it decreases congestion. Cycles are
- generally viewed as less intimidating and safer than vans, pose less dangers to vulnerable road users and are generally well accepted among the population (Leonardi et al., 2012).

Furthermore, delivering by bike do not requires a driving licence, therefore it can provide employment opportunities for disadvantaged people.

It is necessary to clarify that in the debate, when talking about cycle logistics different purposes are being considered, such as commercial transport of passengers and goods, personal transport, provision of services, etc.

[4] At the same time, companies active in this field throughout Europe are growing (see e.g. the number of companies registered as members of the European Cycle Logistics Federation) and consolidating their business.

Some authors suggest to classify cycle logistics into three main categories: passenger transport, freight transport, and provision of services (Jorna & Mallens, 2013). According to this classification, passenger transport includes the use of cycles as a taxi, for transporting children to childcare centres, or as a special service for elderly/disabled people; freight transport includes parcel delivery, last mile logistics, home delivery (meals, grocery, etc.), internal transport in factories; provision of services includes services such as gardening, home care, craftsmen, etc. Other authors (Reiter & Wrighton, 2014) make a distinction between:

- private transport, that refers to commuter travel, shopping trips and leisure trips;
- personal transport, that includes all the purposes mentioned above for private transport but also business trips;
- freight and service transport, that refers to both commercial deliveries and service trips made for the execution of professional services;
- commercial transport, that includes freight and service transport and add business trips.

In this paper, we propose a different classification, identifying two main sets (fig. 1):

1. transport for own use purpose, that can be further divided into:

   a) personal transport of passengers and goods, such as carrying children, carrying groceries or other shopping;

   b) delivering services for commercial purposes. This set includes services such as gardening, home care, craftsmen (painters, plumbers, etc.), internal transport in companies and factories, home delivery of groceries, meals etc. (when made by the company itself, such as a supermarket, a restaurant, etc.);

2. transport for supply to a third part, that can be divided into:

   a) passenger transport, e.g. with taxi-bikes, rickshaws, etc.;

   b) freight transport, including last mile logistics and parcel delivery in urban areas, home delivery of groceries, meals etc. (when made by a delivery company).

This classification proposal, stemming from a reflection on strengths and weaknesses of previous analyses and classifications and on the purposes of this paper, focuses on the distinction between transport for own purpose from transport for supply to a third part, which in our point of view is an important aspect in order to develop considerations on the cycle logistics *market* and on the integration of cycle logistics in the logistic chain.

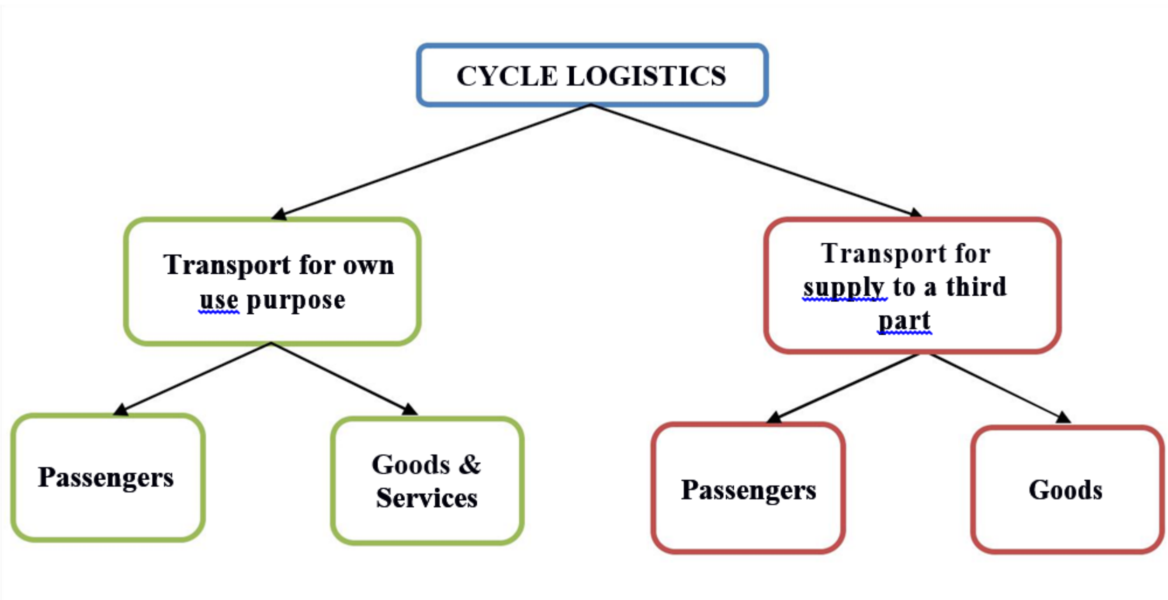

Fig. 1 Classification of cycle logistics categories

As well as the purposes, also the variety of cycles that can be used for cycle logistics, and that the scientific literature takes into consideration, is very wide, including standard bicycles with shoulder bag or panniers, standard bicycles with trailer, cargo bikes, cargo trike/quad (Wrighton, 2014). All these cycles can be also used in their electric or pedelec version. More than 240 cargo bikes products designed specifically for freight transport are available on the market worldwide (Chiffi & Galli, 2015). Another element that can be attributed to the fact that this is a very recent and fast developing field of study is the wide variety of definitions and terms that are used to describe cycle logistics, with little coherence in how they are used. Schilwa et al. (2015) try to systematise at least cycle types, dividing them into bicycles, cargo bikes and cargo tricycles, and reporting some terms that are used in the literature when referring to them.
Within this article, we adopt the definition of cycle logistics proposed by Schliwa et al. (2015): cycle logistics describes the use of human-powered or electrically-assisted standard bicycles, cargo bikes and cargo tricycles for the transport of goods between an origin and a destination, primarily in urban areas.
Even if in the literature and in the debate the expression cycle logistics is used in order to describe a wider set of purposes and uses, in this paper we want to focus on last mile logistics and on commercial freight and documents transport within urban areas for supply to a third part. In effect, we are expressly interested in how cycle logistics integrates with the rest of the logistic chain, since in our point of view this is the aspect on which the configuration and organization of the spatial structure of urban areas can play a more significant role.

2.1 CYCLE LOGISTICS MARKET AND COMPANIES

The market of delivering by cycle includes different services, that can be broadly subdivided into two main categories:

- courier service: generally provided by young and rapidly developing companies that provide alternatives to the use of cars for the delivery of parcels and documents, usually within an urban area; this category includes also door-to-door delivery of goods, meals, etc. for third parties;
- last-mile service: generally provided by big companies themselves or through third parties that provide last-mile delivery by cycle integrating the service within the whole logistic chain.

As it will be reported in more detail in paragraph 3, while the first service is usually concentrated within an urban area, the latter implies one or more steps through consolidation/micro-distribution centres.
The organisation of the companies operating in the field of cycle logistics is directly related to the kinds of services that are offered. While in the past most cycle logistics business operated on a small scale and were rather isolated from other operators in the logistic chain, more recently large logistics companies are increasingly considering cycle logistics solutions, often cooperating with local companies in order to increase the efficiency of the last mile (Jorna & Mallens, 2014; Schliwa et al., 2015). Therefore the business model of companies operating in this field is more and more shifting towards the diversification of services offered, including courier service, door-to-door deliveries and last mile logistics. Since the choice of the cycle depends upon the kind of goods that have to be delivered, cycle logistics companies often dispose of several different types of cycle.
The main limitations for cycle logistics can be referred to three aspects, that are strictly interrelated:

- the weight and volume of the goods that have to be delivered: the limits in terms of weight depends upon several factors, such as the type of cycle and the route slope. A range between 80 and 200 kg, that in exceptional cases may raise up to 400 kg, is suggested by Reiter and Wrighton (2014). As regards the volume, it strongly depends on the design type of the cycle, varying between 400 and 800 litres;
- the distance that can be travelled: it is difficult to identify a precise distance, since it strongly depends on the different patterns of cities and on the differences among the vehicles that are used. The

Cyclelogistics and Cyclelogistics Ahead EU projects set 7 km as an acceptable maximum distance per trip, and 2,5-3,5 km as the average distance per delivery (Reiter & Wrighton, 2014);

- the spatial structure and infrastructure provision of cities: to date the literature does not provide very extensive or detailed information and considerations, generally indicating dense inner urban areas as the most suitable ones for cycle logistics. Any specific or detailed consideration on spatial parameters nor thresholds in terms of density or configuration that could be necessary for effective and efficient cycle logistics operations currently emerge from the literature.

3 A TYPOLOGY OF CYCLE LOGISTICS SCHEMES

As it was anticipated, most scientific literature on cycle logistics is still anecdotal, mainly based on the analysis of single case studies in terms of environmental benefits, models of cycles used, company organization, etc. Less attention has been directed till now to the spatial dimension of cycle logistics, i.e. how deliveries by cycle can be integrated in different urban logistic systems and in different urban systems. Below, we propose a systematisation of cycle logistics schemes, classifying them on the basis of their integration with other urban logistic facilities and of the spatial structure of delivery operations. We will refer to the systemic approach to city logistics (Bektaş, Crainic & von Woensel, 2015; Crainic & Montreuil, 2015; Ducret & Delaître, 2013), that identifies in city logistic systems one or more tiers of consolidation-distribution. We propose a four-level classification, depending on the type of depot/consolidation facilities from which goods are delivered by cycle:

1. only distribution, without consolidation;
2. urban consolidation centres;
3. micro distribution centres;
4. mobile depots.

3.1 ONLY DISTRIBUTION, WITHOUT CONSOLIDATION

This is the case of courier services, i.e. same day deliveries of mails and parcels, which are picked-up from point A and directly delivered to point B, without possibility of consolidation (fig. 2). This scheme favours smaller vehicles and more deliveries being carried out in parallel, as in the case of cycle logistics (Transport for London, 2009). Requests are generally collected in real-time; when time-pressure is not so high, trips can be organized according to the round trip model: the cycle courier proceeds towards the first pick-up point to load and continues to the first delivery point; then he checks his schedule and goes on to the next pick-up point, till the last delivery of the day (Lia et al., 2014).

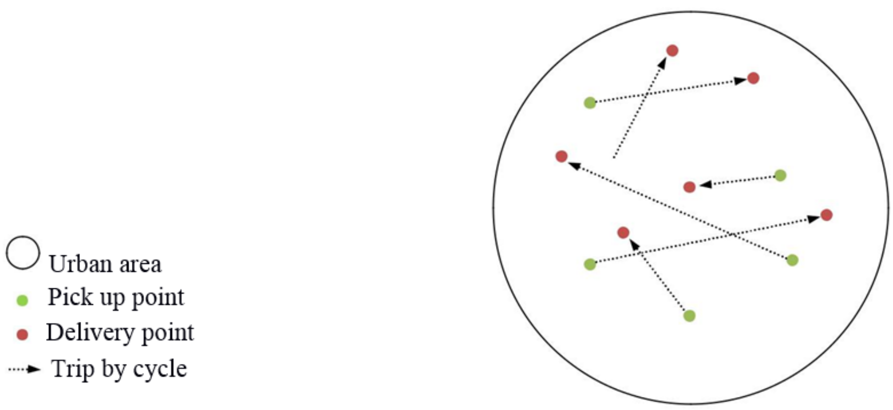

Fig. 2 A cycle logistics scheme for distribution without consolidation

The employment structure of the courier company influences the spatial organization of the service: if cycle messengers work as freelance subcontractors for the company, they generally own their cycle, ride from home in the morning and park their vehicle close to home after duty; otherwise, if messengers are employees, the company operates its own fleet of cycles, and messengers ride directly from the depot (Gruber & Kihm, 2015). Cycle messengers tend to cover each a particular "home area", and they often pass consignments to each other across their home boundaries; studying eight German cities, Gruber et al. (2013) found that each cycle messenger covers in average 5 km^2.

In inner urban areas, a great part of courier deliveries could be managed by electrically-assisted cycles, as Gruber et al. (2014) demonstrate in the case of Berlin: two thirds of the courier shipment relations are inside the inner city (the low emission zone surrounded by the circular railway, having a surface of 88 km^2 and a density of 112 inhabitants per hectare); 56% of the shipments are shorter than 10 km; 42% of the trip chains are below 50 km. Assuming as limiting factors a load rate of up to 100 kg (with no parcel more than 25 kg), a volume of 176 litres and a battery autonomy of 60-100 km, Gruber et al. (2013) estimate that the substitution potential for electrically-assisted cycles is equivalent to 42% of the deliveries and 19% of the generated trip distances, for a maximum shipment distance of 10 km. If this distance is increased to 20 km, the percentages grow to 68% and 48%, respectively.

Courier services have been extended also to interurban deliveries by a train-bike combination. In 2011, 5PL Ltd., a British logistic company, formed a partnership with railway passenger train operator East Midlands Trains, to utilize otherwise wasted space on the hourly Nottingham to London passenger services for the movement of small volume freight (in 2014, the service has been extended to the Leicester-London service). First mile in Nottingham and Leicester and last mile in London are entrusted to 5PL's partners WeGo Carbon Neutral Couriers and Courier Systems, which mainly use cycles. The transhipment operations between train and bicycle require less than the nominal train dwell time of two minutes. The high frequency of trains to London makes this system particularly fit for bringing regional food produce from different parts of the country into the capital; refrigerated vehicles are not necessary, as packaging for chilled and frozen food is sufficient for longer times than those required for the journey. In 2015, a new InterCity RailFreight (ICRF) service has been launched on the Great Western Railway, to deliver fresh seafood by train from Cornwall to the centre of London: fish, live lobsters and crab are loaded at Penzance station on the
10:00 high speed train, which in 5 and a half hours arrives at London's Paddington station. WeGo couriers then deliver the fresh seafood to top London restaurants using cycles (Eltis, n.d.). Combinations of train and cycles for interurban courier services have also been performed in Italy by Pony Zero between Turin and Milan, and by ImagineCargo in Switzerland.

3.2 URBAN CONSOLIDATION CENTRES

The basic element of these schemes is the Urban Consolidation Centre (UCC), i.e. a logistic facility situated in relatively close proximity to the urban area, be that a city centre or an entire town (fig. 3). Goods are generally transported by trucks and vans to the UCC, where they can be consolidated and transhipped to environmentally friendly vehicles (such as electric and gas-powered vans, cycles etc.) for last mile deliveries. UCCs (also defined in the literature as "urban transhipment centres", "freight consolidation centres", "urban distribution centres"; Allen et al., 2012) offer important advantages to cycle logistics: first, bringing goods near the densest part of the city, they reduce the total distance that cycles have to cover, and concentrate it in the urban centre, where cycles are more competitive when compared to vans in terms of average speed; moreover, cycles can go back to the UCC more times in a day to be reloaded, so mitigating their limited payload capacity (Browne, Allen & Leonardi, 2011). Choubassi (2015) highlights that last mile cycle logistics operations are more efficient if the UCC is located within the delivery area, and the higher is this area's density.

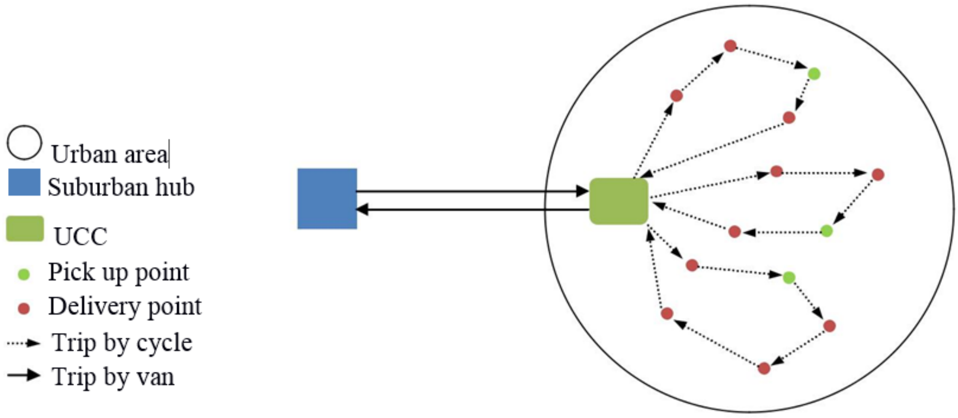

Fig. 3 A cycle logistics scheme for distribution after consolidation in a fixed urban consolidation centre

In the case of cycle logistics, UCCs generally correspond to the premises of the cycle logistics company[5]. A well-known example is La Petite Reine, a French logistic company founded in 2001 in Paris and later expanded to Bordeaux, Rouen, Dijon, Geneva and Lyon.

In Paris, it operates from two own logistic warehouses in the city centre: one in the underground parking Saint Germain l'Auxerrois close to the Louvre museum since 2003, and another in the underground parking Saint Germain des Pres on the left bank since 2010. Before the morning peak hour, La Petite Reine receives in these depots parcels from different companies (DHL, ColiPoste, Monoprix, Dannon, etc.) and consolidates them by routes and destinations; final deliveries are performed by its 50 cycles, each of them consigning about 70 parcels per day, at the average speed of 12 km/h. About 3,000 locations are served every day (Dablanc, 2011).

Similar schemes are used in other European cities: in the United Kingdom, Gnewt Cargo operates from two depots in central London to serve the Congestion charging zone, Outspoken Delivery has an edge-of-city-centre depot in Cambridge, Last Mile Leeds performs deliveries for DHL in Leeds from its city centre premises within a radius of 1-2 miles (Schliwa et al., 2015); in France, this logistic organization is utilized by Becycle in the centre of Lyon (Ducret & Delaître, 2013), in Germany by GO! Express & Logistics in the centre of Berlin (Sacher, 2015), in Belgium by Ecopostale in Brussels (Maes & Vanelslander, 2012), in Italy by PonyZero in Turin, Milan and Bologna.

The environmental advantages of this cycle logistics schemes are shown by Browne et al. (2011): when Office Depot replaced in 2010 its diesel vans making deliveries directly from the suburban depot to customers in the City of London with Gnewt Cargo electric vans and tricycles operating from a micro-consolidation centre in the City of London, the total distance travelled and the CO_2 emissions per parcel delivered fell by 20% and 54% respectively.

5 As highlighted by Schliwa et al. (2015), a major barrier to expanding cycle logistics market share is that big companies such as DHL, TNT etc, do not want parcels from different courier companies to be mixed in the same delivery vehicle, significantly reducing the opportunities to create economies of scale and efficient consolidation. As a consequence, each cycle logistics company tend to operate its own UCC, rather than relying on a unique urban UCC managed by a third public o private operator.

3.3 MICRO DISTRIBUTION CENTRES

In large cities, one or two UCCs can turn out to be not sufficient for supporting cycle logistics schemes, as the distances bikes should cover are too large. In this case, UCCs can be integrated (or even replaced) by a set of micro-distribution centres, i.e. storage facilities in which parcels can be stocked from the main UCC or directly from the suburban depot; cycles can then pick up the parcels from the containers and deliver them to the final customers. Each container focuses not on the whole city but only on a particular district. Janjevic and Ndiaye (2014) classify micro-distribution centres in six typologies, and identify a set of attributes (accessibility to the area, loading and unloading infrastructures, access restriction, dedicated infrastructures) to be taken into consideration when choosing their urban location.

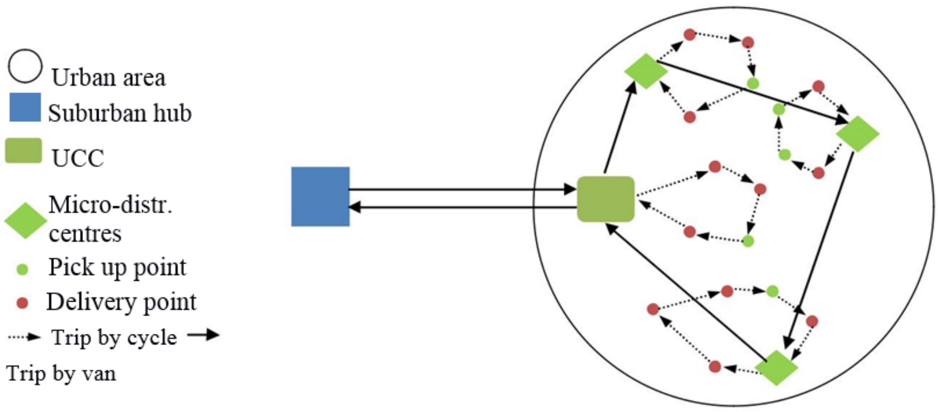

Fig. 4 A cycle logistics scheme based on a UCC and micro-distribution centres

Micro-distribution centres are often containers like BentoBoxes that can be placed near bus shelters, railway or underground stations, car parks, shopping malls etc. Brüning, Abdolrahimi and Schönewolf (2014) illustrate a test field in Berlin: a BentoBox was placed to support cycle logistics operations in the neighbourhood of Steglitz-Friedenau, allowing to replace by cycle 85% of parcel deliveries previously carried out by car. According to the results of the test, the authors conclude that ten BentoBoxes should be necessary to support last miles deliveries by cycle in the whole "environmental zone" of Berlin (88 km^2), not because of storage volumes (that on the contrary would not be completely used) but to avoid excessive distances between the containers.

Parcels are usually carried to micro-consolidation centres by vans, but other means can be used. For example, in the city of Porto Sładkowski, Dantas, Micu, Sekar, Arena and Singhania (2014) hypothesize to locate the UCC next to Verdes metro station, which connects two metro lines and has a strategic position: beside the airport, not far from the Port of Leixões and well served by the motorway network. In the UCC, goods are stacked in BentoBoxes, which are then trolleyed to the adjacent metro station; here, they are loaded on old regular passenger metro coaches that have been transformed in hollow units (without seats and grab poles, so to allow fast and easy manoeuvring of BentoBoxes).

These freight metros are planned to run during off-peak hours or other times of the day, when they can be accommodated without significantly altering the existing passenger timetable. Three destination stations are identified: Bolhão, Sete Bicas and Espaço Natureza, which are beside the most important commercial and industrial areas or the city region; here BentoBox are transferred to a "council warehouse" set up in the station, and then delivered to the final customers by cycle (for distances less than 4 km) or electric vehicles (for greater distances or big volume goods). According to the authors' estimation, this system would allow to reduce CO_2 and NO_x emissions by about 50%.

3.4 MOBILE DEPOTS

Further advanced multi-tiers logistic systems are emerging to handle the complexity of large cities, where a single UCC can turn out to be not sufficient. They multiply and diversify the types of logistic facilities and transportation modes used, to adapt to the specific characteristics of each distinctive city. In particular, different private and public transport modes are utilized as mobile depots (and sometimes as mobile consolidation centres), allowing cycles to cover a wider urban area (fig. 4). Two different schemes can be identified, depending on the interface between the cycles and the mobile depot:

1. the cycles are transported on the mobile depot, together with the parcels to be delivered;
2. the cycles meet the mobile depot in one or more "rendez-vous" points of the city, where freights are transhipped from the depot to the bikes for final delivery;

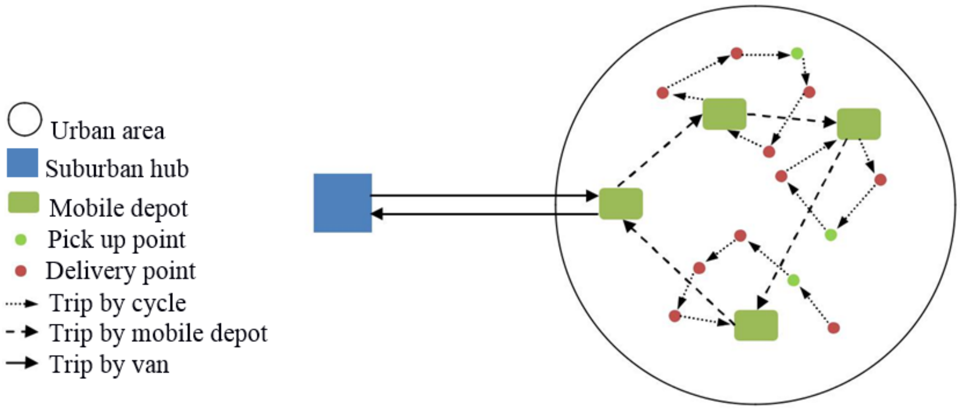

Fig. 5 A cycle logistics scheme for distribution using a mobile depot

Below, examples of cycle logistics schemes will be classified according to the type of transportation mode used as a mobile depot.

BARGE

In 1997 DHL Worldwide Express launched a floating express distribution centre, which combines cycle and river transport. A "grachten boot", i.e. a 17 meter-long canal boat previously used to ferry tourists around Amsterdam, was converted in a parcel delivery vessel, having a net capacity of 30 m^3. In the morning, mails and parcels are loaded on the boat, which then sails over the canals of central Amsterdam on a fixed route. It makes several stops at existing landing stages, to meet up with twenty cycle couriers that pick up the parcels and deliver them in the city to their final destination; these cycle couriers keep in touch with the boat using mobile phones, and also collect return mails that the boat passes to DHL's classical express network in the evening. In this way, DHL has been able to cut down ten of its delivery vans, which means an annual reduction of 150,000 km and 12,000 litres of diesel per year. The main problem in this system can emerge in winter, if the city canals freeze over (Geroliminis & Daganzo, 2005; Maes, Sys & Vanelslander, 2015; Stevenson, 2009). Vert chez vous, a French goods delivery company, has launched a similar service in Paris in 2012. It operates a "warehouse barge" called Vokoli (a Freycinet model, built in 1953 and fully reorganized) on the Seine river, with a fleet of 18 electrically-assisted cargo tricycles on board. The company has a warehouse in Pantin, along Paris inner ring road, 6.4 km from the centre of the city. Parcels are carried by trucks to the port of Tolbiac (Paris 13th arrondissement), where at 7:00 a.m. are loaded on the barge to be consolidated on the tricycles. From 9:30 to 17:00, the boat makes a round trip on the Seine, stopping at ten platforms along the river; at each stop, a team of tricycles leaves to make deliveries in the adjacent area in 1 and a half hours, then re-joins the Vokoli two stops further on. Each team performs four delivery rounds during the day; about 4,000 parcels are consigned (Diziain, Taniguchi & Dablanc, 2013; Heitz, 2015; Janjevic & Ndiaye, 2014).

TRAM

Well known examples of freight tram services in city logistics are the CarGo Tram in Dresden, which every day transports the equivalent of 60 trucks to the Volkswagen factory located in the city centre, and the Cargo Tram in Zurich, which collects bulky waste from households along the city's outskirts (Arvidsson & Browne, 2013); however, in these cases an interface with cycle logistics operators is not envisaged.

A combination of cargo trams and electric distribution vehicles was tested in Amsterdam in 2007. The project (that was expected to reach full scale operations in 2012) aimed at using cargo trams to transport goods from warehouses located in western suburbs near Schiphol airport to inner city UCCs; electric vans or cycles would have then delivered the goods to their final destination. The cargo trams run on the lines which had enough capacity to avoid conflicts with passenger trams, within the time frame 07:00-23:00 to prevent noise disturbances during the night; dead tracks were used as loading and unloading bays. The cargo tram took fifteen minutes extra compared to trucks, but allowed to cut the costs by 15%. Notwithstanding, at the end of 2008 the project failed, due to inability to acquire adequate finance for investment, and the refuse by the city to build extra tracks that were going to be needed (Arvidsson & Browne, 2013).

In Japan, in 2011 Yamato Transport Co. has begun to use trams to transport parcels from the center of Kyoto to Arashiyama, a congested touristic area located 10 km to the west. The service uses the Keifuku Electric Railroad, an existing line opened in 1910 and previously used only for passenger transport; it runs once a day in the morning before the busy hours for passengers. A parcel-only carriage is linked to a regular tram carriage, and is loaded with container dollies bearing parcels; at Arashiyama station, one or two persons from Yamato unload the dollies, reload them onto carriers pulled by electric bicycles, and finally parcels are delivered to customers (Archdeacon, 2011; Diziain et al., 2013).

SUBWAY

Dampier and Marinov (2015) realized a feasibility study of a metro-based freight transportation system between Killingworth and Newcastle upon Tyne, in the United Kingdom. In the proposed scheme, small and medium size parcels are taken by each business to a micro-consolidation centre at Palmersville, the nearest metro station to Killingworth; parcels are condensed in standardized BentoBoxes, that are loaded onto a modified metro train dedicated to freight transportation. This train departs from Palmersville Metro station and in 16 minutes (in an interval between two passenger trains) reaches a dead track between Jesmond and Manors Metro stations, used only late at night to transport trains back to the maintenance depot and located a short distance from the city centre. Goods are then sorted and taken the last mile to businesses by cycle couriers.

A slightly different logistic scheme was tested in Sapporo, Japan. A pilot project was conducted on the Tozai Line of the city metro network, between the Yamato Transport Sapporo Base beside Shin-Sapporo station and the Home Delivery Centre at Odori station, near the city centre. In this case, goods are loaded (three times during off-peak hours from 10:30 to 14:00) not on metro coaches specifically dedicated to goods, but on ordinary passenger metro coaches using a hand cart (0,5x0,9x0,7m) on a wheelchair floor. At Odori station, the cart is unloaded, lifted from the platform to the ticket gate and taken above ground; parcels can then be delivered to final destination using cycles or other small electric vehicles (Kikuta, Itoa, Tomiyamab, Yamamotoc & Yamada, 2012).

BUS

The feasibility of using a bus line to transport goods to the city centre was analyzed by Masson, Trentini, Lehuédé, Malhéné, Péton and Tlahig (2015) for the city of La Rochelle in France, using a mathematical model. Parcels are condensed in containers at the UCC, which is located near a stop of the Illico bus line (74 buses per day). Buses have been modified, so to guarantee an easy and simultaneous access to both freight containers and passengers (Trentini & Mahléné, 2010). The containers are loaded on buses at times of low passenger capacity utilization, carried to one of the six bus stops in the city centre and finally transhipped (without storage facility) to a fleet of city freighters, like electrically-assisted tricycles, to be delivered to final customers. The quantitative assessment in the paper shows the feasibility of this logistic scheme; an efficient transhipment of containers from buses to city freighters turns out to be the key factor in the system performance.

TRAILER

In 2013, TNT Express tested in Brussels for three months a combination of electrically-assisted cycles and a mobile depot, consisting of a trailer fitted with a loading dock, warehousing facilities and an office. The test concerned parcel deliveries and pick-ups in three municipalities (Schaarbeek, Etterbeek and Sint-Joost-ten-Node) in the inner part of the city: an area of just over 12 km^2, densely populated and highly urbanized. In the morning, all parcels to be delivered in the three municipalities were loaded on the trailer at the TNT hub (located near Brussels freight airport Brucargo). The trailer was driven to a parking location in the Parc du Cinquantenaire, which is near the selected demonstration area and the depot of the subcontractor doing the cycle deliveries. From there, deliveries and pick-ups were made by four cycles. During the three weeks of the test, 1,292 pick-ups and 5,286 deliveries were done; 4,534 cyclocargo km were driven. Compared to the regular TNT delivery system based only on vans, the new scheme allowed to replace 1,291 van km to 141 truck km per week; CO_2 and PM_{10} emissions were reduced by 20-25%. At the same time, operations cost nearly doubled (Verlinde, Macharis, Milan & Kin, 2014). Notwithstanding, TNT has launched in March 2016 a new test in Turin, Italy, with a difference: in this case, at TNT hub located in Settimo Torinese (a municipality adjacent to the city, 15 kilometres from the centre of Turin) five cycles are directly loaded on the trailer, together with the parcels to be delivered. The trailer is then parked in Piazza Statuto, at the very centre of the city.

3 DISCUSSION

Cycle logistics has a significant potential for improving the sustainability of small and medium size goods deliveries in urban areas. The typology of cycle logistics schemes we have proposed illustrates how many spatial structures delivery operations by cycle can assume. The efficiency of these schemes depends on how deliveries by cycle are integrated in the whole urban logistic chain, exploit the existing logistic facilities and adapt to the urban system they have to serve. In general, if we recall the three main limitations for cycle logistics quoted in paragraph 2, we can conclude that, moving from the first cycle logistics scheme presented (only distribution without consolidation) to the last one (based on a mobile depot):

- the weight and volume of delivered parcels increase, because cycles can be reloaded more often and easily;
- distances that cycles have to cover decrease, as their departure point is nearest the delivery destinations;
- the urban area that can be served is wider;
- on the other hand, a bigger set of transport means and logistics facilities is required and transhipment costs increase.

Therefore, there is a trade off between the benefits (on environmental emissions, congestion, etc.) of more complex cycle logistics schemes, and their increasing costs; but the research of its balance point, which is strictly linked to the spatial dimension of the schemes, has till now received poor attention, both in theory and in practice. The scientific literature on city logistic network design is quite huge, although rather sparse; many models have been proposed for the location and dimensioning of logistic facilities such as UCCs, micro-distriburion centres, etc., as well as for determining the last mile vehicle fleets composition and size (for a review, see for example Bektaş et al., 2015). But these models have almost never been applied for planning cycle logistics schemes, or for assessing the pertinence of their spatial structure to different types of urban systems. It is generally recognised that cycle logistics performs at its best in urban areas that have high density, narrow streets, limited access (Schliwa et al. 2015); but no systematic study has been realised to identify specific spatial requisites for the effectiveness of cycle logistics schemes, in terms for example of minimum density (inhabitants per hectare), maximum radius that can be served by cycle from a UCC, extension of delivery services also to polycentric metropolitan areas (and not only to central portions of the city) using mobile depots etc.

As regards practice, a deeper knowledge of these spatial issues could support cycle logistics companies in their decisions about the location of their depots or the composition of their cycle fleets. On the contrary – confirming widespread doubts concerning the professionalisation level of most of these companies (Maes & Vanelslander, 2012) –, till now these decisions in many cases have been the result of what was available at the moment, and not based on a real "geographical" assessment (van Duin, Quak & Muñuzuri, 2010).

At the same time, also public policies could take advantage of this kind of scientific research. Cycle logistics can be promoted through a push-and-pull approach: it requires both policies for penalising fossil fuel motorised delivery vehicles (like limited traffic zones, congestion charging mechanisms, restricted delivery time windows) and policies for benefitting alternative vehicles like cycles (reserved lanes or loading/unloading areas etc.) (Russo & Comi, 2010). The realisation of UCCs is often a public initiative of municipalities (for example, in Paris La Petite Reine opened its first depots near the Louvre museum winning a bid for tender organized by the city for allocating the logistic space): an unsuitable location could compromise the success of cycle logistics business.

More scientific research on the spatial dimension of cycle deliveries is also needed to assess if cycle logistics is bound to remain a niche of market, or to replace a relevant share of conventional deliveries (not only in central urban areas but also in wider metropolitan contests), even in competition with innovative delivery solutions like small electric vehicles, drones and crowdsourcing services.

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