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Parcel delivery in urban areas: Opportunities and threats for the mix of traditional and green business models

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A R T I C L E I N F O

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A B S T R A C T

In recent years, the role of freight transportation and parcel delivery in urban areas has increased, supporting the economic and social development of cities. At the same time, the industry is affected by various issues, inefficiencies, and externalities, particularly in the last-mile segment. As such, there is an emerging awareness of a need to improve urban mobility and transportation, making them more sustainable and competitive by mixing traditional and emerging technologies, such as cargo bikes, autonomous vehicles, and drones. In contrast, the complexity of the overall system, characterized by multiple actors with conflicting goals, requires a strategy that harmonizes these actors' business and operational models. This study contributes in this direction along three axes. First, it defines the main actors involved in urban parcel delivery, and then analyzes their business models and the interactions between them. Second, it investigates the integration of traditional and green logistics (mainly cycle-logistics), from both business and operational perspectives, in order to identify synergies, conflicts, and the operational and economic consequences of adopting green vehicles. Third, it introduces a simulation-optimization decision support system tool capable of assessing mixed-fleet policies for the management of parcel delivery in urban areas. Finally, the decision support system is tested using real data of the city of Turin.

1. Introduction

The demand for urban freight transportation has increased considerably owing to urbanization and demographic growth, along with the increased diffusion of e-commerce, management principles (e.g., just-in-time), and pervasive technologies, ensuring the economic dynamics of urban areas. At the same time, freight transportation is affected by various issues, inefficiencies, and externalities, which become more evident in the last-mile segment (Perboli et al., 2014a). In this scenario, several stakeholders operate to develop policies aimed at improving urban mobility and goods transportation. The complexity of the overall system, characterized by multiple actors with conflicting goals, highlights the need to adopt a strategy that harmonizes these actors' business and operational models in order to control the system effectively. In fact, the need to increase the efficiency of delivery activities while marginal revenues are decreasing has led various actors to identify new delivery options among emerging technologies, including drop boxes (Dell'Amico et al., 2011), cargo bikes (Perboli et al., 2016), electric vehicles (Taefi et al., 2016), autonomous vehicles (Gelareh et al., 2013), and drones (Murray and Chu, 2015). Unfortunately, the integration of different delivery options is not straightforward, owing to the interactions and conflicts among actors, their business models, and the technologies themselves (Tadei

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et al., 2016).

As such, this study contributes to the literature on the issues associated with integrating some of the most popular new business models (e.g., green delivery operated by cargo bikes) with those of traditional methods, presenting an analysis conducted in the medium-sized city of Turin (Italy). An analysis of such a complex and hyper connected system requires a holistic vision of the above context, adopting different methodological approaches in order to gain full insight into the extent of the challenge. Our approach includes qualitative business management tools (i.e., Business Model Canvas, Social Business Network), a context-aware integration of business and operational models, and a quantitative analysis of strategic actions and their implementation in operations. We also show how mixing qualitative and quantitative analyses enabled us to derive better results than when using quantitative analyses alone. More specifically, our contributions to the literature are as follows:

- We identify the different players in the transportation and parcel delivery system, considering several combinations of traditional operators (e.g., trucks and vans that use fossil fuel) and green operators (e.g., electric or hybrid vehicles, bikes, and cargo bikes), investigating their business models and behaviors from a managerial perspective.
- From an operational perspective, we investigate how a mix of traditional and low-emission logistics might coexist in the parcel delivery field in urban areas, optimizing the overall system using a win-win strategy, and avoiding the risk of cannibalization between models.
- We introduce a Monte Carlo-based simulation-optimization framework for analyzing mixed-fleet board policies related to managing freight delivery in urban areas, clarifying their cost mix (economic and environmental).

The remainder of the paper is organized as follows. In Section 2, we present a literature review and the main research challenges of urban freight transportation systems. In Section 3, we describe the methodology used in this study. Then, Section 4 describes the multi-actor system of urban parcel delivery, presenting the business models of the actors involved. These actors' operational models are discussed in Section 5 in terms of the times, distances, and costs (both operating and environmental) associated with various types of vehicles. In Section 6, we introduce our Monte Carlo-based simulation-optimization framework, using the results to highlight synergies between operators in the last-mile segment and to extrapolate mixed-fleet policies. Finally, Section 7 concludes the paper.

2. Literature review and research challenges

The need for efficiency and sustainability in the overall freight transportation system and, more specifically, in an urban context, are attracting researchers' attention. In this section, we review the literature on this topic. We investigate the main topics, focusing on urban parcel delivery, and highlight the gaps in the literature this study addresses. The relevant literature can be split into three main streams: operations management and optimization models, sustainability issues, and emerging business models.

The first axis covers operations management and optimization models and methods to do with planning transportation and parcel delivery activities at the tactical, strategic, and operational levels. Several models and methods have been introduced in the past decade, including multi-tier transportation (Crainic et al., 2005, 2009; Perboli et al., 2011; Li et al., 2016), rich vehicle routing methods (Nguyen et al., 2016; Prins et al., 2014; Vidal et al., 2013), and capacity planning problems (Perboli et al., 2014b; Tadei et al., 2012). Normally, these models operate at the technical level, either neglecting or totally disregarding management aspects and, thus, not focusing on a strategic vision.

The second axis concerns the concept of sustainability and the emerging awareness of the environmental problems caused by transportation activities in urban centers. In particular, the literature provides several measures to address such issues, grouped into three main categories: material/infrastructural (e.g., areas for loading and unloading operations, urban distribution centers, etc.), intangible or technological (i.e., Intelligent transportation systems), and governance (e.g., road pricing, maximum parking times, restricted access zones, "low traffic zones" (LTZ), etc.) (Taniguchi, 2014; Russo and Comi, 2010). Moreover, among the seven priority societal challenges under the "Horizon 2020" program, the European Commission has identified the need for "smart, green, and integrated transport," with a heavy investment in research and development (R&D) and innovation in new business models and green vehicles. With regard to this last topic, contributors face the interesting challenge of adopting cargo bikes in order to make city logistics more sustainable, encouraging their diffusion. Most of the relevant research on the subject is limited to a European context, including Paris, London, Brussels, and Barcelona. However, several studies have also examined Manhattan (Conway et al., 2012; Janjevic and Ndiaye, 2014; Schliwa et al., 2015; Lenz and Riehle, 2013; Navarro et al., 2016). Other contributions (e.g., Baldacci et al., 2008; Molina et al., 2014) propose operational research models that focus on scheduling and routing in green or heterogeneous fleet management, including cost and emissions factors.

Finally, the third stream of the literature analyzes new business models based on vehicles that have a low or very low emission impact, including the effects of replacing traditional commercial vans with such vehicles. In particular, Cagliano et al. (2015) developed a system dynamics (SD) model for a freight distribution system. Using this approach, the authors observed how savings in CO2 emissions and operating costs give rise to interesting feedback loops for the adoption of a new distribution system based on electric or hybrid vehicles. Similar approaches can be found in Struben and Sterman (2008) and Park et al. (2011). Those works all share a similar theoretical framework based on the Bass diffusion model (Sterman et al., 2000), which also provides the theoretical background for other models related to city logistics and the last-mile segment.

In our opinion, the literature is lacking in a number of aspects. First, it focuses on an operational aspect, disregarding the business model and the business development of the main players in parcel delivery systems. Second, the literature investigates the adoption of green transportation modes, but without considering integrating them with traditional systems, in terms of operations management, cost and revenue structures, and policies. Our study is the first attempt to fill these gaps. In particular, we propose an unconventional approach, starting with qualitative research from a business perspective of parcel delivery systems. Then, we investigate the operations of such systems and, finally, present a strategic discussion based on a quantitative analysis of the options and policies available. Furthermore, we provide the first analysis of business models that characterize the new practices and technologies of urban parcel delivery by couriers. Thus, our approach does not focus strictly on operations, but proposes a holistic vision, including interactions between international couriers and external firms or subsidiaries managing activities in the last-mile segment. Moreover, we investigate the integration of modes (traditional and green), supported by a detailed cost and revenue analysis based on the business model, which is an area that is under-researched. In fact, although a few studies have investigated the costs associated with the last mile (Gevaersa et al., 2014), ours is the first to consider a cost structure for delivering goods in urban areas that includes economic and environmental costs. In particular, we consider the emissions and costs of the overall last-mile chain, according to the latest regulation, the ISO/TS 14067:2013 “Greenhouse gases - Carbon footprint of product - Requirements and guidelines for quantification and communication,” which is not present in the literature.

3. Methodological framework

As stated in the Section 1, the main innovative feature of this study is the proposal of a holistic vision of a complex parcel delivery system, including both business and operational perspectives. As such, we adopt the GUEST methodology, developed by Perboli and Gentile (2014) and Perboli (2016). This is a lean business approach that extends the work of Osterwalder and Pigneur (2010) and other lean startup movements, adapted for multi-actor complex systems (MACSs), such as freight transportation systems. GUEST is an acronym taken from the five steps of the methodology. In terms of the urban parcel delivery context, the steps are as follows:

- Go. In this phase, a preliminary analysis of the stakeholders in the last mile segment is conducted. Here, we focus on the city of Turin, in particular, and Europe, in general, as well as an international courier delivery service operating in Italy. The aim is to gather information and provide a full description of the stakeholders’ profiles in terms of their needs and cost structures.
- Uniform (see Section 4). The knowledge of the system must be assessed in a standard way in order to obtain a shared vision of a MACS. In particular, in this phase, the system is represented by means of a Social Business Network (SBN), a graphical representation of the system showing the interconnections between actors. The governance and business models are described explicitly for each operator, thus deriving a Business Model Canvas (Osterwalder and Pigneur, 2010).
- Evaluate (see Section 5). The full structure of the costs and revenues is described explicitly for each transportation option. A deep analysis and comparison of the business models is performed, highlighting the key factors linking the business and operational models. This is supported by a performance analysis of the traditional and green delivery options, based on the main variables that affect the last-mile logistics in urban areas (e.g., distance, delivery time, etc.).
- Solve (see Section 6). Given the outcomes from the previous phase, a Monte Carlo simulation is conducted to obtain a comprehensive vision of the overall complex system, rather than focusing on the central area, as in the previous step.
- Test (see Section 6.3). The findings of the Monte Carlo simulation are tested and analyzed in order to extrapolate mixed-fleet policies.

These analyses are conducted using three streams of data related to the business models, the cost structures, and the operations. They are provided by a major international parcel delivery company operating on all continents and involved in the URBan Electronic LOGistics (URBeLOG) (URBeLOG Project Web Site, 2018; De Marco et al., 2017) project and the stakeholders involved in the Synchro-NET H2020 project (Synchro-net h2020 project, 2018; Perboli et al., 2017). With regard to the business models, the data were gathered from interviews with the CEO and COO of this company. The simulation analyses are based on the customer distribution and daily volumes of deliveries in Turin, and registered by the international parcel delivery company during the final three weeks of 2014 and the beginning of 2015. Finally, the data on costs are taken from financial statements and the interviews with the COOs and marketing directors of the stakeholders in order to obtain specific feedback on the financial and operational dynamics.

4. Parcel delivery business model analysis

The transportation and parcel delivery industry, particularly in urban areas, can be represented as a multi-actor system owing to the number of players involved and their high level of interconnection. In order to conduct a comprehensive study of this industry, the operators, and their interactions, we adopt a business-development oriented approach, which has not received significant attention in the literature. The results of this section represent the starting point and the knowledge base needed for the quantitative analysis conducted in this study. As discussed in Section 3, the data used are the result of primary research on parcel delivery systems in Europe, focusing on Turin, along with data gathered and provided by an international courier delivery service company operating in Italy and by several stakeholders from the Synchro-NET EU project. To represent the system, we first use a Social Business Network (SBN), as shown in Fig. 1. The outcome of this tool is a graph-based representation of the multi-actor system, where a node represents an actor and the arcs are proportional to the interactions and relationships between them. The arcs can be of different types: commercial, policy or regulation, partnership/stakeholdership, and competition. Then, in order to study the main actors in further detail, as illustrated in the SBN, we define a business model for each of them using the Business Model Canvas (BMC) tool proposed by Osterwalder (Osterwalder and Pigneur, 2010). The purpose of this analysis is to identify, for each of the nine building blocks of the BMC, similarities, conflicts, and possible synergies between the various strategies adopted by the companies and, in general, to

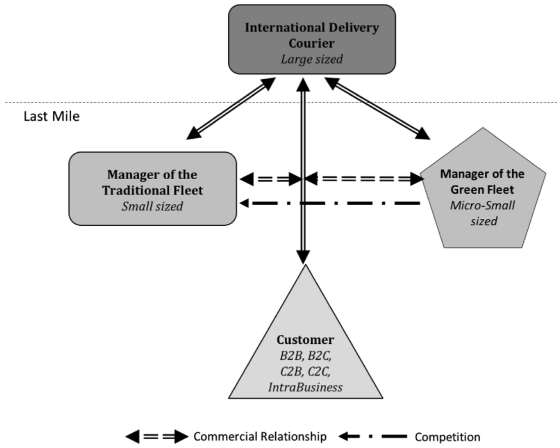

Fig. 1. Social business network.

evaluate their coexistence, especially given the complexities typical of the last-mile segment. For ease of exposition, we first provide a brief definition of the main actors involved and discuss the major outcomes of the BMC analyses. A detailed description of each canvas can be found in Appendix A. The first result of this analysis is that the urban freight transportation system is composed by four main actors, as described in the SBN and in the following list:

- International courier delivery services (hereinafter, International courier). This is a parent company that operates international and national long-haul shipments (e.g., TNT, FedEx, UPS, etc.). Its business model is illustrated in Fig. A.5.
- Manager of a traditional fleet. In general, this actor is responsible for the management of parcel delivery in the last-mile segment and, depending on the geographical area, may take different configurations. For example, in North America, this is an internal department of the international courier, but with autonomy in the management of the area and in the procurement of external capacity in the market. In contrast, in European countries, it is common practice to outsource the operations in the last-mile segments to traditional courier delivery services (hereinafter, traditional subcontractors). These are typically small or medium-sized firms, generally organized as a legal form of cooperatives with limited financial capacity, but capable of managing parcel deliveries locally. From an operational standpoint, the activities are not affected by the different structures. However, in the second case, the flexibility increases because costs can be reduced if demand decreases, and it is necessary to guarantee profit margins for both companies.
- Manager of a green fleet. The increasing awareness of environmental problems related to transportation and the drive toward sustainability has led to the development of new business models for more conscious and optimized management of parcel deliveries in the last-mile segment. In fact, new firms known as green subcontractor courier delivery services (hereinafter, green subcontractors) now operate in several European cities (e.g., Turin, Milan, Paris, Berlin, London, Copenhagen, etc.). Their business models are similar to those of traditional couriers, except they also consider the environmental impact of their activities, often using green vehicles such as bikes and cargo bikes. As mentioned earlier, we focus on the European parcel delivery system and, thus, we consider external firms responsible for the management of traditional and green fleets (see Figs. A.6 and A.7 for the related Business Model Canvases). However, owing to the decision-making and economic autonomy of the single departments in North American companies, the results of this study are still valid when these firms decide to internalize all operations.
- Customers. Customers are the final users of logistics and transportation activities, and include the business-to-business (B2B), business-to-consumer (B2C), consumer-to-consumer (C2B), consumer-to-consumer (C2C), and intra-business segments.

Analyzing the BMCs, all operators offer their customer segments a value proposition consisting of time-sensitive transportation services and express delivery. However, the SBN highlights how the dynamics within the urban transportation and parcel delivery system become more complex with the diffusion of subcontracting and the partial autonomy of fleet managers. In particular, major international couriers in the industry do not manage the entire process. Indeed, to serve their customer segments, they focus on long-haul shipments, while outsourcing the deliveries in the last-mile segment to subcontractors, both traditional and green. This process allows better operational performance and economic efficiency in terms of road transportation in urban areas, as well as capillarity and strategic diffusion in territory, leading to customer proximity.

For all operators, vehicles represent a main item of the cost structure, both in terms of operational costs and social costs related to externalities. Owing to the relevancy of these costs, a further quantitative analysis is provided in Section 5.2. Finally, the SBN shows how the international courier can guide subcontractors using a financial lever. On the other hand, the competition arcs between traditional and green subcontractors represents a threat. In fact, if subcontractors begin competing on operational costs, customers of the international courier may perceive a reduction of in service quality. Such a price war might be caused by the coexistence of traditional and green subcontractors in the same geographical area, or by the similarities in their business models, in terms of their cost and revenue structures, which reduce the margins of differentiation. A similar situation might occur when a fleet is owned internally by the international courier. In fact, the partial organizational independence of local depot fleet managers and their strategic objectives in terms of cost reductions might have similar effects to those of a price war between traditional and green subcontractors.

5. Parcel delivery operational model performance analysis

The analysis of the BMCs (Section 4) shows how combining traditional and green subcontractors might determine benefits in terms of efficient last-mile supply chain management but, at the same time, may hide the threat of a price war, reducing the service quality. Thus, there is a need to better understand the costs and the performance structure of the system. More specifically, we analyze two issues that tend to be disregarded in the literature: (1) the break-even points for vehicles and cargo bikes, in terms of the distance between two consecutive stops, in order to determine the portion of a city where they can coexist (see Section 5.1); and (2) the operational costs per kilometer of the different classes of vehicles (see Section 5.2). In the latter case, partial data can be found in the literature, but no detailed cost analyses have been conducted previously for the parcel delivery sector.

The following analyses are conducted using real data from the customer distribution and daily volumes of deliveries in Turin for the last three weeks of 2014 and the beginning of 2015. The primary data are provided by an international parcel delivery company that operates in Italy and is involved in the URBan Electronic LOGistics (URBeLOG) Project (URBeLOG Project Web Site, 2018).

5.1. Break-even distance between vehicles and bikes

The methodology adopted is based on the main aspects that affect the last-mile logistic system: destination features (e.g., number, localization, delivery frequency, and lead time), parcel features (e.g., quantity, weight, and volume), and the performance of the respective vehicles. Referring to these variables, the following sections analyze the locations of deliveries within the city and the break-even distances between them.

Delivery locations and parcel sizes. According to Gevaers et al. (2011), reaching the critical mass is one of the major problems associated to the last-mile. Thus, to evaluate the presence of a critical mass for the value proposition of green subcontractors, we studied the distribution of the destinations in the urban areas and, in particular, in the city center. In these areas, the benefits related to the use of environment-friendly vehicles are more relevant because of the presence of mobility restrictions (e.g., LTZ areas) and the various aspects related to the quality of life of the public. Therefore, we have designed an ideal area that includes the center of Turin, as well as the surrounding neighborhoods directly reachable by bikes.

First, we filtered the deliveries in this area by the weight of parcels. As defined in the Green Paper proposed by the European Commission (European Commission, 2012), the term "parcel" refers to a box with a weight less than 30 kg, and manageable by a single person. Thus, we classify parcels as follows: "mailer," (0–3 kg), "small parcels" (3–6 kg), and "large deliveries" (more than 6 kg). We observed that the mailers are the predominant parcels and with the small parcels account about the 80% of the total flow of parcels, and the remaining part is represented by the large deliveries. This trend highlights the increasing role of e-commerce that implies frequent deliveries of limited sizes. Despite the 77.49% of deliveries falling outside the city center, the mailers still represent the more profitable category for both subcontractors. They are easy to handle for green couriers using bikes, who can avoid traffic and other urban restrictions. Thus, the distribution of these parcels represents the critical mass to make the business model of green subcontractors sustainable.

Distance analysis and definition of the break-even distance. In this step, we analyze the total time per vehicle stop for traditional vehicles and bikes. Here, we aim to determine the break-even distance, expressed in kilometers, where the performance of traditional subcontractors is equal to that of green subcontractors. Note that the term "stop" refers to the time when the vehicle stops to do one or more deliveries. The term "time per stop" refers to the "travel time" plus the "delivery time," expressed in minutes. The first is the time required to reach the destination point of the delivery from the origin point (e.g., hub, subcontractor location, or a previous destination). The second is the time required for parking and performing the delivery (e.g., customer contact, pick up the parcel in the vehicle, and collect the proof of delivery). The time per stop is strictly related to the distance traveled by the courier. Thus, we calculate the distance from the hub of a green subcontractor operating in Turin to each destination point, referred to as the customer location (URBeLOG Project Web Site, 2018). We measure it using the Manhattan distance, which is the distance measured along axes at right angles. This can be computed by adding, as an ideal point, an intermediate point with the latitude of point A and the longitude of point B. This approach considers the topography of the grid of Turin, according to Roman town planning.

We extract a representative sample with mean $\mu = 0.58$ km and variance $\sigma^2 = 0.05$ km^2. Then, we conduct an analysis based on the total time per stop, using different speed profiles and delivery times for the traditional and green subcontractors. These parameters are assumed as follows:

- for traditional subcontractors, the average speed in the town center is 25 km/h, 35 km/h, and 40 km/h, with a delivery time between 4 and 5 min, considering the complexities related to parking;
- for green subcontractors, the average speed is 15 km/h, 20 km/h, and 30 km/h, with delivery times between 2 and 2.5 min.

This analysis is based on several scenarios related to speed and delivery times for both types of couriers, and on the location of the final customers destinations. The findings confirm those of the previous qualitative and BMC analyses. Thus, although traditional subcontractors can travel faster, the analysis highlights the benefits of cargo bikes. In fact, given the delivery time of traditional subcontractors, when urban congestion reduces the speed (e.g., from 40 km/h to 25 km/h) the total time per stop increases from

Table 1
Break even distances

v_D [km/h]/t_D [min]	4	4.5	5	4	4.5	5	
		2			2.5		t_B [min]/v_B [km/h]
25	1.25	1.56	1.88	0.94	1.25	1.56	15
35	0.88	1.09	1.31	0.66	0.88	1.09	
40	0.80	1.00	1.20	0.60	0.80	1.00	
25	3.33	4.17	5.00	2.50	3.33	4.17	20
35	1.56	1.94	2.33	1.17	1.56	1.94	
40	1.33	1.67	2.00	1.00	1.33	1.67	
25	Bike	Bike	Bike	Bike	Bike	Bike	30
35	7.00	8.75	10.50	5.25	7.00	8.75	
40	4.00	5.00	6.00	3.00	4.00	5.00	

about 5.40 to 6 min, increasing the benefit of using bikes. Therefore, we analyze the break-even distance between the two options (see Table 1). The average break-even distance is about 1.89 km. By varying the values of speed and time, we deduce the following. The break-even distance increases when the driver speed increases or the delivery time decreases. Similarly, the break-even distance increases when the condition $v_B < v_D^o$ is true and the bike speed increases or its delivery time decreases. The combination of the speed of the vehicle at 25 km/h and the bike at 30 km/h gives a constant advantage to the bike. This setting is similar to the values measured in congested city centers, showing the advantage of using cargo bikes in urban delivery operations.

5.2. Cost efficiency analysis of vehicular and cargo bike delivery

Operating cost analysis. In recent years, several companies have been faced with a trade-off between a reduced environmental impact of their activities and the reduced economic efficiency as a result of the consequent additional costs. However, they have also recognized the benefits for competitiveness, in terms of value proposition and brand reputation, of having a greener image. According to this new perspective, they have adopted measures in the city logistics domain when renewing vehicles in their fleets, eliminating those lower than the Euro 4 class and experimenting with green vehicles. The first type of vehicle uses innovative propulsion systems (e.g., electric, hybrid, or methane vans). We also consider alternative vehicles, such as bikes and cargo bikes, and traditional and electric pedal cycles. An actual case is represented by the partnership between Nissan Motor Co. Ltd. and DHL Express in their *"GoGreen"* program. They introduced fully electric vehicles ("e-NV200") in their courier fleet, first testing them in Tokyo's urban area, and then adopting this option in several Italian branches (NISSAN, 2014). Each type of vehicle has different impacts, both environmental and economic. Here, couriers need to consider the financial requirements and investment, as well as the outsourcing strategies and the costs related to fleet management and maintenance. The operating cost analysis (see Table 2) compares the

Table 2
Cost analysis results.

Costs	Tariffs carbon tax [€/tons]	Fossil fuel vehicle	Diesel fuel vehicle	Electric vehicle	Bike
TCK [€/km]					
Annual kilometer cost		2.70	2.68	2.66	1.50
Environmental costs [€]					
Direct CO2 Emissions [tons]		4.15	3.38		
Indirect CO2 Emissions [tons]		4.15	3.38		
Equivalent CO2 Emissions [tons]		8.46	5.52		
Total Emissions [tons]		16.76	12.28		
Carbon Tax [€]	17.00	284.92	208.63		
	30.00	502.80	368.18		
	90.00	1508.40	1104.53		
	150.00	2514.00	1840.88		
Electric Battery Emissions [tons]				3.08	
Carbon Tax [€]	17.00			52.31	
	30.00			92.31	
	90.00			276.94	
	150.00			461.56	
Direct CO2 Emissions [tons]					0.00

different vehicles in terms of cost efficiency and environmental impact. The selection of the benchmark vehicles in our study reflects the transition occurring in the industry. In particular, we consider traditional vehicles (gasoline or diesel), fully electric vehicles, and cargo bikes. These vehicles cover a large part of couriers' fleets. In the proposed methodology, we estimate and compare the total cost per kilometer (*TCK*) (Canadian Automobile Association, 2012) for each vehicle. According to (Canadian Automobile Association, 2012), the *TCK* includes both operating costs (*OPC*), represented by variable costs (e.g., gasoline) and the cost of ownership *OWC*, which includes fixed monthly costs. Moreover, the latter costs are not related to the distance traveled, which means the courier incurs these costs regardless of usage (e.g., purchase costs, personnel costs). The sum of these two costs is then expressed in euros per kilometer for the last-mile segment [€/km], which the company incurs when using the vehicle for a year of its technical life cycle. The *TCK* (Canadian Automobile Association, 2012) function is:

$$TCK = (OPC + OWC)/TK = ((v + tx + i + p) + (f + t + mr))/TK, \tag{1}$$

where:

- *OWC* is the cost of ownership, including all annual fixed costs (i.e., purchase cost of vehicles, taxes, and personnel costs). In particular, concerning the purchase cost of vehicles, we consider the interests based on fixed rate paid by the company according to the financial plan and we imputed a fixed depreciation rate (20% annual) due to usage and obsolescence of the vehicle, allocating the cost of vehicle over its useful life. For simplicity, we did not considered neither value discounts due to inflation, nor opportunity costs being the considered assets essential for the core business of the parcel delivery company and the investment in these physical assets in line with the current practice;
- *OPC* is the total annual variable (operating) cost (i.e., fuel and tire costs);
- *TK* is the total kilometers traveled annually.

The values for each item, described in detail below, were estimated from the primary data with regard to the commercial practices and costs. These data were obtained from financial statements and from the interviews with the COOs and the marketing directors of the international courier, its service providers and suppliers, as well as the partners and the Advisory Board members of the Synchro-NET project. A number of further assumptions are made with regard to the operational aspects of the company in our study, considering actual conditions:

- total annual usage, in terms of kilometers traveled in the last mile segment, of about 25,000 km/year;
- total annual usage, in terms of hours required to reach each destination and to deliver the parcels, of about 2000 h/year;
- the speed of commercial vehicles in urban areas is about 35 km/h;
- each driver must make about 80 deliveries per day, with an average time of 4.5 min per delivery to perform all operations, from parking the vehicle to the collecting the proof of delivery;
- each cost component refers to the technical life cycle of the vehicle, estimated to be five years.

For sake of brevity, we directly include in Table 2 the annual *TCK* for each vehicle. However, for further details concerning all the components of the *TCK*, the interested reader can refer to the analysis conducted in Perboli and Rosano (2017).

Environmental costs. According to the technical specification ISO/TS 14067:2013 "Greenhouse gases – Carbon footprint of product - Requirements and guidelines for quantification and communication," the carbon footprint is defined as the total amount of GHG emitted directly or indirectly by an activity, a product, a company, or an individual. As such, we quantify the amount of emissions for the last-mile delivery process. In particular, we consider the GHG emissions derived directly from fuel combustion, the indirect emissions emitted during the production process of the fossil fuel, and the consumption of energy related to the charging of batteries. However, because we focus on the last-mile segment, we omit the GHG emissions from the long-haul shipment that connects the first and the last mile, and those of the production and disposal process of vehicles. We also consider other pollutants involved in the process, such as nitrogen oxides (NO_x), which are included in the conversion to CO2, using an appropriate factor of 4.7 kg per liter of fuel consumed (Knörr, 2008). To evaluate how the environmental impact affects the cost efficiency of the courier, we express the carbon footprint in economic terms by applying the Pigouvian tax, known as the carbon tax, based on the price paid for CO2 emissions in the atmosphere (see Table 2). This price mechanism does not limit the quantity of emissions, but reduces them by making it cost-effective to switch to innovative technologies with a lower environmental impact. In particular, we conduct a scenario analysis imposing different values of the carbon tax, based on the tariffs applied in several counties, for example, 17 €/t in France (Elbeze, 2014), and 150 €/t in Sweden (Johansson, 2000).

As shown in the BMCs, all operators incur costs related to vehicles used, including the operational and social costs. As illustrated in the above analysis, this cost is higher for the traditional subcontractors using fossil-fuel vehicles than it is for green subcontractors. In particular, while diesel vans are preferred to petrol engines, few of which are used because of the high running costs, electric vehicles permit greater cost savings because of the lower insurance tariff and the exemption from the ownership tax payment. Bike couriers obtain an economic efficiency derived from lower vehicle management costs, as well as from lower personnel costs related to the skills of riders (e.g., they do require a driving license, lower job time). Moreover, they benefit from the additional revenue earned from CO2 savings and carbon credit trading. In fact, assuming that carbon credit prices are 30% lower than the carbon tax tariffs, using bike subcontractors might earn an average revenue of about 0.02 € per stop (Perboli and Rosano, 2017), as compared with traditional vehicles (petrol and diesel). This estimate assumes greater relevance when we consider the high volumes of parcels delivered in urban areas.

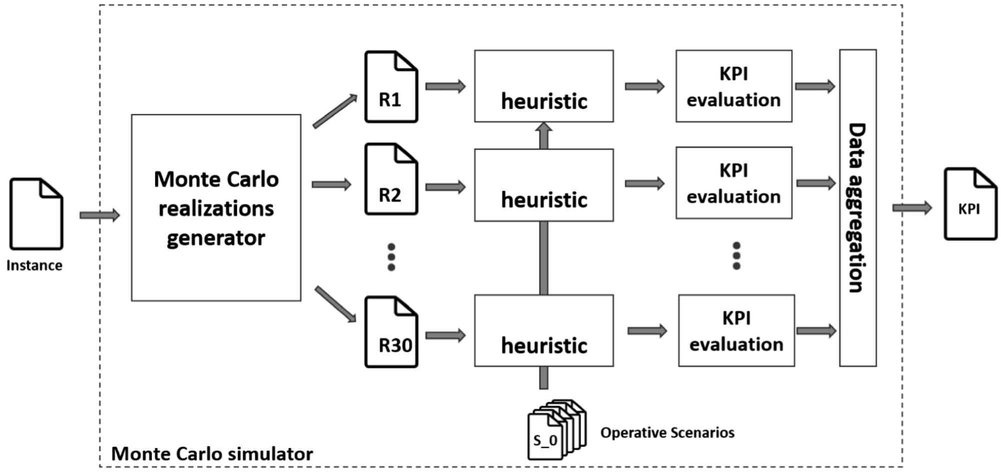

Fig. 2. Monte Carlo simulator diagram.

6. Simulation analysis

As stated in Section 4, in order to avoid the service quality reduction due to competition among traditional and green subcontractors, the international courier should identify strategic policies able to harmonize the two. The complexity of the overall system suggests adopting a tool that considers the interconnection between the actors, while explicitly considering their operations and optimization. Thus, we develop a decision support system (DSS) for managing and deploying mixed-fleet policies in a specified urban area. The overall system is based on the simulation-optimization approach presented in (Perboli et al., 2015) for the air transportation market, while the economic and operational data are the same as those used in Section 5.

6.1. The DSS

The diagram of the DSS is shown in Fig. 2. According to Crainic et al. (2018), the DSS applies a sequential simulation-optimization, where the simulations are numerical. It is based on a Monte Carlo simulation, a last-mile optimization meta-heuristic, and a data aggregation and analytic module. The first block is a high-level generator of realizations. These are the inputs to the meta-heuristic that optimizes the day-to-day operations of the various fleets. The solutions to each realization are then analyzed in terms of the KPIs. Finally, the data aggregation block computes the average KPIs from the Monte Carlo simulation, which is performed to evaluate the impact of the combination of traditional and green subcontractors. For this simulation, we focus only on couriers using bikes and cargo bikes. Future studies will also consider other green vehicles, such as fully electric and hybrid vans.

The simulator implements a Monte Carlo method, a module for geo-referencing the data, and a post optimization software to compute the KPIs. It requires a logical graph of the city including a set of depots and customers, an instance that describes the deliveries to be performed, and the operational scenarios needing to be evaluated. These inputs include also information concerning the customer density, specificities of the vehicles adopted in a certain operational scenario, as well as their travel times and costs matrices. Moreover, time dependence and sources of uncertainty in the travel times, classes of parcels and service times can be also taken into account in the simulation. The overall simulation process for a given demand situation is described as follows:

- Consider an instance defining the number of parcels and, for each parcel, the volume and the parcel types (mailer, standard, etc.).
- Create a set of 30 realizations **R**, one for each day of a month, with the same number of parcels and characteristics, but different destinations. Each of them represents the realization of all the random variables and thus, corresponds to a operational working day. The process is the following:
  – Identify the set of destinations located in central and semi-central areas;
  – For each parcel, find the node of the logical graph nearest to its actual GIS position, and assign the parcel to the node. The distance between the GIS position of the parcel destination and a logical node is computed by means of the Manhattan distance.
- For each realization $r \in \mathbf{R}$, build a vehicle routing problem. Then, evaluate the resulting problem for each operational scenario. To evaluate the scenarios, the simulator integrates an optimization algorithm that minimizes the costs of deliveries and computes the routes for the fleet of the vehicles. Our algorithm is inspired by the method based by Ropke and Pisinger (2006), which is one of the most successful approach for different Vehicle Routing problems, including the Vehicle Routing with Time Windows (VRPTW), and it implements the ruin and recreate paradigm with an adaptive selection of its destruction and reparation operation. The existing time slots make this problem a VRPTW, and the number of trip settings made it necessary to have an underlying flexible algorithm capable of handling multiple configurations. Additional constraints are related to technical restrictions due to the usage of the bikes, the possibility to fix the number of routes, and balancing of the routes in terms of workload. In fact, the algorithm can be run in two different ways: minimization of the fleet or fleet with fix dimension and load

balancing among the vehicles. In the first, the costs are minimized reducing the number of vehicles to use. While in the second, the fleet is given and the algorithm split the deliveries among the vehicles, balancing the load.
After building an initial solution using a best insertion algorithm, the heuristic iteratively chooses a removal heuristic $\mathcal{R}$, removes q customers from the routes in the current solution by applying $\mathcal{R}$, and reinserts the previously removed customers in the existing routes. If the new solution is better than the best one found so far, the new solution is accepted as both the new best and the new current solution. On the contrary, if it is not better, the new solution becomes the current solution according to the greedy acceptance concept defined in Schrimpf et al. (2000). We use three removal heuristics:
– random removal: q customers are chosen randomly;
– radial ruin: given a customer c^*, a percentage chosen at random on the total number of customers equal to $\alpha = 0.5$ is removed. The customers are the ones nearest to c^* according to the distance matrix;
– small radial ruin: similar to radial ruin, but with $\alpha = 0.3$.
The removal heuristics are chosen by a roulette wheel algorithm, where the probability of each heuristic is set to 0.2, 0.4, and 0.6, respectively. The insertion heuristic implies a standard regret insertion. In order to increase its portability in cloud-based environments, the algorithm was implemented using Jsprit, a Java based, open source toolkit for solving rich traveling salesman and vehicle routing problems (GraphHopper, 2018).
- Given the solutions and the KPIs, the data aggregation module geo-references the routes using the Google Maps API, attaches their respective KPIs, computes the fleet KPIs, and presents the performances of the traditional and the green subcontractors. Then, in order to obtain more accurate values of the KPIs, each route duration is evaluated using the empirical distribution of the travel times over the day, as presented in Maggioni et al. (2014).

6.2. Test instances and KPIs

This section briefly describes the test instances used for the numerical experiments. We performed our experiment using data from actual missions observed during the URBeLOG project (URBeLOG Project Web Site, 2018). More specifically, we consider three typical settings, named I1, I2, and I3, ranging from 1000 to 4000 parcels. The settings were generated from real data gathered during the three weeks at the end of 2014 and the beginning of 2015 in a medium-sized city (e.g., Turin, Italy). For each setting, 30 instances were considered. Each parcel is characterized by a destination point (e.g., latitude and longitude), a weight, a volume, and a time window within the delivery must be made. We also consider that parcels are available at the depot of the (traditional or green) subcontractor at the beginning of the working day. Each instance includes more than 50% “mailer” parcels, distributed mainly in the central area. “Large” parcels comprise, on average, 20% of all parcels, but their destinations are located in semi-central or suburban areas, where the green courier cannot operate. The courier operates from a central depot outside the city for the vehicles, while a secondary depot is located nearby the city center for the cargo bikes. All parcels are considered to be destined for urban areas only. For the sake of simplicity, we suppose there are no availability issues for vehicles and cargo bikes. The TCK are those computed in Section 5.2.

The traditional and green subcontractors are characterized by the classes of parcels they can handle, their average speed in central and semi-central areas, service time, and maximum capacity. The values use in this study are taken from interviews with the CEO and the COO of the international courier company.

- **Classes**. The traditional subcontractor can handle any class of parcels, while the green subcontractor one only handle “mailer” and “small” parcels.
- **Speed**. In the meta-heuristic, the cost function considers travel times. The vans of traditional subcontractors have an average speed of 20 km/h in city center, which is usually affected by traffic congestion, and 35 km/h in a semi-central area. The speed of green subcontractors is 20 km/h, on average, in both areas.
- **Service Time**. The service time is about four minutes when operators handle large deliveries, and three minutes for smaller parcels. On the other hand, green subcontractors can easily stop their bikes (e.g., on the sidewalk), so the average service time is about two minutes.
- **Capacity**. Vans have a maximum capacity of 700 kg. The green subcontractor uses messenger bags, with a capacity of 20 kg, and cargo bikes that have a box that can contain up to 50 kg. When necessary, green subcontractors combine a cargo bike and a messenger bag.

All data come from the URBeLOG project.

For each instance, we define five operational scenarios combining the two areas to be served by the green subcontractor and the three classes of parcels that each subcontractor can handle. Note that for the simulation, we defined the “small” parcel class as those parcels with a weight of up to 5 kg. The scenarios are as follows:

- **Scenario S_0**. Only the traditional subcontractor operates in this area.
- **Scenario S_3_C**. The green subcontractor delivers “mailer” parcels (up to 3 kg) in the central area. The traditional subcontractor delivers all remaining parcels.
- **Scenario S_3_S**. The green subcontractor delivers “mailer” parcels (up to 3 kg) in both the central and semi-central areas. The traditional subcontractor delivers all remaining parcels.
- **Scenario S_5_C**. The green subcontractor delivers “mailer” and “small” parcels (up to 5 kg) in the central area. The traditional

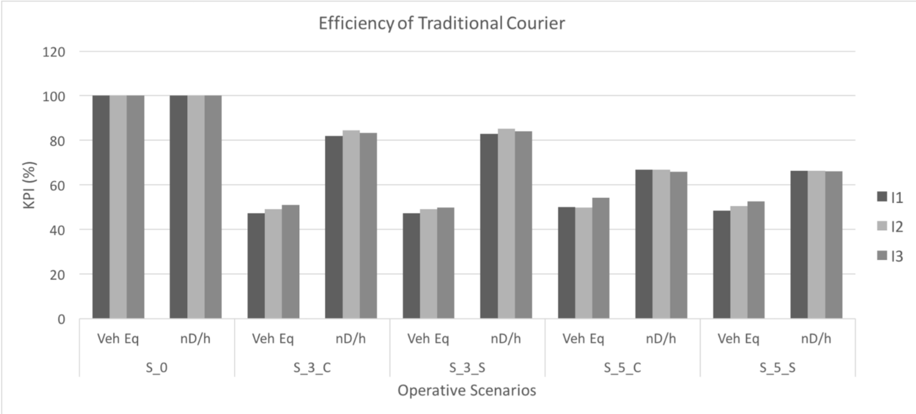

Fig. 3. Traditional subcontractor efficiency in terms of equivalent vehicles (Veh Eq) and parcels delivered per hour (nD/h).

subcontractor delivers all remaining parcels.
- **Scenario S_5_S**. The green subcontractor delivers "mailer" and "small" parcels (up to 5 kg) in both the central and semi-central area. The traditional subcontractor delivers all remaining parcels.

To evaluate the efficiency of combining traditional and green subcontractors in each scenario, we measure three key performance indices (KPIs):

- **Equivalent vehicle (Veh Eq)**. The number of equivalent vehicles used by the subcontractors. Note that to compare traditional and green subcontractors, we implement a conversion from bikes to vans. The conversion considers a full-time work shift of a traditional subcontractor, which, based on European regulations, is six-and-a-half hours. More specifically, we compute the number of equivalent vehicles as the sum of the working time of each biker, divided by the hours in a work shift of a traditional subcontractor.
- **Number of parcels per hour (nD/h)**. It is common practice to define the efficiency of a courier in terms of the number of parcels per hour. This KPI considers only the speed and the service type of the courier.
- **CO2 savings**. CO2 savings measures the kilograms of CO2 not emitted in the case of green subcontractors and their environment-friendly vehicles.

6.3. Computational results

The simulation highlights how the emergence of green subcontractors changes the dynamics of urban freight distribution systems in the last-mile segment. Figs. 3 and 4 summarize the efficiencies of the traditional subcontractor and green subcontractor, respectively. These are measured in terms of equivalent vehicles and number of parcels per hour, when the green subcontractor delivers "mailer" and "small" parcels. Note that KPIs are expressed in percentages with respect to the benchmark scenario S_0. The detailed results obtained from the Monte Carlo simulation are shown in Table 3. The values reported in the table are the mean values of the 30

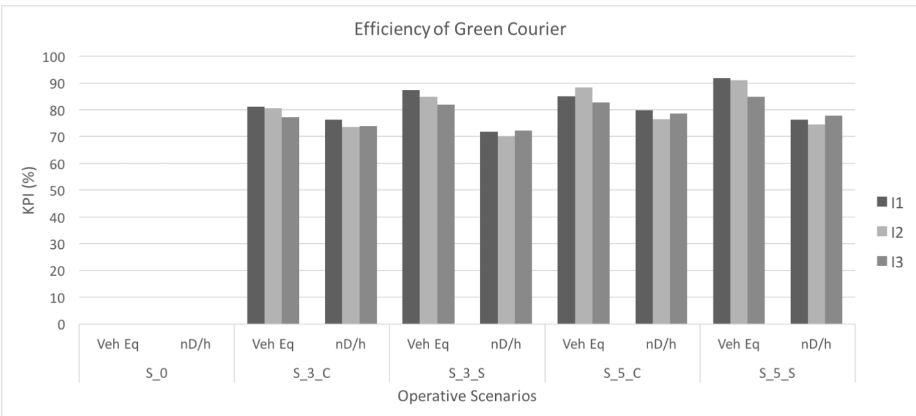

Fig. 4. Green subcontractor efficiency in terms of equivalent vehicles (Veh Eq) and parcels delivered per hour (nD/h). Notice that S_0 has no value because the green subcontractor is not used in this scenario.

Table 3
Results of Monte Carlo simulation. Note that the green subcontractor has no value in *S_0* because it is not included in this scenario.

Instances	nD/h					Veh Eq				
	S_0	S_3_C	S_3_S	S_5_C	S_5_S	S_0	S_3_C	S_3_S	S_5_C	S_5_S
					Traditional subcontractor					
I1	15.65	12.82	12.98	10.44	10.38	7.49	2.16	3.53	2.28	3.62
I2	16.18	13.79	13.77	10.92	10.73	9.89	3.03	4.86	3.07	4.98
I3	15.47	13.29	13.01	10.50	10.21	8.40	2.54	4.18	2.70	4.41
					Green subcontractor					
I1	NA	11.94	11.24	12.47	11.94	NA	3.70	6.55	3.88	6.88
I2	NA	12.03	11.36	12.51	12.06	NA	4.96	8.39	5.45	9.02
I3	NA	11.82	11.16	12.56	12.04	NA	3.85	6.89	4.12	7.14

replications. We do not report the detailed measures of the variance or the confidence level, because they are relatively low. In particular, the intervals of the variances of the values of equivalent vehicles and parcels per hour are less than 1%, while for CO2, they are less than 3%. This proves the significance of the discussion in terms of a combination of traditional and green vehicles. With regard to the performance of the traditional subcontractor, the simulation highlights three main results:

- the number of equivalent vehicles is reduced by half;
- there is a loss of efficiency;
- the capacity of vans is saturated.

By outsourcing “mailer” and “small” parcels, the traditional subcontractor manages only large parcels (over 5 kg), which are usually difficult to handle, with a consequent increase in the service time needed to execute the delivery operations. The latter causes a rapid saturation of the vans’ capacity and, thus, a reduction in the number of parcels in a single round and in the duration of each route. Consequently, the traditional subcontractor needs double the number of rounds and loses efficiency, here measured as the number of deliveries per hour. Fig. 3 shows that the traditional subcontractor loses more than 15% efficiency when “mailer” parcels are delivered by the green subcontractor, and more than 30% when “small” parcels are outsourced as well. Finally, it is interesting that the choice of the city area where the green subcontractor operates does not affect the KPIs of the traditional subcontractor, owing to the distribution of the parcels. In contrast, Fig. 4 shows that, for the green subcontractor, the area of service is relevant for its efficiency. In fact, when it manages “mailers” and “small” parcels, extending the service from the central area to the semi-central area decreases the efficiency of the green subcontractor, in terms of the number of deliveries. However, to maintain an equilibrium condition in the system after the transition to low-emission vehicles, it is necessary to improve quality of service, which, based on the value proposition of the green subcontractor’s business model, must at least compensate for the loss of efficiency the traditional subcontractor incurs. In fact, the results of the simulation highlight that when the green subcontractor manages parcels up to 5 kg in size, the benefits are negligible compared with the consequent inefficiency incurred by the traditional operator. However, particularly when the green subcontractor operates in the central and semi-central areas, the benefits in terms of costs savings (operational and environmental) are, on average, 29% and, thus, are lower than the reduction in efficiency of about 34%. This negative variance discourages the traditional courier from outsourcing this segment, while it is more inclined to outsource parcels up to 5 kg in the central area. Moreover, it is important to extend this analysis to the case in which the fleet of vehicles is owned by the international courier (internal fleet) as opposed to being owned and managed by another firm (external fleet). In the latter case, the green subcontractor incurs costs related to the vehicles, general costs, those related to the structure, and a percentage of its margin. Thus, according to this classification, the above-mentioned values refer to the case of an internal fleet. In contrast, when the fleet is external, the dynamics change. First, we have to move from a cost per kilometer to a cost per stop, owing to the typical contract scheme. This can be done by considering an average distance between two vehicle stops of about 700 m and a minimum requirement of 80 deliveries per day (URBeLOG Project Web Site, 2018). Then, the results of the analysis show that a loss of efficiency of 30% for the traditional subcontractor, as illustrated in Fig. 3, must be overturned by an increase in the performance of the green subcontractor of about 70%, without guaranteeing its desired fee of a 15% margin. This percentage, related to the increase in the performance, translates to 130 deliveries per day, which is difficult to achieve for the green subcontractor. Moreover, for the external fleet, the cost savings connected to parcels between 3 and 5 kg in the semi-central area are, on average, 36%, compared with the loss of efficiency of the 34%. Therefore, the consequences of this inefficiency do not justify outsourcing the deliveries. More specifically, the contractual schemes imply revenue based on the number of deliveries and penalties should a minimum number not be fulfilled. Thus, the loss of efficiency owing to the smaller number of deliveries of the traditional subcontractor, resulting from the outsourcing to the green subcontractor, and the higher distance of the remaining deliveries might have a negative impact on the service quality of the traditional subcontractor, forcing a renegotiation of the agreement conditions. The new contract should consider increasing the number of deliveries required for the green subcontractor in order to balance the loss of efficiency for the traditional subcontractor, without altering the equilibrium state of the service level in the system. Specifically, the green subcontractor should decrease its costs per stop to a value of about 1.90 €/stop and have a critical margin of the 10%, which is nearly identical to the gross contribution margin. Moreover, the outsourcing of all parcels leads to complexity in the management of a high number of agreements with

Table 4
CO_2 savings per day with respect to scenario S_0.

Instances	CO2 savings			
	S_3_C	S_3_S	S_5_C	S_5_S
I1	22%	34%	27%	45%
I2	16%	34%	26%	44%
I3	16%	41%	20%	48%

different contractual clauses, based on the class of parcels. This could imply strategic risks, owing to reduced control over the process, entrusting activities that could be strategic levers, and increasing the bargaining power of green subcontractors.

With regard to environmental issues, we compute the CO2 savings from outsourcing "mailer" and "small" deliveries. Table 4 shows the CO2 savings in each scenario as the difference between the total emissions generated in scenario S_0 and those generated in the other scenarios by traditional vans. Outsourcing both "mailer" and "small" parcels (scenarios S_5_C and S_5_S) to the green subcontractor can lead the highest reduction of emissions, close to 14 tons of CO2 per year. The area served by the green subcontractor has a strong impact on the number of kilometers traveled and, thus, on emissions. Reducing the need to access the central and semi-central areas, the length of the routes traveled by the traditional subcontractor reduce by about 25%. Consequently, the CO2 savings are more than 40%.

Thus, it is possible to derive policies that guide the behavior of the various operators and stakeholders in the urban freight transportation system. In particular, the main actions to consider in order to guarantee a balanced mix of traditional and green transportation and, thus, the efficient performance of the system are as follows:

- In the case of an internal fleet (i.e., the fleet is owned by the international courier), the green subcontractor must manage the "mailers" in the central and semi-central areas. In fact, as shown in the analysis described in Section 5.1, this is the most profitable segment for this courier, because it permits it to maintain the high quality level imposed by the international courier customers. Moreover, the green subcontractor must manage the small parcels in the center of the city, where traffic conditions and mobility restrictions increase its benefits and reduce the costs for the traditional subcontractor. In contrast, outsourcing the management of deliveries of parcels greater than 5 kg in the rest of the city not only affects the quality level perceived by the final customer, but also decreases the efficiency, reducing the margins for the traditional subcontractor.
- In the case of an external fleet (i.e., the fleet is owned by a series of subcontractors), the green subcontractor must manage the "mailers" in the central and semi-central areas. The outsourcing of parcels between 3 kg and 5 kg requires a change in the contractual scheme, decreasing the margins of the green subcontractor, which must increase its role in the selling of energy and environmental credits. Thus, the results show that the goal required by the green subcontractor in terms of increases in deliveries, and the reduction in the efficiency of the traditional subcontractor means the model is neither feasible nor sustainable. For the traditional subcontractor, a better solution is to internalize the green fleet, which it will use to manage parcels up to 3 kg in the central area.
- However, the green aspects of the problem are currently important topics. The introduction of business models based on a low environmental impact leads to a reduction in emissions in a medium-sized city, such as Turin, which means efficient management and control of the system are needed. In fact, focusing only on a reduction of emissions could lead to a cannibalization between the two types of business models. As such, the operational processes of the two couriers need to be optimized and monitored.

6.4. Sensitivity analysis

The main sources of uncertainty in our study that have been the subject of our assumptions are related to the service times, classes of parcels and travel times. While the service times are monitored by the companies and the travel times depend mainly to the speed of vehicles, heavily affected by traffic and congestion, the composition of the demand is the most relevant parameter whose uncertainty will affect in the near future the congestion and the development of urban areas (Giusti et al., 2018). Moreover, according to the annual report by Amazon (Amazon Inc., 2017), the parcels weighing up to 5 kg represents about 85% of e-commerce parcels in Italy. Thus, we now turn to the sensitivity of the problem, analyzing how the sustainability performance indicators vary when e-commerce conditions change significantly resulting in higher (e-commerce market growth) or lower (e-commerce market downturn) demands of mailers and small parcels. In doing so, we created a second set of instances with up to 500 customers, varying the composition of the demand in terms of classes of parcels, as follows:

- current situation: 55% of mailers, 25% of small parcels and 20% of large parcels;
- e-commerce market downturn: 50% of mailers, 20% of small parcels and 30% of large parcels;
- e-commerce market growth: 60% of mailers, 30% of small parcels and 10% of large parcels.

Table 5 reports the average results of the sensitivity analysis, assuming that the best policy suggested in the previous section has been designed. In particular, we show the changes in the solutions with respect to the cost of the vehicle used (Column 3), CO2 savings (Column 4) and nD/h (Column 5.) Notice that the CO2 savings are not reported in the scenario S_0, which refers to the

Table 5
Sensitivity analysis.

Scenario	Market condition	VehEq costs [Euro]	CO2 savings [kg]	nD/h [n.]
S_0	Downturn (−15%)	−18%		−22%
S_3,5_C,S	Downturn (−15%)	−21%	3%	−23%
	μ	998,55	−1.16	0.99
	σ^2	535041.03	333.29	0.014
S_0	Growth (+15%)	25%		20%
S_3,5_C,S	Growth (+15%)	12%	28%	14%
	μ	−1197.93	−55.56	−0.81
	σ^2	1620417.72	278.45	0.39

adoption of vans only. We observe that the e-commerce market downturn, and the relative reduction of the number of parcels up to 5 kg, take benefit in terms of reduction of vehicle costs. On the contrary, nD/h are more sensitive to this market condition. Indeed, the downturn increases the number of parcels with more than 5 kg and penalizes the number of deliveries, causing a decrease of the operative efficiency of the traditional courier (−22% and −23%, in the scenario without and with green subcontractors, respectively). The e-commerce market growth increases the number of vehicles needed to cope with the higher flows of mailers and small parcels, with a consequent increase in the operative cost (25% in S_0), while the effect of this condition in the vehicles cost is limited in the scenarios in which the cargo bikes are adopted (12%). Despite the nD/h increase, the results confirm the outcomes above, highlighting that in the scenarios with the subcontracting to green operators, the traditional subcontractor incurs in a potential deterioration of its operative performance. The increasing number of mailers and small parcels typical of e-commerce growth allows obtaining the highest CO2 savings (28%), due to the possibility to outsource these classes of parcels to the green subcontractor. On the contrary, in case of a market downturn, the higher number of large parcels may cause the saturation of vehicles and the increase of traveled distances, penalizing the environmental sustainability (3% of CO2 savings compared to 28%), as discussed in the computational results.

7. Conclusions

In this study, we analyzed freight transportation in urban areas, given its important role in recent years and the emergence of sustainable mobility, also promoted by the "Horizon 2020" program. In particular, we highlight the impact of adopting green vehicles, such as electric vehicles and bikes, as part of the city logistics field. Based on our analysis and simulation results, the outsourcing of deliveries to green subcontractors could result in benefits in terms of CO2 emissions and on the quality level required by time-sensitive services, owing to the reduction of delivery times. However, the switch to vehicles with a low environmental impact could cause a loss of efficiency for traditional subcontractors. For this reason, to maintain an equilibrium in the system, it is important that this inefficiency is contained and balanced by an increase in service quality when using green vehicles. This requires redefining contractual schemes between traditional and green subcontractors or integrating the green fleet into the international Courier company. Moreover, a continuous process of optimizing activities by implementing a DSS is needed in order to achieve reasonable levels of efficiency. Based on this emerging bi-vehicular model, future research should analyze how the dynamics in urban freight transportation systems change after introducing vehicles with a low environmental impact, such as electric and the hybrid vehicles, as well as other delivery technologies, such as mobile hubs and lockers.

Acknowledgments

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Appendix A. Business models of the main actors involved in the urban freight transportation system

A.1. Business model of international couriers

The main customers served by the international courier (see Fig. A.5 for the Business Model Canvas) are differentiated in the following segments, each with their own behaviors and needs that must be satisfied. The business-to-business (B2B) segment consists

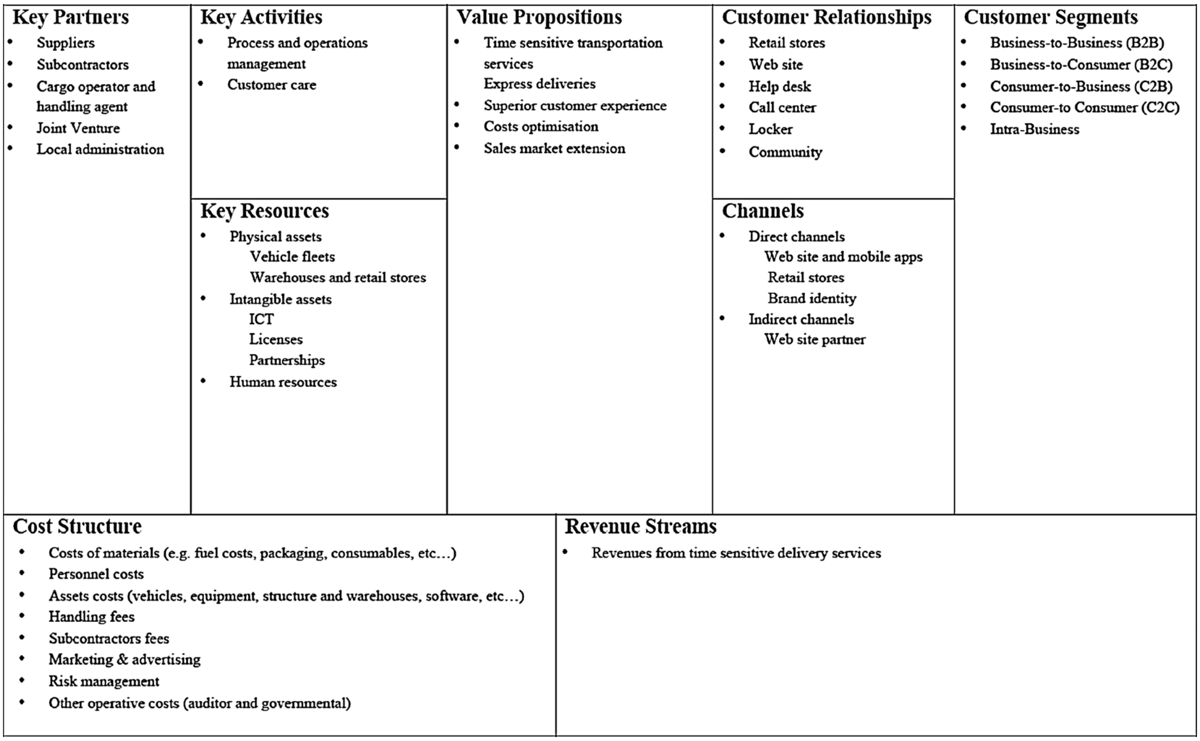

Fig. A.5. Business Model Canvas of an international courier.

of firms that use couriers as a means to move products output from their logistic chain, which represent the inputs to other customer firms. The B2B segment also includes e-commerce, involving goods flows between e-retailers and producers. The business-to-consumer (B2C) segment consists of firms that sell goods directly to final consumers, bypassing distribution chains. Examples include e-stores and website service providers. Then, the consumer-to-business (C2B) segment is strictly related to reverse logistics. This represents the process of returning products, which retrace the supply chain, for different reasons, such as the disposal of waste, processing scraps or packaging, end-user guarantees, dismantling or recycling end-of-life products, customer rejections, or order mismatches for new products. Individuals who require transportation of goods or documents for private needs and online auction websites (e.g., eBay) are parts of the consumer-to-consumer (C2C) segment. Finally, intra-business consists of firms that use courier services to link plants and warehouses. The value proposition that the international courier offers is mainly represented by "time sensitive" or "time critical" transportation of products. For their features of speed and reliability, these services are also called "express and overnight deliveries," because they must be performed in a shorter time window. For this reason, couriers provide more than a transportation service, and include a specific time, called a "transit time" (Caroli et al., 2010). Another component of the value proposition is a superior customer experience, owing to the high added value of express deliveries. In fact, customers obtain benefits deriving from the shipment efficiency, speed, reliability, and security (e.g., through "tracking & tracing") of the services received. Other important benefits are customized pickup and delivery activities in the last mile, and solutions based on product types to be transported (e.g., fragile or perishable products). For small and medium-sized business customers, the international courier offers two other types of value, namely cost optimization and sales market extension. First, firms using express deliveries are capable of realizing JIT manufacturing, with the resulting reduction in inventory levels and optimized production process and costs. The last component of the value proposition is strictly related to the customer strategy. In fact, time-sensitive transport, together with internationalization, increase catchment areas and create new business opportunities for firms. The main channels used to reach customers and to communicate with them to deliver this value proposition can be classified as direct and indirect channels. Website and mobile applications represent the first contact points with customers to raise the awareness of the services offered and to help them to evaluate several propositions. Retail stores are physical structures located throughout a territory in order to increase customer proximity. Another type of channel related to marketing strategy is brand identity, realized through personalized vehicles showing the brand of the courier. These channels are generally owned by the company, and allow an immediate awareness, without intermediaries. The indirect channels are mainly partner-owned websites used in e-commerce. Customer relationships are maintained through the availability of retail stores, websites, help desks, and call centers. These provide customers, both businesses and consumers, with direct support and assistance in all phases of the shipment process, offering a high level of customer retention and loyalty. Lockers and, in general, delivery machines located in urban areas allow an indirect relationship with customers and provide them with a self-service option, available 24 h a day, throughout the year. Moreover, in order to increase the strength of customer relationships, the international courier interacts with its customers through social initiatives and the creation of a community (e.g., the "UPS Foundation" (UPS Foundation Web Site, 2018)). The revenue streams that the international courier obtains derive from selling time-sensitive delivery services to each customer segment, through identified channels. The key resources required to make the business model work are the physical assets, such as vehicle fleets and point-of-sale systems, intangible assets, such as software and other tools used to optimally allocate trips, licenses and partnerships, and, finally, the human resources, including drivers. According to the analysis of the value chain conducted by LUISS Business School and Associazione Italiana Corrieri Aerei Internazionali (AICAI) (Caroli et al., 2010), the main activities that represent the core business of the international couriers are process and operations management and customer care. The first consists of ordinary activities, such as route planning, intermodal transportation, customs clearance, pickups and deliveries, and monitoring the overall process. The second refers to activities for customer relationship management, and are strictly related to the steps in the transportation process: pre- and after-sales support, tracking and tracing of parcels, and proof of delivery. To support its business model, the international courier creates partnerships and alliances with high strategic value. The key partners are suppliers, subcontractors for outsourcing activities in the last mile, cargo operators and handling agents, logistics, and commercial joint ventures, all aimed at making the business more efficient and developing new models. Finally, another relevant partnership is created with local administrations in order to meet government regulations and to ensure the sustainability of parcel delivery in urban areas (e.g., the URBeLOG project (URBeLOG Project Web Site, 2018)). To operate the business model, the main costs the international courier incurs are related to the key resources, as well as materials (e.g., fuel costs, packaging, consumables, etc.), personnel costs, handling fees, acquisition and maintenance of vehicles, equipment, structures and ICT systems, operation costs, such as government and auditors fees, and subcontractor fees when outsourcing activities. Other costs include marketing and advertising expenditure, and those related to risk management.

A.2. Business model of traditional subcontractors

As discussed in Section 4, international couriers in the transportation and parcel delivery industry outsource pickups, deliveries, and transportation activities in the last-mile segment to subcontractor couriers (see Fig. A.6 for the Business Model Canvas), representing the main customer segment to whom they offer a value proposition, consisting of last-mile parcel deliveries. Outsourcing generates value for customers through several benefits in terms of more efficiency and flexibility, owing to better management of activities in urban areas with respect to peak demand and qualitative and temporal constraints imposed by time-sensitive deliveries. Other advantages for the international courier are the wide geographical coverage, cost reductions, the possibility of focusing on its core activities (e.g., multimodal and intermodal transport or customer care), access to specialized resources and expertise (e.g., about territorial knowledge), and benefits from learning economies. The traditional subcontractor firms reach customers through commercial agreements and tenders, which represent their best practice. Thus, subcontractors establish a relationship with the customer segment, maintained by a constant information exchange along all transportation activities (e.g., tracking services and feedback), permitting the co-creation of value for the final user. The main revenue stream for traditional subcontractors consists of the income they receive from customers for last-mile parcel delivery services. The key resources required to make their business models work are the physical assets, such as vehicles (mainly vans, often customized with the customer brand), warehouses, and human resources, such as drivers and the employees responsible of parcel handling and warehouse management. The key activities included in the core

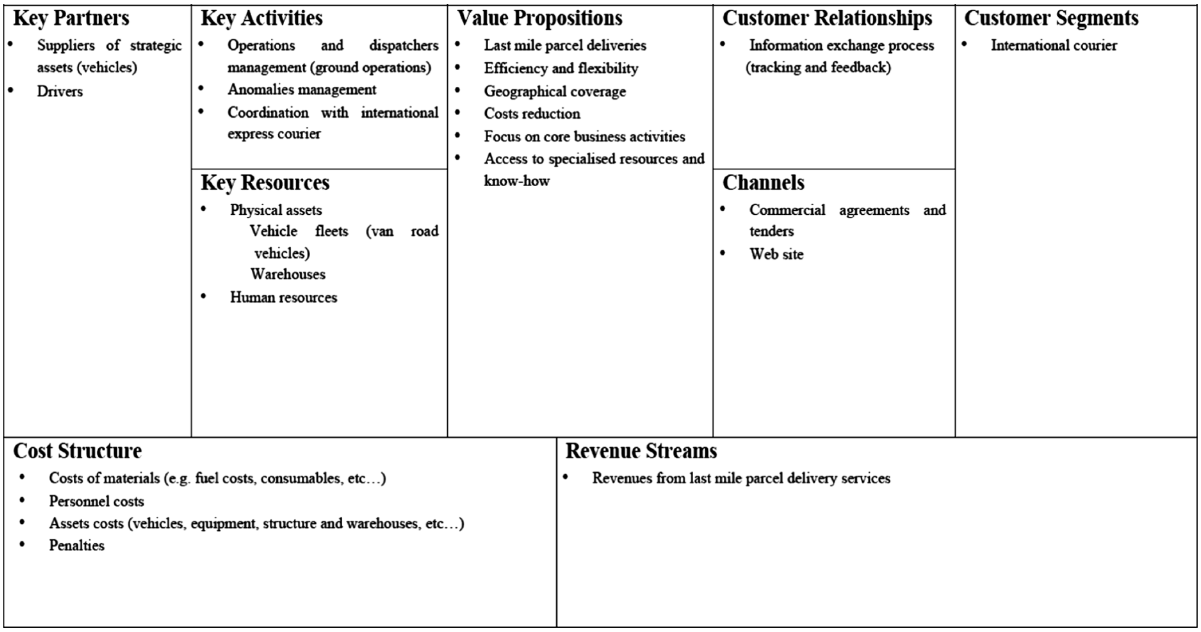

Fig. A.6. Business Model Canvas of a traditional subcontractor.

business of traditional subcontractors are the optimal management of transportation services and the planning of trips and dispatchers in order to achieve high service levels in terms of parcel delivery, fulfilling their timeline constraints. After receiving parcels at the hub, the traditional subcontractor checks on the accuracy and integrity of packages, as well as the related information and bar codes, along conveyors called "sorters". Then, parcels are assigned to a driver according to zoning criteria, and are ready for shipment (Perboli et al., 2016). An important key activity is also the management of anomalies, such as returns for data errors or residuals when receivers are not at home. These days, there is a considerable impact of deliveries that fail at the first attempt (approximately 12% of all deliveries) (Visser et al., 2014). Another key activity is related to its coordination with international courier customers. The interplay between these two actors is important to the success of multimodality and to the correct fulfilment of parcel deliveries, along with the subsequent satisfaction of final users. A key partnership is established with suppliers of strategic assets, particularly with vehicle dealers and leasing companies, but also with drivers. The cost structure consists of expenses related to acquisitions, maintaining and fueling vehicles, equipment and materials, warehouses, personnel costs, and penalties, which may be incurred as a result of breaching contractual terms.

A.3. Business model of the green subcontractor

The increasing awareness of environmental problems related to transportation and the intent to make the industry more sustainable have led to the development of new business models for more conscious and optimized management of parcel deliveries in the last-mile segment. Examples are new firms that use business models similar to those of traditional subcontractors, but that also consider the environmental impact of their activities, often using green vehicles such as bikes and cargo bikes (see Fig. A.7 for the related Business Model Canvas). The customer segments are identifiable principally as those where international couriers outsource last-mile operations, but also include the B2B and B2C segments for intercity and intracity postal services. The value proposition offered by green subcontractors consists of cycle-logistics services capable of overcoming the complexities of parcel deliveries in urban areas. For example, these include mobility restrictions (e.g., LTZ areas), and inadequate or insufficient infrastructure (e.g., limited usability of loading and unloading zones). Furthermore, their value proposition penalizes the competitiveness of traditional subcontractors. Cycle-logistics provide customers with several sources of gain creators and pain relievers, including speed, punctuality, and flexible service, because of the better performance of bikes in city traffic, the interoperability between traditional road vehicles and bikes, and cost reductions, but without compromising quality of service. This last factor is another important component of the value proposition. In fact, better management of parcel delivery in the last mile, and the decreases in expenditure (e.g., fuel, insurance, parking fine, etc.) lead to cost optimization. Green subcontractors offer their customer segments the possibility of delivering small-sized parcels, between 0 to 3 kg, or up to 6 kg. Finally, another value proposition for customer segments is provided by the green image and green credentials required to create a sustainable supply chain. Green subcontractors reach their customers through websites, which are the first channel through which they can increase awareness and knowledge of their services. Other channels include media and interviews published in magazines that specialize in transportation and environmental issues. As was the case with traditional subcontractors, green subcontractors establish relationships with customer segments that are maintained by

Key Partners
- Technological partners
- Investors
- Partner
- Bikers
- Local administration

Key Activities
- Operations and dispatchers management
- Anomalies management
- Fund raising

Key Resources
- Physical assets
  - Vehicle fleets (bike and cargo bike)
  - Warehouses
- Human resources (bikers)
- Intangibles assets
  - Partnership
  - ICT tools

Value Propositions
- Cycle-logistics services
- Costs optimisation
- Small sized parcel delivery (0-3 kg and 3-6 kg)
- Green image and green credentials

Customer Relationships
- Information exchange process (tracking, feedback, CO2 savings)

Channels
- Web site
- Media and interviews

Customer Segments
- International courier
- B2B and B2C for intercity and intracity postal services

Cost Structure
- Costs of materials (e.g. consumables, bags etc…)
- Personnel costs
- Assets costs (vehicles, equipment, structure and warehouses, ICT tools etc…)
- Marketing & advertising

Revenue Streams
- Revenues from last mile parcel delivery services
- Revenues from CO2 savings and carbon credits trading

Fig. A.7. Business Model Canvas of a green subcontractor.

constant information exchange along all transportation activities (e.g., tracking services, feedback, and information about CO2 savings). The main revenue stream for green subcontractors consists of the income they receive from customers for the sale of last-mile parcel delivery services and cycle logistics, revenue from CO2 savings and the carbon credit trading, and fees and royalties from affiliates. The key resources required to make the business model work are the physical assets, such as vehicles with a low environmental impact (bikes and cargo bikes), warehouses, and fit human resources (bikers), whose performance determines the service quality and punctuality. Owing to the simplicity of this business model, it is affected by high repeatability. Thus, important key resources include intangible assets such as partnerships, but also the ICT tools and software required to optimize operations management (Perboli et al., 2016). The key activities underlying the business model are the same as those of the traditional subcontractors. In fact, green subcontractors are generally start-ups and, thus, fundraising is an important activity, necessary for the future development of their business models. Key partnerships are established with technical partners, investors, and sponsors, who are all important in terms of providing support and improving the business model. Other key partners are the bikers and, importantly, local administrations. In order to operate their business models, the main costs to green subcontractors are related to their key resources, as well as to vehicles, equipment (e.g., bags customized for parcel transportation), consumables, information technologies, personnel, warehouses, and marketing and advertising.

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