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Comparison of various urban distribution systems supporting e-commerce. Point-to-point vs collection-point-based deliveries

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Abstract

E-commerce is a sector in continual growth in all countries and, in particular, the increase in B2C (Business to Consumer) e-commerce market has important effects on last-mile deliveries in city areas. The delivery of a parcel to a consumer's address involves not only high costs for both couriers (extended car routes) and consumers (high prices) and also greater environmental pollution. The growing demand for deliveries in urban areas involves increases in traffic and congestion problems and, consequently, environmental issues. In recent years, many studies have focused on alternative measures to reduce the negative aspects and impact of last-mile deliveries. Good practice to rationalize last-mile delivery should involve the use of various systems, such as reception boxes, delivery boxes, controlled access systems, collection points and lockers. This paper compares two alternative options to home delivery. In particular, it makes comparisons between point-to-point and lockers, states the pro and cons of both, and defines the best positions to locate lockers to reduce consumers' deviations. The proposed method is applied to a real case: the Italian municipality of Dolo (near Venice).

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Keywords: City logistics, freight urban distribution, vehicle routing

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1. Introduction

Internet purchases have recently grown steadily and now represent a significant market sector (Taylor Nelson Sofres Interactive, 2002; Logistic Institute, 2016). In 2016, the e-commerce market in Italy had increased by 18 percent over the previous year, and this growth rate was larger than that of other large European markets, confirming that e-commerce in Italy has high growth margins (Freight Leaders Council, 2017). It has also led to a different destination of freight traffic toward users' residences rather than retail stores, increasing the volumes and complexity of distribution logistics. Another consequence is increased urban traffic generated by the greater number of delivery trucks and the consequent increase in polluting gas emissions. This type of problem is called the City Logistics problem and has been extensively studied in recent years (Taniguchi et al., 2001, 2016; Crainic, 2008; Wang et al. 2014, Taniguchi, 2015).

There are various reasons which show that operational delivery methods should be revised, in order to reduce logistic costs (storage and delivery) by grouping deliveries in small urban collection centres to reduce the number of points of destination, to reduce the risk of non-delivery due to the absence of the recipient at home, and to ensure that users can receive their goods at a collection centre along one of the routes they usually take during the day, examples being home/work, home/school and home/other.

Many studies have presented alternative measures which could reduce the negative aspects and effects of 'last-mile' deliveries. Good practices to rationalize them are: the use of different systems such as reception boxes, delivery boxes, controlled access systems, collection points and lockers (Allen et al. 2007). In particular, the last-mentioned system may be optimal, because lockers are independent of usually available time slots (24 hours, 7 days a week) and sited in strategic locations where consumers are not obliged to make long deviations in their journeys.

In a study from Poland (Iwan et al., 2015), the reasons for locker use are the low price of deliveries, their availability, and location. The most important expectations of locker users regarding location include: they are near home or on the way to work, and parking space is available. Locker location is a determinant factor in allowing these systems to be exploited to a greater extent. The idea is to combine home-to-work travel with travel to reach the locker. Therefore, the best places are supermarkets, shopping malls, service stations, pedestrian zones, etc., i.e. all areas where consumers expect to find them.

In the case of young people, because they represent a generation which uses the internet intensively and engages in online shopping, they have a proclivity for electronic shopping and, in particular, use lockers for to collect delivered goods. The main reasons for this choice are convenience, delivery time, and cost, although ecological reasons are not cited as much as might have been expected (Moroz et al., 2016).

Locker use has benefits for both consumers and couriers and shipping companies. Lockers allow hitherto unused spaces to be commercialized, new social gatherings to be created, and the use of lockers for advertising and allowing sustainable development (Bilik, 2014).

Torrentellè et al. (2012) studied the strengths, weaknesses, opportunities and disadvantages of lockers. As strengths, the above authors stress the availability of taking parcels whenever consumers want them, lower delivery costs, and reduced kilometers travelled. The authors emphasize the first weakness of lockers, which is the necessary movements by consumers, because some consumers may not be able to accept these displacements. There are also various opportunities, such as the easy exportation of systems to all countries, and more efficiency for shipping companies, although it should be noted that the possible limitless increase in the number of locker sites in the city is due to the constant growth of e-commerce.

The InPost report (2015) studied the advantages of the locker solution compared with classic home delivery. The study included number of daily deliveries, kilometers travelled, annual fuel consumption and carbon dioxide emissions. It inferred that it is possible to deliver more packages with the locker solution (600 packages in a day instead of 60) compared with less than half the number of kilometers travelled. This involves substantial reductions in carbon dioxide emissions (about 95% lower) and fuel consumption (21 million liters fewer). If we also consider that home deliveries may involve failed deliveries and therefore, as provided by the standard procedures of many shipping companies, a second delivery attempt is made, we see that this is not a problem which arises in the case of lockers, although differences would still increase: for 10%, 30% and 50% of failed deliveries, there is, respectively, a 15%, 45% and 75% increase in carbon dioxide emissions (Edwards et al., 2009).

In cities, where lockers are sited, satisfaction is very high, and about 95% of consumers who use lockers are satisfied with their choice (Lemke et al., 2016).

Several works have focused on analysing the cost of deliveries. In particular, Blauwens, De Baere & Van de Voorde (2010) define a function based on time and distance of transport. Delivery costs also depend on the number of stops, the number of failed deliveries, and possible added management fees during delivery.

Another study by Gevaers, Van de Voorde e Vanelslander (2014) estimated the cost for home deliveries under the assumption that vehicle speed is always constant. Therefore, the cost depends on area population density, time windows in which delivery can be completed, and the possibility of completing it at workplaces. The study takes into account the possible presence of collection points or lockers; cost decreases, reaching the lowest amount in all simulations.

It may thus be stated that the possibility of having lockers located in various well-known places should reduce delivery costs and, at the same time, lead to more packages delivered to more consumers in the same day. In Italy, especially, the solution of lockers is not yet used frequently.

Another main difficulty in analysing freight mobility is how to identify the decision-makers involved in the process, because a complex set of decision-makers responsible for production, distribution and marketing often exists (Russo, Comi, 2006). Freight demand is derived from the socio-economic system, so it is essential to estimate demand through a population survey.

The state-of-the-art of these models, especially urban-scale models, is large and expanding. The literature contains commodity-based models which are derived from the concept that freight systems are essentially concerned with the movement of goods, not of vehicles, and movements of goods are modelled directly. There are multi-step models (Ogden, 1992), input-output models (Harris and Liu, 1998) and spatial equilibrium of prices (Oppenheim, 1994).

Other model types are truck-based, focusing on truck movements estimated directly (Taniguchi, 2001) or even urban distribution centres which can identify optimal sizes and locations to analyse the effects and impact of Urban Distribution Centers (Crainic at al., 2004). Lastly, e-commerce models study the effects (and impacts) on urban freight distribution.

However, the models described above do have some limitations: they are not integrated with other components of urban mobility, they have no connection with measures implemented on an urban scale, and do not include examination of connections with end-consumers.

Russo and Comi (2006) overcame these limitations by analysing freight mobility through models of attraction, defining some distribution channels in which consumers can buy or pick up their packages. Exploiting an existing network which includes vehicle flows and other characteristics and matching demand in freight quantity depending on socio-economic characteristics, real-life path choices can be determined. Russo and Comi use a four-stage model (Generation, Distribution, Assignment).

Despite the extensive literature on City Logistics, most of the proposed experiments are based on generalization of classical instances, not directly comparable with real-life cases. Ambrosino et al. (1999) defined a method to support technicians in recognizing the traffic asset and decision-makers in evaluating interventions on urban transport infrastructures, allowing an updated analysis of the mobility, energy and environment situation by using a real-life data set. More recently, Perboli et al. (2018) tried to overcome the limitation between the use of classic and real-life instances. They proposed a simulation-optimization framework for building examples and assessed operational settings, using real-life data sources and stakeholder requirements.

The present work describes a city delivery model based on small-town collection centres which can be located at sites frequently visited by users for other reasons without adding additional travel costs (i.e. supermarkets, post offices, shopping centres, metro or railway stations, etc.). The model evaluates an indicator of savings (km travelled) compared with deliveries made in the AS IS situation (direct delivery to end-user) and the TO BE situation (delivery to city collection centres or lockers). To carry out a more realistic experiment, a traffic assignment model was used to evaluate travel time in both scenarios.

2. Methodology

In the logistic context described above, it is clear that, both in the AS IS scenario (deliveries to users' domiciles) and the TO BE scenario (deliveries to lockers in a location other than the user's domicile but often visited by that user for other reasons), a Capacitated Vehicle Routing problem must be solved. In particular, since the test case examines several depots from which to make deliveries, the problem in both cases is generalized as a Multi Depot Capacitated Vehicle Routing Problem (MDCVRP). It is well-known in the literature (Toth and Vigo, 2002; Golden et al., 2008) that this problem is difficult to address and solve in the case of small problems, so that heuristics or meta-heuristics must be used (Lim and Wang, 2005).

In this work, we dealt with the MDCVRP heuristically by subdividing it into two phases, applying a math-heuristic approach in order to have a good-quality solution in acceptable times, since we had to solve cases of non-small size. In particular, in our case, we pre-identified a certain number of lockers on the territory and can assume, in the first instance, that they are sufficiently large compared with the demand of the customers allocated to them. We also assumed that users who order delivery of goods will go to the nearest possible lockers (from home, or from the usual site where they receive the goods). In each locker, we will then have a finite request equal to the sum of the requests of the nearest users.

Given customer demand and obtained demand for lockers, we can evaluate the AS IS and TO BE scenarios, solving the problem of MDCVRP for each of them. As mentioned above, we do this heuristically in two phases. In the first phase, an excellent clustering problem is resolved, which allows customers (AS IS scenario) or lockers (TO BE scenario) to be grouped into clusters of total demand not exceeding that of the vehicle and the allocation of clusters to depots. The result of the first phase is therefore a partition of the set of customers/lockers in subassemblies to be served by a single vehicle starting from a specific depot, determining in the second phase the optimal route to visit each subset of customers/lockers. In the second phase, therefore, it is only necessary to resolve an instance of the traveller's problem (TSP) for each of the customer/locker subsets identified in the first phase. The model used for first-phase clustering is described below.

Let D be the set of depots and U the set of users (clients or lockers). We consider the direct graph $G = (N, A)$, where $N = U \cup D$ is the set of nodes and $A = N \times N$ the set of arcs. c_{ij} is the distance cost (length or travel time) for going from node i to node j. d_i is the demand of user i, and Q the capacity of each vehicle. For clustering, we consider a set V of virtual centres and, for the sake of simplicity, we assume $V = N$, introducing set V' containing set V and a certain number of copies of each virtual centre.

w_{ij} is a binary variable representing the assignment of user $i \in U$ to virtual centre $j \in V'$, and h_{kj} is a binary variable representing the assignment of virtual centre $j \in V'$ to depot $k \in D$. We want to assign each user to exactly one virtual centre, so that the total demand of the users assigned to each virtual centre is not greater than vehicle capacity Q, and to assign each virtual centre to exactly one depot. The aim is to minimize the total distance cost between users and assigned virtual centres and the total distance cost for going from depots to assigned virtual centres; in both cases we considered the distance round-trip.

The problem is formulated as follows.

$$\min \sum_{i\in U; j\in V'} (c_{ij} + c_{ji}) w_{ij} + \sum_{k\in D; j\in V'} (c_{kj} + c_{jk}) h_{kj} \tag{1}$$

$$\sum_{j\in V'} w_{ij} = 1 \quad \forall i \in U \tag{2}$$

$$\sum_{k\in D} h_{kj} \leq 1 \quad \forall j \in V' \tag{3}$$

$$\sum_{i \in U} d_i w_{ij} \leq Q \sum_{k \in D} h_{kj} \quad \forall j \in V' \tag{4}$$

$$w_{ij} \in \{0, 1\} \quad \forall i \in U, \forall j \in V' \tag{5}$$

$$h_{kj} \in \{0, 1\} \quad \forall k \in D, \forall j \in V' \tag{6}$$

In the model described above, equation (1) is the total distance cost to be minimized. Constraints (2) ensure that each user must be associated with only one virtual centre. Constraints (3) require each virtual centre to be assigned to one depot at most. Constraints (4) ensure that the total demand of users assigned to the same virtual centre cannot exceed vehicle capacity *Q*. Lastly, equations (5) and (6) constrain the variables to be binary.

3. Case study

The method described above was applied to a real-life case: the town of Dolo, an Italian municipality of about 15,000 inhabitants and part of the metropolitan city of Venice (Veneto region). Starting from the dataset of its population and statistics on online purchases in Dolo, the average number of deliveries on a weekday working day was determined for each of the 65 user zones shown in blue on the map (Figure 1). A survey of the territory identified 21 lockers, shown in green. Shipments take place from three depots, also displayed on the map (red).

These data were supplemented by two matrixes of the lengths of the minimum road itineraries and two regarding the minimum times between each couple of the above-mentioned points (user zones, depots, lockers) obtained from a deterministic user-equilibrium assignment (DUE) based on BPR delay functions, calibrated for each road segment. A matrix relative to the lengths of the minimum itineraries and one of the travel times refer to the AS-IS problem, which examines direct shipments from the three depots to the end-user zones; the other two concern shipments from the three depots to lockers.

On this basis, the question of lockers was based on the assumption that they had sufficient capacity and that customers used the locker closest to them in terms of distance per kilometer or time to travel, depending on the two cases examined. This also allowed us to set the capacity of each individual vehicle at 75 loading units, so that we can serve a customer or a locker from a depot with a single vehicle.

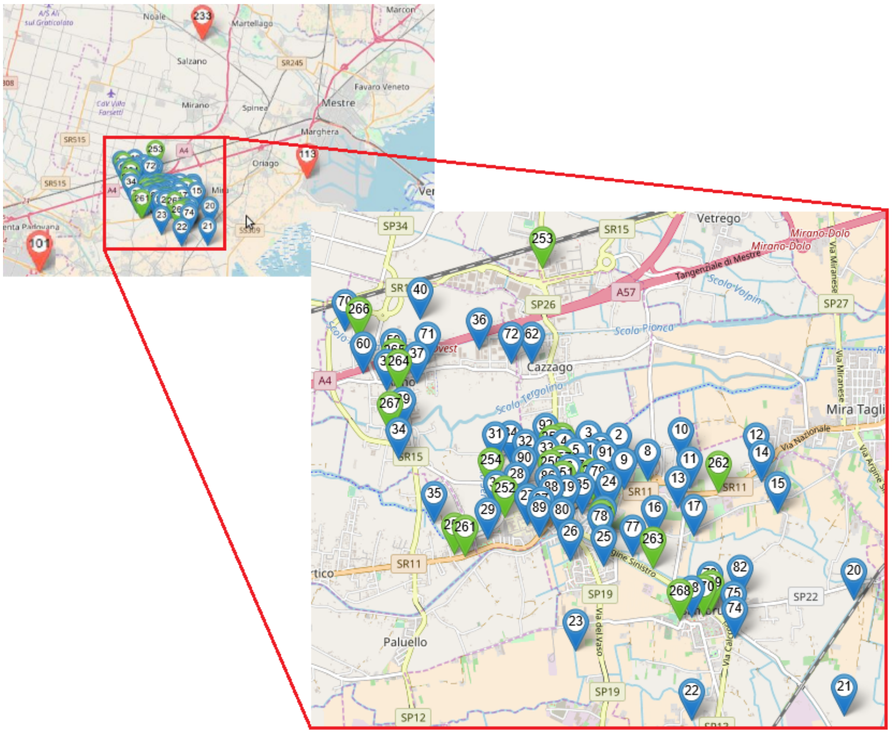

Figure 1: Test case: the town of Dolo.

Sequential application of the clustering and TSP algorithms enabled us to determine the routes of each vehicle from each depot to reach end-customers in the AS-IS scenario, by considering both the distance matrix (Table 1) and the time matrix (Table 3). Similarly, the routes of each vehicle from each depot were identified for the tour of lockers in the TO-BE scenario (Tables 2 and 4).

Table1: The AS-IS Distribution tours: Depot-Users

Depot	Tour	Demand	Length (m)	CO_2(kg)
101	101-12-9-13-18-17-14-11-2-8-10-101	64,99195	33.776,8	7,21
101	101-35-31-30-28-84-90-32-92-4-3-101	69,83514	29.867,9	6,34
101	101-70-40-60-71-36-72-37-39-34-38-59-101	65,05846	30.650,7	6,55
101	101-16-24-76-78-77-25-23-26-80-101	74,27445	31.206,7	6,64
101	101-91-79-93-1-7-5-6-85-19-88-89-27-29-87-86-33-101	45,51182	29.876,4	6,37
113	113-20-82-73-75-21-22-74-15-113	72,47595	34.700,8	7,4
	Total	392,15	190.079,2	40,51

Table2: The TO-BE Distribution tours: Depot-Lockers

Depot	Tour	Demand	Length (m)	CO_2(kg)
101	101-261-252-254-250-251-262-101	70,79	26.785,38	5,71
101	101-260-255-101	70,63	23.796,20	5,07
101	101-266-265-267-264-101	65,06	22.775,86	4,86
101	110-256-257-259-101	66,85	23.105,07	4,89
113	113-270-268-113	57,37	23.994,01	5,12
113	113-263-269-113	61,44	23.990,67	5,12
	Total	392,15	144.447,19	31,75

Table3: The AS-IS Distribution tours: Depot-Users

Depot	Tour	Demand	Time (s)	CO_2(kg)
101	101-70-40-71-72-36-37-39-38-59-60-101	63,36	3.355,32	6,18
113	113-91-93-1-3-4-7-5-6-26-79-113	67,93	2.991,48	6,88
113	113-12-13-17-18-15-16-9-14-11-2-8-10-113	74,45	3.577,36	8,25
113	113-33-92-32-90-84-31-35-34-30-28-27-29-89-87-88-113	71,07	3.971,53	8,06
113	113-20-82-22-74-21-75-73-113	64,71	2.767,56	7,44
113	113-77-25-23-80-85-19-78-76-24-113	50,63	2.852,93	7,13
	Total	392,15	19.516,18	43,94

Table4: The TO-BE Distribution tours: Depot-Lockers

Depot	Tour	Demand	Time (s)	CO_2(kg)
101	101-267-264-265-266-101	65,06	1.937,88	4,90
113	113-269-113	72,48	1.378,62	5,48
113	113-261-252-254-256-250-257-113	71,96	1.865,24	6,58
113	113-260-113	74,68	1.427,15	5,72
113	113-259-251-255-113	35,60	1.548,41	5,76
113	113-263-268-270-262-113	72,37	1.553,64	5,91
	Total	392,15	9.710,94	34,35

The results are clear: comparing the two scenarios by using path length matrix, total distance travelled fell by more than 24%; similarly, using the path travel time matrix, total travelled time decreased by more than 50%.

From the viewpoint of externalities, these initial results also allow us to assess CO2 emissions in the urban environment by simulating the routes of fleet vehicles for city deliveries. In both cases, using distances or the time matrix and examining the traditional types of transport operated with motor vehicles, CO2 emissions decreased by more than 21% in the TO BE scenario.

4. Conclusions

This work proposes a city delivery model aimed at evaluating an indicator of savings (km travelled or time spent) by comparing direct delivery to end-users and delivery to city collection centres or lockers; it also examined traffic congestion. In the first phase of our approach, a clustering problem was resolved for the AS IS and TO BE scenarios by grouping customers or lockers to depots in several subsets, without exceeding vehicle capacity. In the second phase, for each subset, we found the solution of related instance of the 'travelling salesman problem' (TSP). The sequential application of the clustering and TSP algorithms allowed us to identify the routes of each vehicle, by considering both distance and time matrices. Lastly, according to the resulting routes, we compared the two scenarios and evaluated CO2 emissions. The proposed method was applied to a real-life case: the Italian municipality of Dolo.

Application of the method did not exhaust the analysis for comparing the two distribution logistics, but it did allow us to evaluate a 'technical' savings indicator which can be used in an economic model to determine the actual convenience between the distribution policies.

At present, with the sole criterion of proximity, a first selection of lockers was made, although in fact two of them were not used. Introducing additional economic criteria (costs of activation, use, available budget) a more detailed targeted selection of them could be made. Selecting different lockers obviously also influences the 'technical' indicator of logistic-distribution savings, which must be re-evaluated accordingly.

From the viewpoint of externalities, these initial results will also allow us to assess CO2 emissions in the urban environment by simulating the routes of vehicle fleets for city deliveries. In both cases, using distances or time matrices, CO2 emissions decrease by more than 21% with the TO BE scenario; however, users' CO2 emissions, related to users-to-lockers movement, are not taken into consideration, since we assumed that, in any case, each user goes to the nearest lockers or along the itinerary usually followed.

The current model considers traditional types of transport operated with motor vehicles, and current trends in transport policy are increasingly oriented toward the use of electric vehicles in city centres to at least zero CO2 emissions locally. The model presented here may therefore be updated to take account of constraints arising from the use of electric vehicles when assessing delivery routes and the economic value of the solutions.

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