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'Pony express' crowdsourcing logistics for last-mile delivery in B2C e-commerce: an economic analysis

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The last-mile delivery is one of the most challenging logistics issues arising from B2C e-commerce. Companies operating online have to meet stringent requirements in terms of service level; moreover, the features of e-commerce orders – e.g. small dimension – make last-mile delivery the most expensive part of the delivery process. In this context, crowdsourcing logistics emerges as an innovative and promising solution: deliveries are assigned to a network of 'common' people through an open call. This solution may imply great advantages for the urban society. Nonetheless, in order to spread, it has to be economically sustainable for companies. In this regard, the paper investigates the economic profitability of a 'pony express' crowdsourcing logistics initiative in an urban area. A model has been developed in order to estimate the cost of deliveries using crowdsourced services, and to compare it with the cost of 'traditional' pony express couriers.

Keywords: crowdsourcing logistics, last-mile delivery, urban logistics, pony express, B2C e-commerce

1. Introduction

Business to consumer (B2C) e-commerce is nowadays gaining increasing importance in many countries and across different industries, and it is expected to grow also in the future (Mangiaracina et al. 2016). If compared to traditional offline retailing, B2C e-commerce opens new challenges, especially for companies selling products. As a matter of fact, the complexities of the physical distribution of products should not be underestimated, and among the different aspects contributing to the success of an e-commerce initiative, logistics plays a fundamental role. Online customers are indeed very demanding in terms of service level, and special attention is paid to performance indicators related to time (Davarzani and Norrman 2015), namely the timeliness - i.e. receiving the products within an established delivery time lapse (Hays, Keskinocak, and De López 2005) - and the delivery speed - i.e. minimising the time interval between the customer order and the delivery (Savelsbergh and Woensel 2016). This being the scenario, the logistics management, and in particular the management of the delivery process, gains a fundamental role: according to Vanelslander, Deketele, and Van Hove (2013), last-mile delivery costs may amount up to half of the overall logistic costs. Fast deliveries imply very high costs, and companies are not always able to bear them. Therefore, there is a search for new solutions that allow to increase the efficiency of the last-mile delivery (Mangiaracina et al., 2019), e.g. parcel lockers (Wang et al. 2014), delivery drones (Slabinac 2015) and – more recently – crowdsourcing (Wang et al. 2016).

In this context, among the alternative strategies and solutions that can be selected, the application of crowdsourcing to logistics emerges as an innovative and promising option (Wang et al. 2016). It is gaining the interest of academics, and recent contributions in this field are flourishing. Crowdsourcing can be intended as ‘the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (and generally large) network of people in the form of an open call' (Howe 2006). According to a later and more comprehensive definition (Estellés-Arolas and González-Ladrón-de-Guevara 2012), crowdsourcing is

> 'a type of participative online activity in which an individual, an institution, a non-profit organisation, or a company proposes to a group of individuals of varying knowledge, heterogeneity, and number, via a flexible open call, the voluntary undertaking of a task'.

The application of crowdsourcing to logistics, and in particular to the last-mile delivery process, thus consists into outsourcing the delivery of the goods to 'common' people that give their availability for bringing the parcel from a point of collection, generally a warehouse or a store, to a point of delivery. From the perspective of the people offering these services (often referred to as 'riders'), crowdsourcing logistics is an opportunity to earn money from a task that does not require a huge effort, since they usually have to move on a similar route for personal or working reasons. From the point of view of the final customer, crowdsourced deliveries are associated to a better service level, due to the high degree of operational flexibility entailed by this model. Considering the perspective of the merchants, crowdsourcing logistics could imply a great reduction in transport costs. In fact, companies do not have to pay for expensive services offered by traditional express couriers, since there are numerous people that may accept a lower remuneration (e.g. students, unemployed people). Therefore, it is interesting to better investigate the opportunities that crowdsourcing logistics, intended as a solution aimed at assuring fast deliveries in an efficient way, may generate for organisations.

This paper is organised as follows: section 2 presents the results of the literature review, section 3 defines the research objectives and the methodology, section 4 illustrates the model and its application, and section 5 summarises the conclusions stemming from the work.

2. Literature review

A review of the scientific literature was performed in order to investigate the state of the art related to the application of crowdsourcing logistics to last-mile delivery in B2C e-commerce. First, works addressing the last-mile delivery in B2C e-commerce were analysed, to provide a wider and deeper comprehension of this process and of the related issues. Second, a more focused step was accomplished about the implementation of crowdsourcing logistics in e-commerce, and more in detail as a last-mile delivery solution for B2C parcels.

2.1 Last-mile delivery

Last-mile delivery for B2C e-commerce – i.e. the delivery of products ordered online to the final customers (Lim, Jin, and Srai 2018) – opens new challenges for retailers with respect to the offline channel. The volumes handled are lower, the delivery frequency and the delivery speed are higher and, more in general, the order profile is different and less predictable (Savelsbergh and Woensel 2016). Moreover, there is the need to organise attended deliveries, i.e. the customers should be at home when the products arrive, or to find alternative solutions for collecting the products - such as parcel lockers (Wang et al., 2014) or collection points (Kedia, Kusumastuti, and Nicholson 2017). All these issues must be carefully considered especially by offline retailers switching to e-commerce, since they cannot simply replicate their logistics offline strategy in the online market (De Koster and Marinus 2014). Since there is not a general optimal strategy that can be applied in all the situations, different research works tried to analyse specific problems, and many of them focus on finding ways to increase the efficiency of the last-mile delivery process. Academics have addressed this search for efficiency by proposing three main types of solutions: (i) solutions optimising the traditional – i.e. by van, with no appointment – home delivery, (ii) alternative solutions to traditional home delivery, which are already used by companies (e.g. by-appointment deliveries, parcel lockers) and (iii) innovative technologically advanced solutions.

In the literature it is possible to find many contributions analysing solutions for the optimisation of traditional home delivery. Many authors propose different versions of the so called VRP (Vehicle Routing Problem), which consists in defining the optimal route to be chosen for delivering a given set of parcels (Wang et al. 2016). Some works define the changes that should be implemented in the structure of the distribution network in order to make B2C deliveries more efficient and effective, e.g. adding an echelon of transit points (Verlinde et al., 2014). Boyer, Prud'homme and Chung (2009) focus on the relation between the customer delivery density and the delivery cost, and they state that an increase in the customer delivery density positively impacts the last-mile delivery efficiency.

Considering the alternatives to traditional home delivery that have already been implemented to some extent, Agatz et al. (2013) recommend the by-appointment delivery. It consists in the prior arrangement of the time-slot in which the delivery will be performed, in order to avoid the occurrence of missed deliveries. Wang et al. (2014) analyse reception boxes (boxes installed at the customers' house in which parcels can be delivered), parcel lockers (boxes shared among different customers, usually grouped into structures located in public places where customers are able to retrieve their parcel using a one-time password) and pick-up points (institutions - like retail stores - providing storage services).

Recent literature also shows different contributions suggesting to introduce innovations that could help companies overcome the traditional limits (e.g. inability to saturate the vehicles), thus reaching better performances (Mangiaracina et al., 2019). These solutions are still in a preliminary phase: Slabinac (2015) proposes underground delivery, that relies on capsules containing the parcels moving within an underground pipeline system. Boysen, Schwerdfeger, and Weidinger (2018) study robots, i.e. self-driving road vehicles that, moving on determined and controlled paths, reach the customers, who unload the vehicle and retrieve their parcels. Dorling et al. (2017) focus on drones, which consist in Unmanned-Aerial-Vehicles that are able to travel from an origin to a destination relying on the on-board GPS; once the destination is reached, the container is dropped off.

Among the possible solutions that can be implemented in order to face B2C e-commerce last-mile delivery issues, crowdsourcing logistics emerges as a very promising option. On the one side, the interest of practitioners is proven by the presence of different successful initiatives, such as Amazon Flex (Arslan et al. 2018). On the other side, crowdsourcing logistics is gaining increasing attention in the academic community, and contributions are flourishing (e.g. Lin et al. 2018; Qi et al. 2018).

2.2 Crowdsourcing logistics

In the literature, it is possible to find different qualitative papers aimed at depicting a general framework about crowdsourcing logistics. Carbone, Rouquet, and Roussat (2015) propose a classification matrix identifying four logistics models, each one characterised by a different degree of maturity, that differ in terms of two variables: the level of centralisation of logistics management (centralised vs. decentralised) and the type of relationship between logistics and collaboration (logistics as supporting collaboration or as the purpose of the collaboration). The most innovative ‘Crowd-Party

Logistics' solution is characterised by a decentralised logistics management coupled with the definition of logistics as the purpose of the collaboration. Another framework by Carbone, Rouquet, and Roussat (2017) distinguishes instead among four types of crowd logistics based on the nature of the provided services: crowd storage, crowd local delivery, crowd freight shipping and crowd freight forwarding. The main difference among the last three options refers to the distance covered, which may be local (crowd local delivery), domestic and continental (crowd freight shipping), or intercontinental (crowd freight forwarding).

Crowdsourcing logistics appears to be a very promising option to be implemented in B2C e-commerce last-mile deliveries, since it allows to reach very high performances in terms of both efficiency and effectiveness. Accordingly, this solution has gained the interest of academics, who have identified and analysed different alternative models (Table 1) according to which crowdsourcing may be applied to the last-mile delivery.

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The first model consists in completely for-free deliveries, in which people collect and deliver parcels for friends or acquaintances, typically making a very little detour from their original route (Devari, Nikolaev, and He, 2017; Suh, Smith, and Linhoff, 2012). The second model still has mainly social scopes: a platform coordinates people that accomplish occasional deliveries, usually bringing parcels to members of their community. For instance, there may be the delivery of books among library regulars (Paloheimo, Lettenmeier, and Waris, 2016) or of parcels among university mates (Kim, 2015). Both these models provide great benefits from a social perspective.

Even in cases of no remuneration (Devari, Nikolaev, and He, 2017), crowdsourcing logistics initiatives may be successful if they are based on reciprocity and community building values. Accordingly, two pilot projects found in the literature show as, in some peculiar contexts, this phenomenon is strictly linked to the shared profound sense of community. In the deliveries from the Finnish library studied by Paloheimo, Lettenmeier, and Waris (2016), the social cohesion allowed to avoid security or legal issues, and prevailed on both the low compensation and the potential lack of trust in giving own products to strangers. The other initiative took place among students in Illinois (US), and it was based on a mobile application aimed at collecting delivery requests and assigning them to available people. Also in this case, the success came from social reasons, such as reciprocity and community building, as the students involved collected the parcels primarily to help their busy friends (Kim, 2015). Since there is a huge interest in the environmental impacts of the physical distribution of products ordered online (Mangiaracina et al. 2016), some authors have also investigated the potential contribution of these crowdsourcing logistics models in reducing gas emissions. Academics show a general consensus about the positive effects of this solution on the environment, and different works have attempted to quantify the benefits in different specific contexts. According to Suh, Smith, and Linhoff (2012), crowdsourced deliveries lead to a decrease in the amount of the CO_2 emissions with respect to traditional ones, and the reductions can reach 94% in urban areas and 82% in suburban areas. Devari, Nikolaev, and He (2017) estimate that, in case shipments are assigned to friends or acquaintances of the recipient, the volumes of pollutants (NO_x, PM2.5 and PM10) emitted by delivery vehicles led by crowdsourcing logistics are 55% less with respect to 'traditional couriers'. In general, these positive effects on the environment are linked to the fact that crowdsourcing initiatives usually rely on ‘common’ people that would move even if the task was not assigned to them: thus, there is a lower total number of vehicles needed and carbon emissions are consequently lower (Wang et al. 2016).

The third B2C crowd local delivery model may be seen as a ‘hybrid’ solution combining traditional and crowdsourced deliveries. More in detail, an e-commerce player integrates the own van fleet with a group of occasional riders, who still deliver parcels in small quantities, and typically not deviating too much from their original route (Dahle, Andersson, and Christiansen 2017; Macrina et al. 2017). This solution has gained the interest of academics, and different contributions may be found in this direction. There are many works aimed at quantifying the economic positive impact of this option if compared to traditional deliveries. Beside traditional transport means, different authors have also recently addressed the implementation of this solution based on the use of alternative modes. Chen et al. (2014) propose applying crowdsourcing logistics to last-mile deliveries relying on the use of taxis, as an option that may lead to lower costs for shipping companies, thus allowing to offer lower prices to the final customers. Wang et al. (2016) rather show the more specific application of a large-scale mobile crowd tasking model - i.e. a crowdsourcing initiative involving a large pool of citizens and relying on mobile devices - based on buses and taxis in Singapore and Beijing areas. Some other authors focus instead on the analysis of variables and parameters that could affect the achievement of these cost reductions, such as the uncertainty about the dynamic appearance of drivers during the day (Dahle, Andersson, and Christiansen 2017) or the possibility to set time windows (Macrina et al. 2017).

A fourth crowd local delivery model, which is less investigated in literature, implies instead the composition of an ad-hoc fleet of riders, whose operations are centrally coordinated and optimised in order to meet great efficiency levels, e.g. to reach a higher transport mean saturation (Chen, Mes, and Schutten, 2018). On the one side, this type of model may allow to reduce the cost of the delivery phase; on the other side, it creates opportunities to improve effectiveness performances, offering the customers fast deliveries (Chen, Mes, and Schutten, 2018). Moreover, the schedule of riders allows to gain great advantages in terms of flexibility (Kafle, Zou, and Lin, 2017). This model may assume different configurations, e.g. the multi-parcel option (in which one rider typically delivers a high number of parcels), and the pony express option (in which one rider is associated to one or few – typically urgent – deliveries).

In general, according to many authors, crowdsourcing may allow to grant the required shipping fastness at affordable costs, and it could create a source of competitive advantage for retailers operating in the e-commerce arena. Moreover – according to both academics and practitioners – it does not only entail efficiency and effectiveness benefits, but it may also have, to different extents according to the specific model applied, remarkable social and environmental implications. Nonetheless, this promising solution may take several forms. Even if different authors have been dealing with this last-mile delivery option, there is still great room for addressing issues associated to specific applicative models with peculiar characteristics.

More in detail, an option that appears to be very interesting to investigate is the fourth crowdsourcing logistics model, and more in detail the ‘pony express’ configuration: it is characterised by express and super-express deliveries (usually associated to urgent occasional customer orders), one – or few – order per rider and different dispersed points of origin. In this model, in order to preserve the ‘social’ element of crowdsourcing, riders – who are not friends/acquaintances nor community-mates, but typically occasional employees – may decide whether to give their availability for accomplishing a specific delivery task. This solution seems to be very promising for the B2C e-commerce scenario, in which customers are increasingly demanding for very low delivery times – or even “instant” deliveries (Dablanc et al., 2017) – and it may lead great potential advantages in many directions.

First, it may significantly increase the delivery service level. As a matter of fact, the use of online platforms is typically associated to the exploitation of advanced potentialities, e.g. geo-localisation services, real-time order collection (Rai et al., 2017; Rougès and Montreuil, 2014). Moreover, such a model could allow to grant stringent service level targets while leveraging on riders dispersed over the city, who could thus be very close to the points of origin. Second, this model may have positive social effects. In fact – as other paradigms – it allows to create a real ‘value proposition for the crowd’, since it offers flexible work opportunities to earn extra incomes (Vecera and Pribyl 2017). In addition, it could reduce gas emissions. Riders that already have to move for personal/working reasons will tend to accept a delivery task that implies only a short deviation from their route. In this case, the overall number of travelling vehicle could decrease (riders would move anyway), and the overall travelled distance could be reduced (riders would have travelled a part of the path independently from the delivery) (Wang et al. 2016). Though, this potential advantage strictly depends on the detour the riders have to make with respect to their original path.

Based on these premises, this solution seems to be very promising. Nonetheless, in order to adopt it as a real alternative to traditional deliveries and to foster its diffusion, companies need to evaluate the economic implications of implementing this type of crowdsourced deliveries. Accordingly, both the academic and the managerial communities could benefit from an evaluation of the cost reduction that its implementation may entail for retailers operating online, and opportunities for research in this direction are open.

3. Objectives and methodology

Recent contributions in the extant literature mention crowdsourcing logistics as a promising alternative to traditional express couriers for delivering products in the B2C e-commerce context, as it could imply great advantages for different players. As a matter of fact, according to the specific implemented model, it actually seems to be an option that may reduce the number of travelling vehicles and offer flexible working opportunities and remuneration to many people. Though, in order to spread, it has to entail also economic benefits for companies. In particular, it is interesting to investigate the applicability and profitability of crowdsourcing logistics as a last-mile delivery option for companies selling products online, to provide express and super-express deliveries starting from different points of origin within a city.

Based on these premises, this paper describes an original quantitative model aimed at estimating the cost of deliveries performed through 'pony express' crowdsourcing logistics, and at comparing it with the case of traditional pony express couriers. More specifically, this works attempts to answer the following research question: 'what is the average cost for a B2C e-commerce delivery performed through crowdsourcing logistics in an urban area, if compared to a traditional one performed by pony express couriers?'.

In order to answer this research question, the work was structured in four main steps. First, a literature analysis was performed to explore the existing contributions on the subject of interest, i.e. crowdsourcing logistics for B2C e-commerce last-mile delivery. Second, a model aimed at estimating the average cost of a crowdsourced delivery in a city area was developed and applied to the city of Milan (Italy), in order to perform a comparison with the use of pony express couriers. A reference dataset was created with some representative city coordinates and, relying on the support of Google

Maps, the routes among them were found and the associated time values were defined. Then, an algorithm was developed that, based on the reference time dataset, associates an expected delivery time to each couple of point of origin (rider) and point of destination (customer). Starting from these values, the delivery cost was estimated. The selection of Milan for the model application is due to two main reasons: on the one hand, some crowdsourcing initiatives (e.g. Glovo) are actually implemented there; on the other hand, B2C e-commerce is already quite widespread, and Milan could thus benefit from the implementation of this solution. Third, some sensitivity analyses were performed, aimed at evaluating the robustness of the achieved outcomes and the reliability of the model itself. Fourth, the economic profitability for the riders was evaluated by comparing the incomes earned for accomplishing a delivery and the costs faced to perform it.

4. The model

4.1 Model development

The model consists of four main elements: (i) the inputs, i.e. the variables of the last-mile delivery problem, (ii) the context data, i.e. the parameters describing the context, (iii) the algorithm, i.e. the set of computations to estimate costs, and (iv) the outputs. The model provides two main outcomes: the average delivery costs of a delivery performed by the crowd and the unavailability rate of the riders, intended as the percentage of riders that, even if available, are not eligible for the delivery because they are not able to perform it.

This work focuses on express and super-express deliveries. Accordingly, two main hypotheses were defined.

(i) The benchmark to which the cost of crowdsourcing logistics is compared, in order to identify the cheaper alternative, is represented by pony express couriers. They are operators that provide express urban delivery services to both companies and consumers, to which retailers may outsource the very last stretch of the transport phase (e.g. *Delivery Agency*, *Bici couriers*, *Pony zero*, *Urban Bike Messengers*). More in detail, the cost is evaluated by considering the amount of money paid by online retailers for this delivery service. Accordingly, the scope of the model is the very last stretch of the delivery phase, i.e. from the delivery starting point in the urban area to the customer's home. As a matter of fact, this is the only transport phase that is differential between the crowdsourcing logistics and the pony express cases.

(ii) Deliveries start from a point within the city area. Being able to offer express deliveries (and this is particularly true for the 1-hour and 2-hour options) needs this point to be in the city, otherwise the stringent service level cannot be met (Dablanc et al., 2017). The starting point is often a store (e.g. pharmacies for drugs delivery), whose replenishment process is independent from the online order (and anyway much less expensive than the last-mile delivery). These points will be referred to as delivery starting points (DSP).

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4.1.1 Input variables

The input variables are six.

(1) The dimension of the crowd, i.e. the number of available riders.

(2) The position of the riders (2a) and of the customers (2b) that are respectively the geographical coordinates of the points of origin and of the final destinations to be reached.

(3) The vehicles used by riders (among the allowed ones - i.e. foot, bike, motorbike and car).

(4) The weight of the parcel, that is fundamental to decide whether the delivery can be performed, and through which vehicle (due to the existing legal health constraints).

(5) The required service level, intended as the maximum time between the order and the delivery. The model considers three possible alternatives (one hour, two hours or same day), which were selected based on the offer of different companies operating online.

4.1.2 Context data

The context parameters are five.

(1) The fees of the riders (Table 2). They are computed as the sum of a fixed part, linked to the delivery accomplishment, and a variable one, related to the time needed. The hourly wages increase when the service level becomes more demanding, in order to avoid opportunistic behaviours. The main reasons behind the choice of this dual remuneration system are three. First, recent scientific contributions highlight the importance of considering not only the fixed part, but also a variable one (Wang et al., 2016; Chen, Mes, and Schutten, 2018), thus remunerating riders both based on the delivery accomplishment and on the travelled distance (Arslan et al., 2018; Qi et al., 2018). Second, interviews with operators highlighted that this type of fee is the one actually used by many

crowdsourcing logistics players (e.g. *Deliveroo, Doordash*). Third, defining this type of fee implies greater flexibility in future possible applications of the model to different contexts. For instance, if the model is applied to crowdsourcing initiatives that remunerate the riders only based on the accomplished deliveries, it is possible to set the variable component to 0.

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(2) The costs faced by the riders to accomplish the delivery. These costs (Table 3) were computed only for cars and motorbikes, while for bikes and foot they were considered negligible. They include both the variable (fuel, transport mean usage and maintenance) and the fixed costs (insurance, taxes).

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(3) The legal weight lifting limits, i.e. the maximum weight a person is allowed to carry without the risk of incurring in health damages. They depend on the transport mean used. Based on current regulations, the limits were set to 5 kg for riders on foot, to 10 kg for riders moving by bike or motorbike, and to 15 kg for riders driving a car.

(4) The delivery fares of pony express couriers. These costs (Table 4) (i.e. the amount online retailers pay pony express for the delivery service) were empirically derived as the average among the values referred to the main players operating in the market. More in detail, data about the prices proposed by 20 players operating in Milan were collected combining both the analysis of

secondary sources (e.g. websites of pony express couriers, journals of logistics practitioners, reports) and interviews with practitioners. For each of the three considered service level, the cost has been computed as the average among the values referred to those players.

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(5) The coordinates for the locations of the riders, the customers and the delivery starting points. Milan area has been represented using 100 possible locations/addresses ($L_1 \ldots L_{100}$), not evenly distributed: a higher number of locations was assigned to the districts with the highest population densities. The algorithm randomly generates possible rider's and customer's locations that are taken as inputs for the model, which are then associated to one of these 100 locations. In addition, 10 couples of coordinates were selected as potential locations for the delivery starting points in which the parcels are stored, and where they have to be collected by the riders before being delivered.

4.1.3 Outputs

The main outputs provided by the model are two.

(1) The average cost for a delivery performed through the crowdsourcing logistics solution. It is computed as the average among the costs associated to the eligible riders, i.e. those riders who meet the whole set of constraints (transport mean, weight and service level). The reason why the considered value is the average – and not the lowest – cost, is tied to the logic behind many 'pony express' crowdsourcing platforms. Once a delivery has to be performed, it is not directly

assigned only to one – i.e. the ‘cheapest’ – rider, but the call is shared with different available users. In this way, riders have higher flexibility in deciding how to organise and schedule their tasks (social component of crowdsourcing).

(2) The unavailability rate of the riders. It represents the ratio between those available riders that are not eligible for the delivery completion, since they do not meet all the constraints, and the total number of riders in the crowd. If the unavailability rate is high, it means that there are a lot of riders that are willing to deliver, though the majority of them is not able to perform the task.

4.1.4 Algorithm

The algorithm works following two main steps. The first step is the model initialisation: the distances among the potential representative points of origin (riders) and points of destination (customers) are computed, and the travel time is estimated. The results of this step can be used in different delivery problems (i.e. problems with different points of origin and of destination). The second step, which has to be repeated for each delivery problem individually, is the rider definition: for each rider (among the eligible ones), 10 delivery costs are computed considering the 10 points of origin in which the parcel could be picked up, and the average cost is evaluated; then the riders with the lowest costs may be selected. Both the average delivery cost and the unavailability rate of the riders are computed.

First step: model initialisation. As stated in section 4.1.2, some representative coordinates for the points of origin (riders) and points of destination (customers) were selected, so that any possible rider’s and customer’s location – taken as an input for the model – can be associated to the nearest one among them. The initialisation consisted in creating a delivery time dataset that associates to each representative rider-customer couple of points the average distance to be travelled to perform a delivery, and the related delivery time (one for each transport mean).

For each rider(R)-customer(C) couple of points, there are 10 possible itineraries, that correspond to the 10 alternative delivery starting points (DSP), where the rider may have to go before reaching the customer (for path R1C1: R1DSP1C1, R1DSP2C1, …, R1DSP10C1). For reducing the complexity of the model, the delivery time associated to each rider-customer combination was computed as the average among the time related to the ten alternative itineraries (delivery time for path R1C1 found as the average among: time for itinerary R1DSP1C1, time for itinerary R1DSP2C1, …, time for itinerary R1DSP10C1). The same reasoning was repeated for each of the 10,000 possible rider-customer combination (R1C1, R1C2, …, R1C100, R2C1, R2C2, …, R2C100, … R100C100), thus allowing to create a complete delivery time dataset for all the possible rider-customer combinations (an example is displayed in Figure 2).

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Take in Figure 2

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The travel time estimation was made through the support of Google Maps, but implementing some adjustments: for motorbikes and foot, data suggested by the software were not modified, while for cars and bikes corrective factors were used. Time by car was computed multiplying motorbike time by 1.5 in order to consider the negative effect of traffic. Time by bike was instead estimated considering an average speed of 15 km/h. These computations allowed to estimate the average time needed to deliver a parcel from a representative rider's location to a representative customer's location in Milan area, whatever the transport mean of the rider is.

Two hypotheses were considered in this step of the model development. First, no waiting time for the riders at the delivery starting point is considered: when they arrive, the parcel is ready to be collected. Second, no failures are contemplated, neither for the eligible riders, who are always able to complete the delivery, nor for the customers, who are at home waiting for the parcel, thus avoiding unattended deliveries.

Second step: Rider definition. The second step of the algorithm associates to a specific delivery problem (i.e. real coordinates of the available riders and of the customer, required service level and weight of the parcel to be delivered) the related solution. Within this process, four main phases may be identified.

(1) Representative coordinates selection - The first process is performed by the algorithm before associating the rider to the customer, and it finds the representative locations (among the 100 ones selected to define Milan) that best describe the position of the riders and of the customer. It thus consists in associating to each input location – for both the riders R_i and the point of destination (i.e. the customer) C – the nearest one among Milan representative coordinates (that will then be taken as its proxy). Considering each rider R_i, his/her position is associated to a location L_j (x_{Lj}; y_{Lj}) belonging to the representative ones; more in detail this location is the one – among the 100 – minimising the distance d from the considered point (R_i: x_{Ri}; y_{Ri}).

$$d = \sqrt{(x_{Ri}-x_{Lj})^2 + (y_{Ri}-y_{Lj})^2} \cdot k^1.$$

The same process is repeated for each available rider R_i and for the customer C. At the end, the positions of all the riders and of the customer are expressed in

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[1] k = 69 · 1609. The 69 corrective factor allows to switch from coordinates to miles, while 1609 from miles to kilometres.

terms of a set of representative locations.

(2) Delivery time and costs estimation - Once all the representative coordinates are defined, the algorithm assigns to each rider-customer couple the delivery time, relying on the reference time dataset defined during the initialisation. Accordingly, the fare of the rider for performing the delivery is then computed – based on the required service level and on the time needed – as:

$$\text{Delivery cost} = \text{Fixed fee}\left(\frac{\text{€}}{\text{delivery}}\right) + \text{Hourly wage}\ \left(\frac{\text{€}}{\text{h}}\right) \cdot \text{Delivery time}\ \left(\frac{\text{h}}{\text{delivery}}\right).$$

Input data are displayed in section 4.1.2.

(3) Constraints check - In order to exclude not eligible riders, i.e. those who are not able to accomplish the delivery, two constraints are checked for all the candidates. First, the weight of the parcel is evaluated. It has both to be lower than the generic maximum limit (15 kg) and to meet the constraint associated to the specific transport mean, otherwise the rider is rejected. Second, there is the service level check. The estimated time needed by the rider to complete the delivery (with the associated transport mean) must be lower than the maximum time required by the customer; if not, the rider is rejected.

(4) Riders' evaluation - Finally, all the available riders (and their delivery costs) are progressively evaluated. For each rider, the delivery cost is compared with that of the reference rider, i.e. the 'most economical' one until that time: if the delivery cost of the current rider is lower, this rider becomes the new reference one, to which the next ones will be compared. The procedure is iterated for all the available riders, and it stops when all of them have been considered. Ideally, the delivery should be assigned to the last reference rider, who is the one able to

perform the delivery at the lowest cost. If there are no riders responding to the requirements, the result of the model is null, meaning that the specific last-mile delivery problem cannot be solved relying on the available crowd. Besides the selected rider, the model provides as outputs both the average cost for performing the delivery and the unavailability rate of the crowd in the considered case.

4.2 Model application

After its development, the model was applied. More in detail, the application considered 100 randomly selected Milan addresses as final destinations and 100 randomly selected Milan addresses as locations of available drivers (each of them evaluated for each of the customers' locations); for those combinations, all the three standard service levels (same day, 2 hours and 1 hour) were evaluated one at a time.

4.2.1 Inputs

Data about the considered parcel weight distribution (determined taking into account the distribution of the weights in the B2C e-commerce market) and vehicle mix (in which bikes and motorbikes are the two most diffused means of transport to perform express home deliveries) are shown in Table 5 and 6. These distributions were derived combining both the analysis of secondary sources (e.g. e-commerce websites, journals of logistics practitioners, reports) and interviews with e-commerce players (retailers and logistics service providers).

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Take in Table 5

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Take in Table 6

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Therefore, in the end, the model was run for 100 riders for each of the 100 customers, and for all the three service level options.

4.2.2 Results

The results of the model application are shown in Table 7.

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Take in Table 7

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First, the average cost for each delivery, computed as the average among the costs associated to the eligible riders – i.e. those meeting all the constraints for that delivery – was found. Then, the overall average crowdsourcing delivery cost was calculated for each value of the service level, as the average among the computed average costs of the different deliveries. Considering this average delivery cost, it is always lower than that of pony express couriers: performing the delivery through crowdsourcing logistics is less expensive for any service level option.

Besides the average cost, the maximum delivery cost, i.e. the cost associated to the most expensive delivery, was highlighted for each service level option, in order to evaluate also the worst scenarios of the crowdsourcing logistics option. For the 1 hour and 2 hour deliveries, also this cost is lower than that of pony express couriers: even if the delivery is ‘expensive’, crowdsourcing logistics is still convenient if compared to pony express couriers. When considering the same day delivery instead of the 1 or 2 hour options, the cost for pony express couriers becomes lower, and crowdsourcing is the best solution only if the delivery can be assigned to riders that are close to the final destination.

For what the unavailability rate is concerned, the ratio between those available riders that are not eligible for the delivery completion, since they do not meet all the constraints, and the total number of riders in the crowd was computed for each delivery. Based on these values, an average rate was then calculated for each service level option. The results show that the unavailability rate increases as much as the service level becomes more stringent: this is due to the fact that more restrictive time requirements imply lower probabilities for a rider to meet all the constraints.

The model does not evaluate of the ‘original destination’ of the riders, which would allow to compute the detour the rider should undertake from the original path in case he/she completes the delivery. The value of this detour could affect the willingness to perform a delivery task, and more in general the unavailability rate of the riders. Despite this estimation is not included, the sensitivity analyses performed on the number of riders do partially indirectly take this issue into consideration.

4.3 Sensitivity analyses

Two sensitivity analyses were performed in order to test the robustness of the results, and to evaluate the effects on the outcomes of possible changes in the considered scenario, for both the number of riders and the vehicle mix. As a matter of fact, both the availability of riders during the day (Dahle et al., 2017) and the considered transport mean (Kafle, Zou, and Lin, 2017) may strongly affect the performances of a crowdsourcing logistics solution.

4.3.1 Number of riders

In the base case scenario 100 riders were supposed to be available for each delivery call; nevertheless, it may sometimes happen that – in some moments during the day – there is a lower number of riders that are ready to accept the task. An analysis was thus performed in order to identify the consequences of a potential decrease in the dimension of the crowd on the found results. The expectation was that a decrease in the number of drivers would have corresponded to an increase in the unavailability rate, and to an increase in the delivery costs. The increase in costs would be due to the fact that the lower the number of eligible riders, the lower the probability that they are near to the point of destination, thus requiring a higher travel time.

The model was run with 4 different crowd dimensions (20, 40, 60 and 80 riders) for each of the three considered service levels, in order to test the presented hypotheses and to evaluate the variations in the average cost and in the unavailability rate.

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Take in Table 8

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The results (Table 8) show how, contrary to expectations, a lower number of riders implies a very limited cost variation. If comparing the base case with the case of 20 riders, an 80% decrease in the number of riders causes a 0.51% cost increase for the 1 hour delivery (+0.44% for 2 hours and +1.79% for the same day deliveries). The economic performances of a crowdsourced delivery are thus only slightly affected by a reduction in the dimension of the crowd. Considering instead the unavailability rate, it remains nearly the same as the base case scenario: it means that the number of not eligible riders (numerator of the index) decreases nearly proportionally to the total number of riders (denominator of the index), thus not showing high impact of the implemented changes.

Based on the above, the outcome of the model application appears to be robust enough with respect to the crowd dimension.

4.3.2 Vehicle mix

Variations in the vehicle mix were considered in order to evaluate their effect on the obtained outcomes. Indeed, the transport means impact the results of the model, since different means are associated to different time performances; moreover, also the weight constraint depends on them.

The model was thus applied to four differently composed crowds, each one characterised by the presence of one type of vehicle only, and then to a fifth one composed by half of the drivers riding a motorbike and half riding a bike. The reason behind this last choice is that pony express usually relies on these two transport means.

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Take in Table 9

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The results (Table 9) show how the crowd composed by motorbikes only has the best performances, followed by the one combining bikes and motorbikes. After these two, there is the vehicle distribution of the base-case scenario. This shows how accepting only motorbikes – or half motorbikes and half bikes – would be the most efficient choice; nonetheless, it would drastically reduce the number of potential riders excluding many potential candidates. Crowds with riders only driving cars or only riding bikes are less efficient than the base case scenario, but the worst option is the ‘Foot’ one: not only it costs much more than the base case, but it does not allow to complete the delivery in two service level alternatives (1 hour and 2 hours).

Considering the comparison with pony express couriers, all the considered alternatives keep granting lower delivery costs for any service level. Also in this case, the only exception is represented by the only-foot crowd. The analysis shows how the variations in the vehicle mix do not have a strong impact on the results obtained through the model application, except for the case in which all the riders move on foot: for this option the crowdsourcing initiative would be both less efficient and less effective than traditional logistics. Nonetheless, this scenario is very unlikely to happen, and it could occur only in case the attendance to the crowdsourcing initiative is very low.

The results of both the sensitivity analyses are aligned with those of the base case scenario. Therefore, in most of the considered cases, a delivery performed in Milan through a crowdsourcing logistics initiative would be less expensive if compared to one offered by pony express couriers.

4.4 Riders

Results show a higher level of efficiency when implementing a crowdsourced delivery with respect to the case of the pony express couriers. Accordingly, this last-mile delivery solution is likely to be beneficial also for customers, since the reduced delivery cost may result in lower delivery prices offered by retailers. Nonetheless, the other player whose perspective needs to be analysed is the rider. As a matter of fact, if the incomes earned for accomplishing a delivery are lower than the costs faced to perform it, he/she will not participate to the crowdsourcing initiative.

As stated in section 4.1.2, the considered costs are those faced by riders driving a car or riding a motorbike. Therefore, the analysis of costs and incomes was performed for the only-car and only-motorbike crowds (since they are the two most significant cases if considering the riders’ economic perspective).

In order to perform it, a hypothesis was set (based on the analysis of real cases): the amount of money paid by the retailers is not completely assigned to the rider, but a commission is withdrawn by the online crowdsourcing platform.

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Take in Table 10

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Take in Table 11

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Table 10 and table 11 show – for the motorbike and the car cases respectively – the average delivery profit for the rider, i.e. the amount of money he/she may earn if performing a delivery. It is computed while subtracting the platform fee and the delivery expenses of the rider (i.e. the amount paid by the rider to perform the delivery) to the delivery cost of the merchant (i.e. the cost an online retailer incurs in for a crowdsourced delivery, as computed in section 4.3.2).

In both the scenarios, the costs faced by the riders are lower than the income, for any service level option. This result proves that the crowdsourcing logistics model applied in this paper is feasible, since riders – even if relying on the most expensive transport mean – will tend to give their availability for performing the delivery. Considering the transport mean, the motorbike is associated to higher profits with respect to cars. Focusing instead on the service level, profits are higher for more stringent targets. This result is in line with the expectations, since express deliveries are associated to higher wages. The lowest profits are those of the same day deliveries; nonetheless, in this case, riders have a higher degree of freedom in scheduling the deliveries during the day in the most convenient way, so that they can earn more.

5. Conclusions

This paper studies the ‘pony express’ crowdsourcing logistics model applied to the B2C e-commerce last-mile delivery in urban areas, with special focus on urgent orders; this solution implies different advantages. From a social perspective, even if some doubts have been raised about its potential negative effects, it represents a flexible working opportunity. From the customer perspective, implementing crowdsourced deliveries could create opportunities to improve service level performances, offering fast deliveries at affordable costs. Nonetheless, in order to fully obtain the benefits, this last-mile delivery solution has to spread. The players that are able to make the difference in fostering its diffusion are retailers operating online, which may choose to implement this solution for delivering B2C parcels. This being the premise, this paper proposes a model for evaluating the economic benefits of crowdsourcing deliveries.

This work provides both theoretical and practical contributions. On the academic side, it deepens a topic for which there are still open research gaps. As a matter of fact, it presents the development and the application of a model aimed at estimating the average cost of an urgent delivery performed through a ‘pony express’ crowdsourcing initiative in an urban area, and at comparing it with the cost of a traditional pony express delivery. On the managerial side, the model constitutes a practical tool for B2C e-commerce companies and for traditional retailers moving online. In this context, practitioners who need to select the last-mile delivery option may rely on the proposed analyses in order to make a comparison between traditional and crowdsourcing logistics delivery costs. Moreover, the model is general, since it does not impose stringent constraints, and scalable; it can be easily adapted to different situations (e.g. specific industries).

This work has some limitations that could be overcome through further future research efforts. First, the model focuses only on Milan area. Practitioners interested in evaluating the cost for crowdsourcing deliveries in other contexts should perform the initialisation and the application steps in other scenarios. Second, the number of addresses considered while defining Milan representative coordinates – for the riders’ and customers’ locations, but even more for the delivery starting points, whose number and positions are fixed – is limited. This consideration suggests sparks for future developments, that could be aimed at increasing the number of representative coordinates, thus enhancing the time dataset. Moreover, improvements could be applied to make the position of the delivery starting points an input variable, that may change in accordance with the specific delivery problem considered. Third, the only considered vehicles are bikes, motorbikes and cars; public transport could though be included in the analysis as an alternative for the walking riders. Fourth, the model does not include the evaluation of the original destination of riders, which affects the entity of the detour they have to undertake with respect to their initial path to accomplish the delivery. Future research could be aimed at including this computation, and at accordingly estimating its impact on both the unavailability rate of the riders and the environmental effect of this crowdsourcing logistics model.

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Crowd local delivery model	Main references	Crowd composition	Main advantages
For-free deliveries	Devari, Nikolaev, and He, 2017; Suh, Smith, and Linhoff, 2012	Friends or acquaintances	Social, Environmental
Community deliveries	Kim, 2015; Paloheimo, Lettenmeier, and Waris, 2016	Community members	Social, Environmental
Hybrid deliveries	Dahle, Andersson, and Christiansen 2017; Macrina et al. 2017	Employees	Economic
Ad-hoc fleet deliveries	Chen, Mes, and Schutten, 2018; Kafle, Zou, and Lin, 2017	Employees	Economic, Effectiveness

Table 1: Crowd local delivery models

Service level	Fixed component	Variable component
1 hour	3 €	6 €/hour
2 hours	3 €	4 €/hour
Same day	3 €	2 €/hour

Table 2: Fees of the riders

Motorbike	0.11 €/km
Car	0.2 €/km

Table 3: Transport mean cost per kilometre

Pony express delivery cost [€/delivery]	1 hour	2 hours	Same day
Average	16.83	12.89	8.43

Table 4: Average delivery fares of pony express couriers

Parcel weight	5 kg	5-10 kg	10-15 kg
Percentage distribution	60%	30%	10%

Table 5: Distribution of parcels weight

Vehicle	Bike	Motorbike	Car	Foot
Percentage distribution	40%	30%	20%	10%

Table 6: Vehicle mix

	Crowdsourcing logistics			Pony express cost [€/delivery]
Service Level	Average cost [€/delivery]	Max cost [€/delivery]	Unavailability rate [%]	
1 hour	7.8	8.9	42.85	16.83
2 hours	6.54	9.52	18.29	12.89
Same day	5.04	9.84	11.42	8.43

Table 7: Outcomes of the model application

Number of riders	1 hour		2 hours		Same day	
	Average delivery cost [€]	Unavailability rate [%]	Average delivery cost [€]	Unavailability rate [%]	Average delivery cost [€]	Unavailability rate [%]
Pony express	16.83	-	12.89	-	8.43	-
100 (base case)	7.8	42.85	6.54	18.29	5.04	11.42
80	7.8	42.40	6.54	17.70	5.1	11.68
60	7.8	42.32	6.55	17.88	5.1	11.83
40	7.82	41.60	6.55	17.63	5.11	10.65
20	7.84	43.35	6.57	17.22	5.13	10.60

Table 8: Results of the sensitivity analysis on the number of riders

Vehicle mix	1 hour		2 hours		Same day	
	Average delivery cost [€]	Unavailability rate [%]	Average delivery cost [€]	Unavailability rate [%]	Average delivery cost [€]	Unavailability rate [%]
Pony express	16.83	-	12.89	-	8.43	-
Base case (40% bike, 30% motorbike, 20% car, 10% foot)	7.8	42.85	6.54	18.29	5.04	11.42
Foot	-	100	-	100	9.81	39.39
Bike	8.46	42.82	6.89	10.08	4.94	10.02
Motorbike	7.07	9.87	5.71	9.79	4.36	10.39
Car	8.87	59.69	7.07	2.98	5.03	3.18
50% Bike, 50% Motorbike	7.55	27.01	6.29	9.97	4.65	9.86

Table 9: Results of the sensitivity analysis on the vehicle mix

	Delivery cost (merchant) [€/delivery]	Platform fee [€/delivery]	Delivery expenses (rider) [€/delivery]	Delivery profit (rider) [€/delivery]
1 hour	7.07	0.71	1.36	5
2 hours	5.71	0.57	1.36	3.78
Same day	4.36	0.44	1.36	2.57

Table 10: Riders economic analysis, motorbike case

	Delivery cost (merchant) [€/delivery]	Platform fee [€/delivery]	Delivery expenses (rider) [€/delivery]	Delivery profit (rider) [€/delivery]
1 hour	8.87	0.89	4.31	3.67
2 hours	7.07	0.71	3.82	2.54
Same day	5.03	0.5	3.26	1.27

Table 11: Riders economic analysis, car case

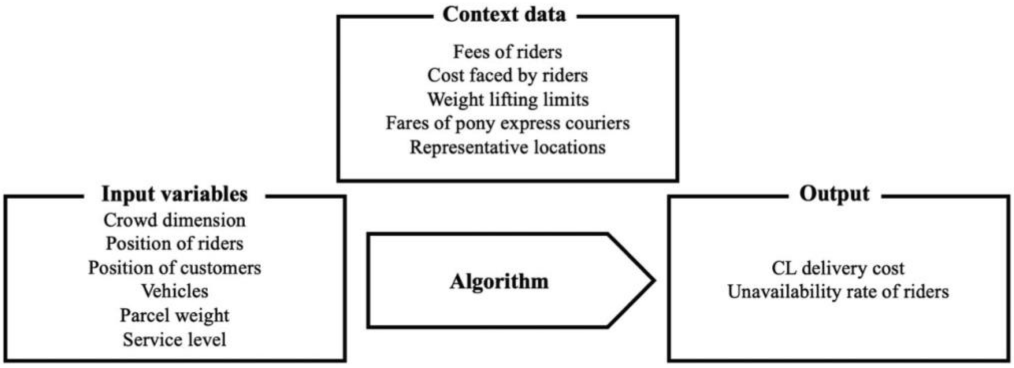
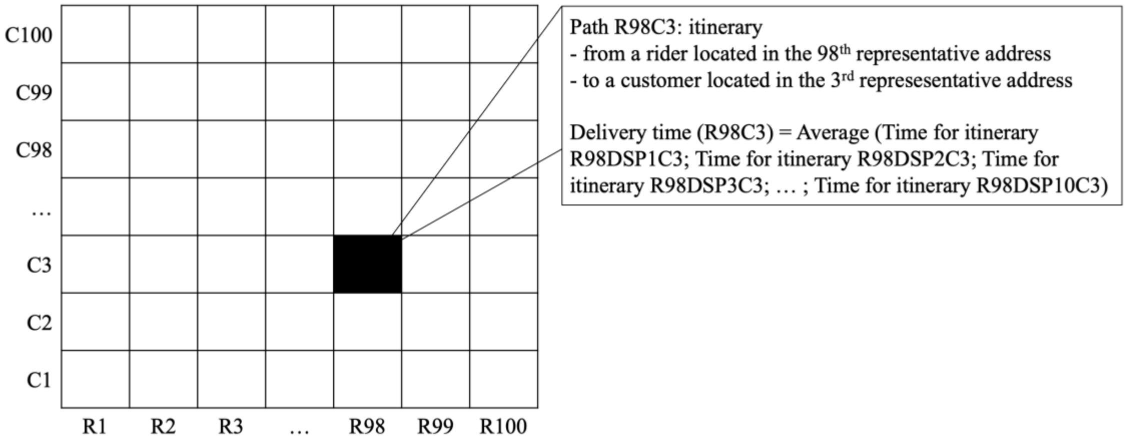


Figure 1



Path R98C3: itinerary
- from a rider located in the 98th representative address
- to a customer located in the 3rd represesentative address

Delivery time (R98C3) = Average (Time for itinerary R98DSP1C3; Time for itinerary R98DSP2C3; Time for itinerary R98DSP3C3; … ; Time for itinerary R98DSP10C3)

Figure 2