TRANSPORT RESEARCH LAB

Integrating passenger and freight transport via public transport-based crowdshipping for sustainable last-mile deliveries

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Abstract: *This paper discusses a shared mobility service that combines passenger and freight transport. Crowdshipping, in fact, implies delivering goods (freight) via the crowd (passengers). Any trip people perform to fulfil individual objectives can, in principle, be transformed shipping freight service too by using the free load capacity passengers have when moving from A to B. If widely developed this could provide a substantial contribution to reduce transport externalities by avoiding dedicated freight trips. This paper discusses both feasibility and behavioural issues with the intent of diffusing its deployment in urban areas. It does so by presenting some recent research advances related to the study of both demand (i.e. buyers) and supply (providers, i.e. crowdshippers) and discussing the main impacts this solution might have from an environmental and an economic point of view. In particular, it focuses on a particularly environmental-friendly crowdshipping service. The service considered assumes using a city mass transit network where customers/crowdshippers pick-up/drop-off goods via automated parcel lockers located either inside the transit stations or in their surroundings. Crowdshipping can play a crucial role in relieving cities from transport-related negative externalities by promoting the sharing economy and Physical Internet paradigm aiming for a shared, hyper connected, sustainable and efficient last-mile logistics.*

Keywords: *urban freight transport, sharing economy, sustainable mobility, behavioural analysis, city logistics innovation, Physical Internet, stated preference, scenario analysis.*

1 Introduction

Demand for mobility is continuously rising in cities due to concurring urban and logistics sprawl. The coinciding peaking of passenger and freight transport demand aggravates negative externalities affecting urban dwellers' health and welfare (Krzyzanowski et al., 2005). Moreover, emerging trends, among which e-commerce plays a key role, are generating a substantial demand for fast, efficient, low-cost and environmentally friendly delivery services. This is not easy to achieve. In fact, additional freight demand is causing an increase of the social and environmental costs urban freight distribution generates (Taniguchi et al., 2016). Researchers have proposed different innovative urban freight transport solutions to increase both efficiency and sustainability (Quak, 2008; Marcucci and Gatta, 2017). Among these, solutions adopting the emergent socio-economic "sharing economy" paradigm are of particular interest. In fact, they have the potential to revolutionize the current economic system based on individualism and consumerism (Rifkin, 2014).

Information and communication technologies (ICT) will support the affirmation of sharing both economy by making new opportunities available for citizens and businesses. Transport-related initiatives in this realm go under the name of shared mobility among which one can recall, among others, car sharing, carpooling, and ridesharing. While recognizing its innovative stance to promote its actual deployment and acceptance one has to investigate under which conditions would people accept the new emerging business model (Ravenelle, 2016).

This paper illustrates and discusses an innovative shared-mobility service that pools passenger and freight transport together. The peculiar focus is on the necessary pre-requisites that one needs to satisfy to make crowdshipping, i.e. delivering goods via the crowd (McKinnon, 2016), successfully implemented. In fact, one can transform any trip people perform to satisfy personal objectives in a freight transport service by using the available spare load capacity each individual typically has. The idea rests on the consideration that one could stimulate a better use of currently unused transport capacity to reduce transport externalities while performing the same amount of deliveries (Bubner et al., 2014).

This approach is fully compliant with the Physical Internet (PI) paradigm and objectives. In fact, the innovative service this paper discusses aims at supporting the creation of a collaborative and robust physical "network of logistics networks". This, in turn, will contribute to standardized parcels shipment optimization while satisfying customer requirements, optimizing operator and customer economic models while minimizing environmental footprint. The service proposed is compatible with existing routing protocols, interoperability and traceability standards, remuneration rules, compensation mechanisms and new trade configurations (Ballot et al., 2014).

E-commerce market growth fosters crowdshipping up-scaling potential (McKinnon, 2016). The last leg of delivery is also the most appropriate section of the e-commerce supply chain where crowdshipping might prove both applicable and useful. In fact, most of the goods are small in size and light in weight, allowing the "crowd" of commuters to act as a last-mile vector (Gatta et al., 2019a). The last decade has witnessed a noticeable increase of crowdshipping services and its diffusion around the world has been substantial. Some platforms use algorithms to match delivery requests with crowdshippers' trip availability. Others let crowdshippers post their offers on a virtual billboard (supply) allowing a possible sender to buy their service (demand) (Marcucci et al., 2017b).

Despite crowdshipping intrinsic potential, initiatives are still struggling in gaining a wider market share when it comes to urban freight transport (McKinnon, 2016). A critical review of urban crowdshipping initiatives offers a set of interesting suggestions with respect to possible success/failure elements. For example, Marcucci et al. (2017b) discovered a strong link between crowdshipping success and people's awareness/perception of sustainability issues implying a willingness to make an effort to solve them.

Furthermore, for crowdshipping to prove socially beneficial one should develop it as an "environmental-friendly" service. The best option to do so is to transform dedicated into non-dedicated trips based on the consideration that the least polluting trip is the one not performed. It is thus necessary to investigate delivery models that can make use of commuters' trips that would be performed anyhow so to avoid generating additional ones (Serafini et al., 2018). It is appropriate to focus on commuters' trips since they are typically frequent and predictable.

The paper critically discusses feasibility and behavioural levers that might foster crowdshipping diffusion in urban areas. This is performed by presenting recent research advances related to the study of both demand (i.e. receivers buying this service) and supply (those who actually perform the service, i.e. crowdshippers) with a focus on the main impacts the solution proposed would have from and an environmental and an economic point of view. In particular, it delves on an environmental-friendly crowdshipping based on the use of a city mass transit network where customers/crowdshippers pick-up/drop-off goods by use of automated parcel lockers (APL) located either inside the transit stations or in their surroundings. Crowdshippers are passengers that would use the transit network anyhow for other activities (e.g., home-to-work), and their delivery activities would not induce additional trips. The idea is to involve people using public transport which, on average, impose lower environmental and congestion costs on society while also allowing for freight deliver within the city in a timely and efficient fashion. In other words, each APL is the final location where parcels are dropped off by the crowdshipper and picked up by the receiver. Therefore, the APL network represents a PI for which appropriate strategic and operational decisions must be taken (Raviv and Tenzer, 2018).

The paper illustrates results related to three main crowdshipping issues:

(1) *supply* - under which circumstances passengers would consider acting as crowdshippers (Marcucci et al., 2017b; Serafini et al., 2018; Gatta et al., 2019b);

(2) *demand* - under which conditions people might consider receiving goods via a crowdshipping service (Marcucci et al., 2017b; Gatta et al., 2019b);

(3) *potential impacts* - what would be the likely implications the solution proposed might have from an economic and environmental perspective (Gatta et al., 2019a).

The potential adoption of the innovative solutions considered made use of stated preference (SP) and discrete choice modelling (DCM). This allows for robust analyses of different crowdshipping future scenarios and the associated main impacts. A hybrid dynamic traffic simulation model constitutes the base for teasing out the macroscopic traffic features (triggering of congestion, queue spillbacks and interactions with traffic signals) in combination with the microscopic features of delivery operations (delivery vehicles are tracked along their routes) so to realistically account for last-mile delivery operations.

The case study is the city of Rome (Italy) characterized by a population of 3 million people performing around 700,000 thousand trips during the morning peak, and where approximately 32,700 vehicles are daily used to perform more than 35,000 loading/unloading operations in the city centre (Gatta et al., 2019b).

This paragraph describes the structure of the paper. Section 2 reports a state of the art literature review on crowdshipping initiatives. Section 3 focuses on the case study, by first illustrating results from a preliminary investigation, focusing on University students, to acquire the necessary knowledge base for developing the full-fledged SP research endeavour (3.1). Subsequently the paper discusses the SP results for both supply (3.2) and demand (3.3). Section 4 concentrates on an evaluation of the potential impacts of this solution from an economic and environmental point of view (4.1) while also presenting the next research step based on a hybrid dynamic traffic simulation approach capable of reproducing the macroscopic features of traffic in combination with the microscopic features of delivery operations (4.2). Section 5 concludes.

2 Crowdshipping analysis

The last decade has witnessed a substantial increase and diffusion of crowdshipping around the world (Figure 1). E-commerce market growth strengthens crowdshipping up-scaling potential. Crowdshippers, entrusted to move goods from senders to recipients, are the key actor. They deliver freight and typically operate on a freelance basis. A citizen, travelling from point A to B, becomes a crowdshipper when agreeing to carry some items for others along her trip. Sender, recipient and crowdshipper typically connect and interact through an online platform. Some platforms use algorithms to match delivery requests with crowdshippers' trip availability. Alternatively, crowdshippers post their offers on a virtual billboard (supply) and wait for a possible sender to buy the service they offer (demand). In principle, crowdshipping is a win-win solution. In fact, sender and recipient both save money thanks to lower transport costs while the crowdshipper obtains a reimbursement. Despite crowdshipping potential, some initiatives are still struggling to gain a wider market share in urban freight transportation while a non-negligible number of initiatives failed soon after inception. A critical review of urban crowdshipping initiatives stimulates some interesting reflections with respect to possible success/failure elements to investigate in further detail. For example, crowdshipping strongly depends on people's awareness/perception of sustainability issues and their willingness to make an effort to solve them.

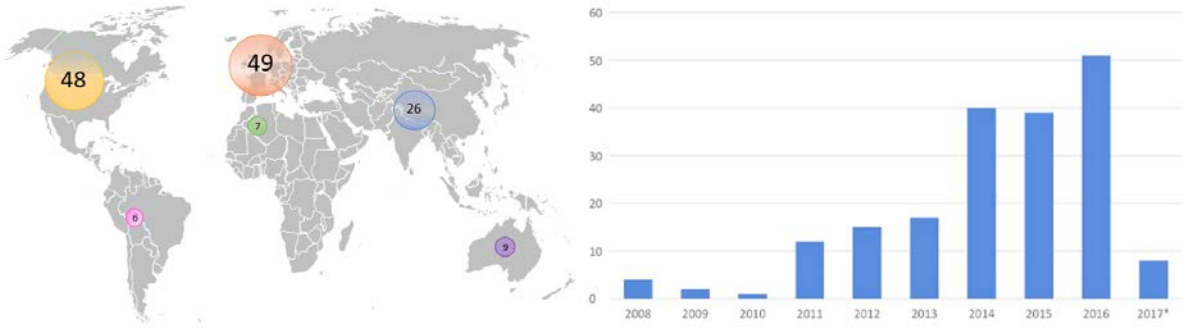


Figure 1: Geographical and temporal distribution of crowdshipping initiatives (Marcucci et al., 2017a,b)

McKinnon (2016) identifies six crowdshipping characteristics, namely:

1) Customer base: crowdshipping can cater for all delivery types: customer to customer (C2C), business to customer (B2C), customer to business (C2B), business to business (B2B). C2C and B2C are the most frequent crowdshipping business models. Both sender and recipient are private actors in C2C while recipient's counterpart is typically a shop in B2C.

2) Pricing: the most common pricing model allows couriers the freedom to bid for deliveries. Customers enter parcel delivery details (e.g. origin, destination, maximum amount they are prepared to pay for delivery). Couriers bid for the work by competing on delivery time and cost. Rates can be predetermined and stable within cities.

3) Distance range: crowdshipping is predominantly an urban phenomenon.

4) Travel type: crowdshipping inception relied on people carrying packages for others on trips they were already making, however, nowadays it this might also imply performing trips just to deliver a given package. Especially in the first case described above, maximum travel deviation from the original path is critical.

5) Commodity: platforms accept shipping almost any non-hazardous freight, while individual couriers decide how big/heavy a consignment can be. Typically, the weight limits are 23kg (50lb) by car and 14kg (30lb) by bicycle. *Postmates*, for example, has so far concentrated on food deliveries by building a crowdshipping platform capable of handling a broad range of products.

6) Transport mode: some platforms heavily rely on motorized deliveries, while others have perform deliveries by bicycle.

Table 1 reports a numerical analysis of 90 crowdshipping initiatives using the six characteristics previously discussed on the base of the work of Marcucci et al. (2017a).

Table 1: Crowdshipping initiative analysis (based on Marcucci et al., 2017a)

Classification of 90 initiatives based on Mc Kinnon's six characteristics											
Customer base		*Pricing*		*Distance range*		*Travel type*		*Transport mode*		*Commodity*	
C2C	34	Freedom to quote	63	Internat.	33	Non-dedicated	61	All	33	Freight	66
B2C	32	Fixed rates	27	National/ Internat.	5	Dedicated	22	Air transport	30	Food	8
C2C+ B2C	22			Urban/ Internat.	4	Both	7	Motorized transport	13	Freight and animals	6
B2B	1			National	10			Public and Private	7	Freight with weight and value restrict.	4
C2C+ B2C+ B2B	1			National/ Urban	4			Private	6	Freight and Passenger	4
				Urban	26			Non-motorized transport	1	Waste	2
				All	6						
				Unknown	2						

The recent increase in crowdshipping initiatives worldwide has attracted academic researchers' attention who started investigating this subject looking both at service characteristics and at the underlying optimization problems. Most studies focus on alternative business models (Rougès and Montreuil, 2014), while little is known about crowdshipping users' and buyers' behaviour and perception. With only few exceptions (e.g. Paloheimo et al., 2016), limited are the works investigating crowdshipping externalities implications. Table 2 reports a selection of the recent literature on crowdshipping based on Gatta et al. (2019b).

Table 2: Literature review (based on Gatta et al., 2019b)

Author(s)	Topic	Methods	Main Findings
Archetti et al. (2016)	Problem of Walkmart using a fleet of capacitated vehicles and drivers to perform deliveries and occasional drivers seeking to minimize the costs of satisfying demand	Multi-start heuristic to solve the Vehicle Routing Problem with Occasional Drivers	Employing occasional drivers may produce significant benefits especially if coupled with an appropriate compensation scheme
Behrend and Meisel (2018)	Analysis of a platform combining shipping requests with community members' planned trips	Three optimization models, two heuristics, a decomposition scheme and a graph-theory based method	Benefit of integrating item-sharing and crowdshipping as a function of crowdshippers' detour flexibility and compensations
Yildiz and Savelsbergh (2019)	crowd-sourced transportation for on-demand meal delivery	stylized equilibrium model for analysing service coverage and delivery capacity design	Quantification of the impact of courier non-compliance and assessment of the benefit of supplementing crowd-sourced delivery capacity
Punel and Stathopoulos (2017)	Investigation of delivery scenarios performed by non-professional shippers compared to traditional shipping options	stated choice experiments and discrete choice models (Multinomial Logit and Mixed Logit models)	Insights into the attributes affecting preferences for goods delivery performed via occasional drivers
Punel et al. (2018)	Analysis of how and to what extent attitudes, preferences, and characteristics of crowdshipping users differ from non-users	Web-based survey - proportional t-test analysis and binary logit model	Crowdshipping is more prevalent among young people, men, and full-time employed individuals and urban areas are preferential
Buldeo Rai et al. (2017)	State of practice of crowdshipping	Systematic literature analysis + interviews with logistics practitioners	Three characteristics affect crowdshipping sustainability: third party involvement, crowd motivation, and its modal choice

Below we present some results from recent research papers. The innovation in research relates to the joint investigation of both crowdshipping demand and supply. The focus is on preferences and on the environmental sustainability of the service, which is supposed to rely on public transportation. Finally, we present a comparative evaluation among different scenarios.

3 Investigating the potential of crowdshipping in Rome

The analysis focuses on Rome. The city has a population of 3 million people performing around 700,000 thousand trips during the morning peak. Approximately 32,700 vehicles perform more than 35,000 loading/unloading operations in the city centre (Gatta et al., 2019b). Crowdshipping initiatives in Rome are still few and mainly linked to the food sector. The all imply performing dedicated trips. Foodora, for instance, delivers food from restaurants to homes, and Take my things/LoPortoPerTe that recently joined forces plan start operating soon in Rome.

Marcucci et al. (2017b) perform a preliminary investigation with respect to the underlying motivations that can facilitate and/or hinder the deployment/diffusion of a crowdshipping initiative in Rome. A more robust evaluation made use of SP and DCM. A SP experiment implies defining several choice sets, each involving two or more alternatives, described by several attributes with two or more levels. Each respondent chooses one of the options presented in the choice set according to her preferences. The core component is the statistical design used to construct the choice sets. The underlying idea is to investigate the relative influence the independent variables (attributes) have on a given observed phenomenon (choice). DCM adopts random utility theory to model SP respondents' choices. Microeconomics assumes rational agents maximise utility. The latter comprises both a deterministic and a stochastic component. Different assumptions about the distribution of the stochastic term imply different DCM models. The simplest model is the multinomial logit (MNL) (Ben-Akiva and Lerman, 1985).

3.1 Preliminary investigation

Marcucci et al. (2017b) investigate the main characteristics of an innovative crowdshipping initiative in Rome. Pursuing this aim, they administer a questionnaire to approximately 200 students enrolled at Roma Tre University. Students can be considered, in general, "early adopters/providers". The questionnaire has two parts. The first investigate under which conditions would students agree to carry freight according to crowdshipping principles. In particular, a typical crowdshipper profile is elaborated along with the necessary conditions that would induce a student to become a crowdshipper. Moreover, the questionnaire delves on which are the preferred locations where to exchange freight between actors and the preferred transport modes. The second part enquires students' preferences for receiving deliveries from a crowdshipper so to study and classify their main concerns.

The sample includes 90 females and 100 males with an average age of 24 years. The majority was not familiar with crowdshipping, and no one had ever operated as a crowdshipper before.

The most important result is the overall positive attitude towards crowdshipping. In fact, 87% of the students stated their willingness to act as crowdshippers. However, depending on the following conditions, the percentage decreases to: (i) 55% if package is not of small dimension (i.e. shoebox); (ii) 40% if remuneration is between 1€ and 5€ (3% up to 3€); (iii)

25% if both of the above. In general, the inclination is slightly higher for men and for people who most frequently buy online.

On the other hand, 93% would accept to receive goods via a crowdshipping service. Also in this case, the percentage drastically decreases to: (i) 18% if customers cannot contact the crowdshipping company; (ii) 16% if there is no direct contact with the crowdshipper; (iii) 14% if no package tracking is possible/available. No one judges crowdshipping an outright "bad idea". Women are more likely to receive goods via crowdshipping.

As it is for the supply side, the most important condition for participating relates to remuneration. On average, the students interviewed would like to earn 5-10€ per delivery. Existing working initiatives usually provide an average remuneration of 2-4€ with a substantial differences depending on the geographical area. The reason why many students overestimate the possible economic gain per delivery is most likely due to the weak understanding of the real aim of crowdshipping. Moreover, students do not often consider that they must perform a given trip anyway and consequently overestimate the true effort the delivery implies. Apart from remuneration, interviewees are willing to act as crowdshippers as long as, on average: no deviation requires more than 15 minutes from a regular trip, or implies more than 2.5 km, or more than 2 additional stops on a regular trip. Additionally, crowdshippers prefer to preserve their privacy and, in general, are unwilling to be traced (57%). Finally, they generally require a proof of crowdshipping sustainability to support it and this relates to its social sustainability.

The results obtained represent a good starting point for a deeper and wider behavioural analysis, aimed at investigating the social and economic acceptability of alternative crowdshipping solutions and the elements/policies needed to produce the required behavioural shift.

3.2 SP survey to investigate supply

Serafini et al. (2018) use SP to identify the most important features associated with the choice of acting as a crowdshipper and DCM to study the underlying behaviour. The SP scenarios refer to the city of Rome and its metro network assuming B2C deliveries. The paper assumes packages can be picked-up/dropped-off in APL located either inside metro stations or in their surroundings. Initially, parcels are delivered in the terminal stations of the metro lines. These represent the origin points in order to start the parcel movements by crowd shippers. In that sense, terminal stations work as transit points where freight is deconsolidated in order to be moved from standard vehicles to "green solutions", i.e. the crowd. Considering such distribution approach, the restocking type model to be followed is a one to one model (from station to station) where the metro user can substitute the usual courier. It has to be noted as the first destination of the parcel would not be also the final destination, while the parcel can be moved between different APLs by different crowd shippers until it reaches the final destination, i.e. the metro station where the user would like to pick up the good.

Data were collected by administering 240 interviews to metro users in the city of Rome. Using hypothetical crowdshipping service's features, the survey investigates the role location of delivery/pickup points (inside metro stations or outside metro stations/adjacent buildings), remuneration (1 or 3 €/delivery), delivery booking (real-time or off-line) and alternative bank crediting modes (single delivery or every 5 deliveries) have in stimulating people to act as crowdshippers. Remuneration was set considering current shipping costs in the B2C market and the rates applied by existing national crowdshipping companies; the "delivery booking"

feature mimics the high/low flexibility the crowdshipper might have in reacting to an on-line delivery request.
One notes with respect to the maximum deviation from the usual path that about half of the potential crowdshippers (43.1%) is not willing to modify the path if the APL is outside the metro stations while 39.2% would walk a maximum of 300 m. Only 15.3% is willing to travel an additional distance of 600 m, while the percentage of those willing to travel more than 600m is negligible (Gatta et al., 2019b). Further investigations on this feature will require inserting a value of time in the modelling approach, depending on socio-economic parameters and characteristics of the trip (length, time, purpose) to refine the willingness to be a crowdshipper.

An MNL was estimated using three independent choices: option A, option B, and "no choice" (as in the SP scenarios). The estimation process adopted a maximum likelihood two-stage approach[1].

APL location is the attribute with the greatest impact while delivery booking the smallest. Having APL inside the metro stations instead of outside is more important than the remuneration (considering the range used in the survey: 1–3€/delivery). Real-time booking is preferred with respect to the off-line option. However, this characteristic is less important than others suggesting that people need to get organized to produce the crowdshipping service using public transport.

Explorative estimation exercises have considered the "not interested" option in the model. Preliminary results suggest that introducing the "not interested" option provokes other attributes (e.g. green attitude) to become statistically significant. Specifically, a stronger green attitude contributes to the choice of one of the two alternatives of being a crowdshipper. Moreover, the survey includes a question to test whether respondents focus more carefully on a specific feature with respect to others. It was possible to identify four types of respondents: the "basic" interested in the bank credit mode in order to obtain an immediate gain, the "static" concerned in the location of APL inside the metro stations, the "dynamic" attentive in higher remuneration, the "flexible" focused on real time booking.

MNL results allowed estimating the probability of choosing each alternative assuming different service specifications and potential crowdshipper characteristics (Figure 2). As far as the characteristics of the service are concerned, the paper considers all possible combinations of the investigated features, while for the "no choice" scenarios, the age attribute is fixed. Specifically, the paper considers three possible profiles assuming different crowdshippers' age:

• Profile 1: considers a crowdshipper aged 50 representing the average age of the population in Rome ("Pop. Roma");

• Profile 2: assumes a young population with an average age of 25 ("Young people");

• Profile 3: focuses on an elderly population with an average age of 65 ("Old people").

Impacts largely depend on the proposed service conditions (level of service). It is interesting to observe also a variability of the probability of acting as a crowdshipper as a function of individual characteristics. This variability is small between the profiles representing the population of Rome and the young people, while it is evident with respect to the elderly.

[1] Please refer to Serafini et al., 2018 for more details about the process and results.

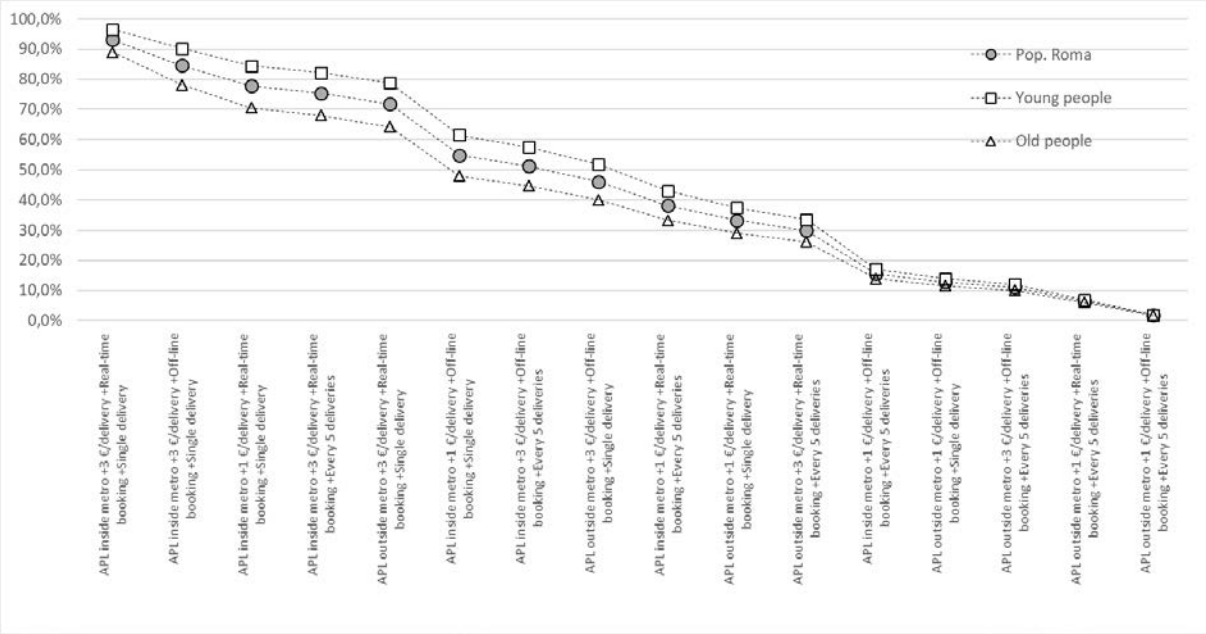


Figure 2: Probability of acting as a crowdshipper with respect to the characteristics of the service (level of service) and the characteristics of the potential crowdshipper (Age) (Serafini et al., 2018)

3.3 SP survey to investigate demand

Gatta et al. (2019b) report the SP survey investigating crowdshipping demand. Data originate from the administration of 240 interviews to inhabitants of the city of Rome. The survey exploring the demand-side investigates the role service time, service cost, parcel tracking availability (available/not available), delivery schedule date/time flexibility (available/non-available) play in stimulating potential e-commerce users to choose a crowdshipping service for receiving goods. Shipping fees and time refer to current national shipping companies operating in Italy (the levels for both attributes are lower/typical). Also in this case, the "no choice" alternative represents the *status quo* implying not using the crowdshipping service.

Most crowdshipping service potential users declared to prefer to pick-up the parcel during the afternoon (38%) or evening (33%) and to have the pick-up option available at least for 24 h (44%). Only 9% of the respondents declared to prefer having a short pick-up time (less than 3 h), mainly for safety reasons.

The Authors, also in this case, estimate a MNL model. All the coefficients have the expected signs and are statistically significant (for more details about the attribute weight results, please see Gatta et al., 2019b).

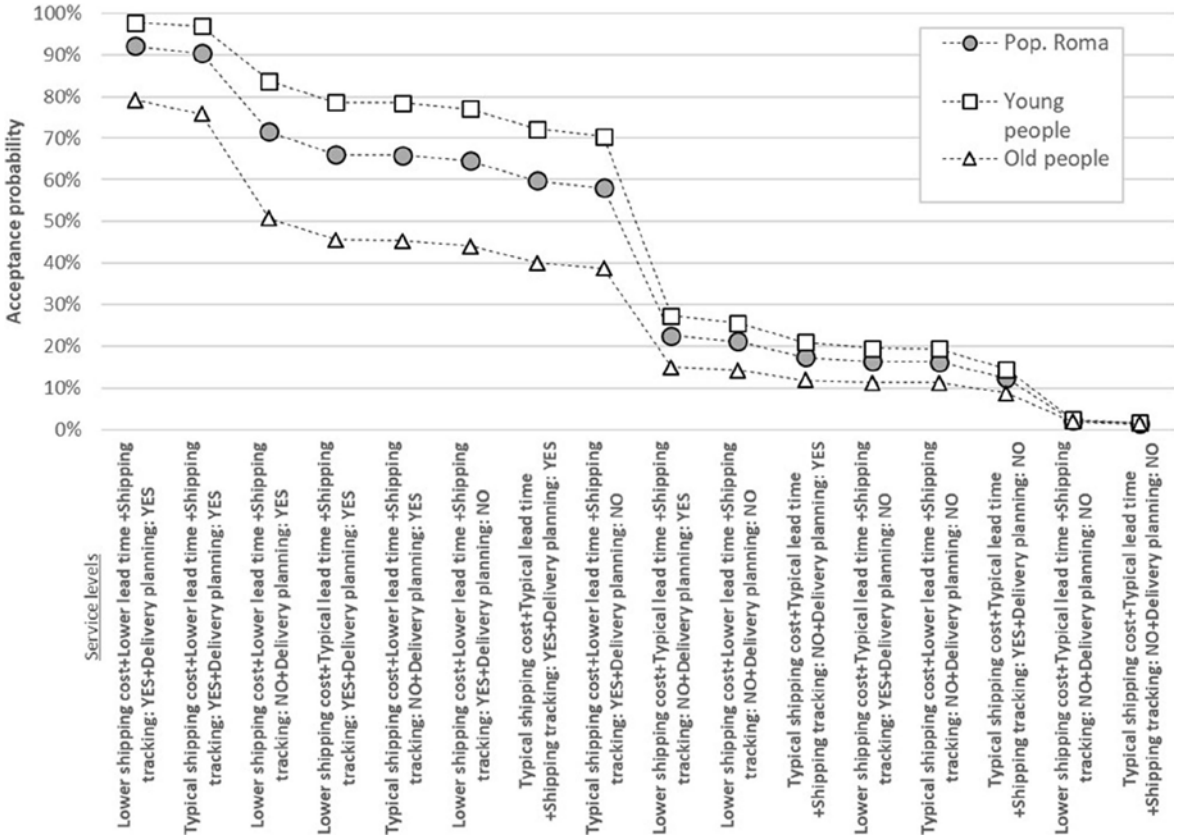


Figure 3: Probability of adopting the crowdshipping with respect to the characteristics of the service (level of service) and the characteristics of the potential user (Age) (Gatta et al., 2019b)

The possibility to plan the delivery date and schedule its timing is the most relevant feature, while having a shorter shipping time with respect to present has the lowest impact on utility. This reflects the fact that the actual delivery system is, in general, efficient in terms of shipping time (e.g. same-day delivery) while time windows are usually wide, and people have to wait at home their goods, inducing either dissatisfaction or missed deliveries.

Starting from the MNL results on can simulate the probability of choosing each alternative assuming different service specifications given the above defined user categories. Most important changes are attributable to the proposed service conditions (level of service). It is also interesting to note a substantial variability linked to age.

4 Evaluating the potential impacts of crowdshipping

Starting from the results obtained, Gatta et al. (2019a) try to understand and evaluate the environmental and economic impacts a crowdshipping platform might have in urban areas.

4.1 Economic and environmental scenario evaluation

Figure 4 reports the methodological architecture. This can be summarised as follows:

1) Define possible crowdshipping demand levels as a function of the main service features;

2) Convert demand into orders, and compute the vehicle-kilometres saved by developing a public transport-based crowdshipping service;

3) Evaluate the benefits and costs of the service in terms of externalities reductions, revenues, investment, and management costs;

4) Compute the net present value of the service.

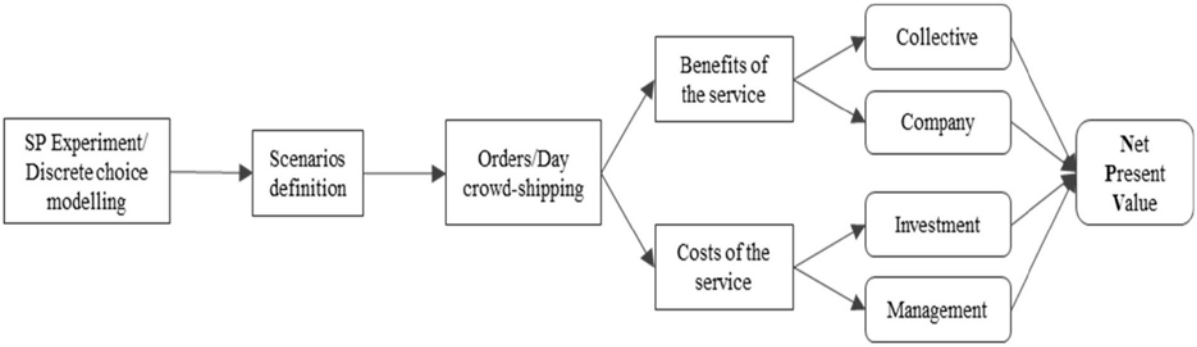


Figure 4: Gatta et al. (2019a) - Methodological structure

The paper reports some scenario simulations assuming different service configurations and using the econometric results obtained. Depending on the acceptability level of the service (base, favourable, and unfavourable) we test three demand scenarios. Transforming individual orders into vehicle equivalent units (i.e., the number of commercial vehicles needed to transport a certain quantity of orders) allows computing vehicle-kilometres savings when implementing a public transport-based crowdshipping service.

Authors use COPERT 5.1.1. (COmputer Programme to calculate Emission from Road Traffic, EMISIA SA, Thessaloniki, Greece) calculation model to estimate the environmental benefit due to lower air pollutants emissions. These include the reduction in emissions for particulate, nitric oxide, carbon monoxide and carbon dioxide, thus covering both local (urban scale) and global impacts (greenhouse gases emissions). Gatta et al. (2019a) reports all the details regarding emission evaluation, traffic conditions data, vehicle fleet composition, kilometres travelled for each year and the cumulative value of the overall amount of kilometres travelled.

The transformation of environmental measures into monetary ones made use of Ricardo-AEA (2014) and Litman (2012). This allowed performing a Cost-Benefit Analysis (CBA) calculation for the crowdshipping service in Rome. The financial sustainability evaluation of the service, assumes a time frame up to 2025 and the following factors: (i) e-commerce demand growth, (ii) socio-demographic evolution, and (iii) metro network expansion. The calculation of the externalities saved assumes, for each demand scenario and each reference year, that a certain share of orders, and therefore equivalent vehicles, are transferred to couriers (crowdshippers) that use the metro network to commute to work. The reductions in environmental externalities were subsequently transformed, using unit costs, in monetary values so to calculate the ensuing economic benefits.

We assume 10% margin on the fee paid to the crowdshippers for the service produced that is the typical private company profits in line with other crowdshipping services already operating in the market. The service costs, split in investment and management costs, are assessed on the base of each scenario. Investment costs refer to the purchase and installation of APLs and the creation of an IT platform to manage the service. Purchasing and management costs have been derived from different sources, including articles and manufacturers' brochures and websites. Gatta et al., (2019a) report and discuss the specific values.

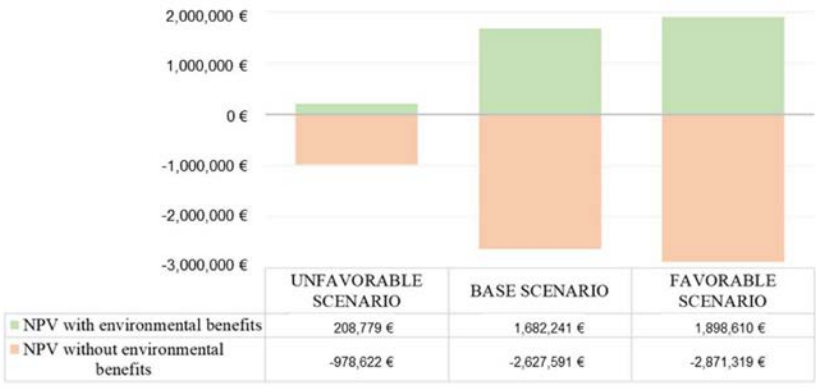
Three demand scenarios have been considered, i.e.: (1) the “base scenario” assuming the most likely configuration of the possible crowdshipping service; (2) a “favourable” scenario with lower shipping fees; (3) an “unfavourable” scenario with no flexibility in delivery date and time schedule. The probability of choosing such a service ranges from 16% to 66%.

The potential crowdshipping demand is mainly generated by the same users of the metro network, as well as by the inhabitants located in the surrounding areas of the metro stations. We use an e-shopping rate of 0.0262, for the whole period considered, to transform demand in potential daily orders. We also account for orders/day per inhabitant, percentage of the population making at least one online purchase, percentage of orders requiring a physical shipment and annual average purchase rate.

The environmental-related benefits for the 2017–2025 period of a crowdshipping service in Rome are summarized as follows:

- 239 kg of particulates per year will, on average, be saved, with oscillation between 66 kg and 265 kg
- 3.76 tons of nitrogen oxide per year will, on average, be saved, with a variation between 1.04 and 4.17 tons
- 2.24 tons of carbon monoxide per year will, on average, be saved, with a minimum of 0.58 and a maximum of 2.49 tons
- finally, for carbon dioxide, the emission avoidance is 1098 tons per year with extreme values reaching 304 and 1215 tons.

If one does not consider public benefits, the NPV obtained is negative, suggesting that discounted costs are greater than revenues for the platform operator. However, considering that environmental benefits and accident reduction impact on society as a whole, it is reasonable to convert their economic value into public incentives and, therefore, deduct them from the total platform cost. This assumption makes the NPV positive (Figure 5).



	UNFAVORABLE SCENARIO	BASE SCENARIO	FAVORABLE SCENARIO
NPV with environmental benefits	208,779 €	1,682,241 €	1,898,610 €
NPV without environmental benefits	-978,622 €	-2,627,591 €	-2,871,319 €

Figure 5: Net present value (Gatta et al., 2019a)

4.2 Next steps: simulation-based evaluation

In the following, we sketch the latest results related to the presented project we have illustrated. In order to analyse externalities of crowdshipping services, a network-wide

perspective is adopted, including public transit as a delivery mode (in addition to car), and explicitly considering operational issues like kerbside parking.

The aim of this investigation stream is twofold:

(1) Provide a systematic investigation of the scale-effects of crowdshipping from a "supply perspective," by analysing the impacts of different operational features (e.g., mode, length of detours, availability of parking, and levels of traffic) on congestion and emissions;

(2) Investigate the effects of crowdshipping in a realistic large-scale scenario, by accounting for real traffic conditions, availability of commercial bays, and freight demand.

The dynamic simulation framework adopted (Simoni and Claudel, 2018) is consistent with the dynamics of congestion and reproduces delivery operations as temporary fixed-bottlenecks in case of double-parking. Its hybrid nature allows for large-scale analyses and, at the same time, detailed investigations of individual delivery tours and crowdshippers' deliveries. This approach allows calculating freight related emissions and traffic congestion effects (including those related to kerbside delivery). In addition, its hybrid nature permits analysing several different scenarios at very low computational costs (few seconds per simulation) thus making it possible to perform robust evaluations accounting for uncertain freight demand and traffic conditions.

Simulations of the crowdshipping in the city centre of Rome can benefit much from this approach using three different alternatives when simulating the last mile delivery process: (i) a "traditional" (i.e., existing) delivery service, (ii) a standard "car-oriented" crowdshipping framework and (iii) a "public transit-oriented" one. One can integrate both of the last two delivery services into the "traditional" one. In both crowdshipping frameworks, the crowdshipper is not the final recipient of the parcel.

In order to reproduce the crowdsourced delivery process we embedded into the original simulation framework thanks to the development of a new algorithm that derives crowdshippers' original and new delivery trips while integrating them in the original delivery framework (by replacing and consolidating existing trucks' tours) based on different input parameters.

We use as a main reference for the implementation of crowdshipping in Rome the investigation of the conditions for public transit passengers to act as crowdshippers and for people to receive goods with crowdshipping performed in the abovementioned studies.

Thanks to simulations, it is possible to study the influence of mode and matched demand, the effects of operational aspects such as the length of detour made by and the parking behaviour of crowdsourced drivers, and the influence of daily traffic fluctuations. By doing so, it is possible to assess the impacts of different crowdshipping implementation features on the overall levels of pollution and congestion.

To synthetize, traffic simulations can be adopted to properly model the effects on traffic and pollution of delivery operations dynamic. This modelling approach is uncommon in city logistics related studies and, to the best of our knowledge, no systematic simulation-based study of crowdshipping has yet been performed.

5 Conclusion

This paper presents an innovative crowdshipping service relying on public transport. Following PI paradigm, one can imagine a collaborative network of "crowdshippers", i.e.

those performing the delivery service, customers, and a platform that matches demand with supply, aiming at optimizing the shipment of standardized parcels, focusing on routing protocols, interoperability and traceability standards, remuneration rules, compensation mechanisms and new trade configurations (Ballot et al., 2014). This can prove particularly valuable in managing peak situations (Christmas, Black Friday, San Valentine day, etc.).

The paper discusses the feasibility and behavioural levers that might facilitate the diffusion of crowdshipping in urban areas. It reports some recent research advances related to the study of both demand (i.e. receivers of this service) and supply (those who perform the service, i.e. crowdshippers) and of the main related impacts this solution would have from and an environmental and an economic point of view. It specifically focuses on an environmental-friendly crowdshipping service. This innovative service uses the mass transit network of a city, where customers/crowdshippers pick-up/drop-off goods in APL located either inside the transit stations or in their surroundings. The case study we consider is the city of Rome. With respect to this city, we administer surveys and perform simulations. The study of the potential adoption of this innovative solution rests on SP and DCM techniques that allow performing sound analyses of different crowdshipping future scenarios and estimate the main associated impacts. A hybrid dynamic traffic simulation methodology is presented capable of accounting for realistic last-mile delivery operations.
This research paves the way for further investigation of crowdshipping, given its potential to relieve the city from transport-related negative externalities and to fully affirm the sharing economy and Physical Internet paradigm aiming at a shared, hyper-connected, sustainable and efficient last-mile logistics. Potential research lines are: 1) making the user aware of the environmental benefits of a public transport based crowdshipping, thus inserting an ecolabel as an explicit variable in the choice process; 2) quantifying the economic benefits for a crowdshipping company due to the adoption of such a green delivery solution; 3) evaluating the freight type and parcel dimension that can be handled by a public transport based crowdshipping; 4) inserting the public transport based crowdshipping into a network design problem combining both transit and logistic network design, thorough the simulation approach. Finally, from a policy perspective, when moving private services inside public areas, safety and security issues need to be taken into account. Thus, ad hoc regulations are expected to be developed to assure the feasibility and real operation of the service.

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