# POLITECNICO DI TORINO

**Master of Science in**

**Computer Engineering**

# *Impact of crowdsourcing in last mile logistics*


**Supervisor:**

Prof. Guido Perboli

**Candidate:**

Junaid Ali (s241445)


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# ABSTRACT

Last mile delivery is an area of concern for the logistics companies as it comprises of 55% of the delivery shipment cost. There are several business models proposed to address minimal cost for last mile delivery. Typically, managers used to hire professional drivers to deliver the parcels with a specific daily target with traditional vehicles i.e. vans. However, with technological advancement, there has been evolvement in this process and as a result, crowd-sourcing has emerged as a possible solution which is named as crowd-logistics. Crowd-logistics enables individuals (crowd workers) having any sort of vehicle to take part in the delivery process provided that they get their incentives, hence creating employment opportunities. The involvement of general crowd in the last mile delivery would not only impact efficiency and cost of the process but also address the environmental and social problems. In this study, we will be evaluating these impacts of crowd-logistics in comparison to in-house fleet.

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# 1. Introduction

In this chapter, we present the overview of the fundamental concepts of the urban logistics in section 1.1, and then we present changing dynamics of urban parcel delivery in modern economy in section 1.2. In section 1.3, we identify existing challenges that urban logistics rises being a multi-actor system. After identifying challenges, we discuss the different models adopted by the companies to overcome those challenges in section 1.4.

## 1.1 Urban Freight Transport and Logistics

The urban transportation refers to the mobility for people and goods connecting origin and destination points within the urban areas [39]. Thus, it includes, for example, the public and private transportation, pedestrians and non-motorized transport modes (e.g. Bikes) and freight distribution [39]. Urban freight transport, defined as all movements of goods into, out of, through or within the urban area, made by light or heavy vehicles [38], including:

- Delivery of parcels (business and home).
- Service transport and demolition traffic.
- Shopping trips made by private households.
- Reverse logistics for waste removal and for returns management.
- Service vans for maintenance, supply and removal of parts.

In the context of urban freight management, the goal is to achieve maximum integration of freight movements in urban operations and activities that allow people to get the goods they need, along with keeping in mind the sustainable development. Sustainable development is most commonly defined as 'meeting the needs of the present without compromising the ability of future generations to meet their own needs' [42]. With this, the joint harmonization of three issues is implied: economic growth, social equality and protection of environmental resources [43]. Hence, there are several areas on which researches have been conducted, they aim to:

- Efficient energy consumption in whole urban logistics system.
- Improve the city environment by achieving better air quality and reducing noise.
- Enhance customer satisfaction by efficient last-mile delivery.

However, before trying to address these issues, there are several aspects to consider. First, concentration of urban population in the EU has climbed up to 72% according to research conducted by ERTRAC and ALICE (European Road Transport Research Advisory Council, and Alliance for Logistics Innovation through Collaboration); Moreover, urban freight vehicles makes 10 to 15% of vehicular equivalent miles in city traffic. Due to this reason, urban transport can easily get congested due to heavy traffic. Second, according to same research organization mentioned above, urban freight is responsible for 25% of urban transport related $CO_2$ emissions and 30 to 50% of other transport related pollutants (Particulate matter, Nitrogen Oxide). In addition, urban freight account for a significant part of ambient noise. European Policy for zero $CO_2$ emissions in cities by 2030 obliges logistics companies to opt green models for logistics activities. Lastly, the estimated successful B2C deliveries are 70 to 75% in urban environment [38], the goal should be to increase the efficiency of the logistics and delivery systems within the urban areas to get this to 100%. Spontaneous increase in e-commerce is a tough challenge in this respect.

## 1.2 Paradigm Shift

With the rise of E-commerce industry and urbanization, it has become tough task for city administrations to manage traffic congestion in highly populous cities. On one hand, adequate public transport is vital to daily lives and economic activities of the citizens, on the other hand growing e-commerce activities has made the conditions more critical as e-commerce sector has also become key indicator in modern economic system. In New York City more than 1.5 million packages are delivered daily [1]. The main concern for the stakeholders i.e. (city administration and e-commerce business) is to maintain equilibrium between sustainable public transport and supply chain.

Modern economic system includes the shared creation, production, distribution, trade and consumption of goods and services by different people and organizations. [2] Argue that the boom of the shared economy followed the financial recession of 2008, which has created a greater need to reduce customer costs. Consequently, over a decade or so, there has been a paradigm shift in retail industry. Most of the retail stores has shifted their business from physical stores to e-commerce channel. Rise of internet has transformed traditional retail business into e-commerce. This e-commerce revolution has affected the traditional supply chain. Fig. 1 gives information on retail e-commerce sales worldwide from 2014 to 2023. In 2019, retail e-commerce sales worldwide amounted to 3.53 trillion US dollars and e-retail revenues are projected to grow to 6.54 trillion US dollars in 2022.

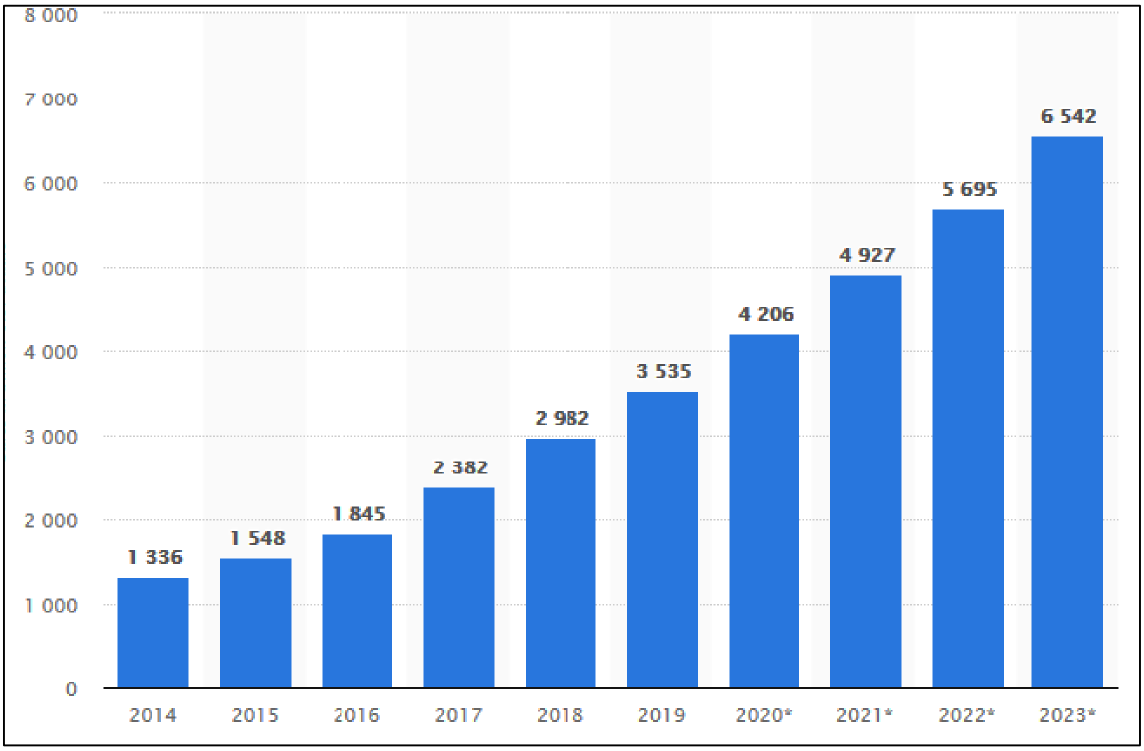


*FIGURE 1 E-COMMERCE WORLD WIDE SALES*

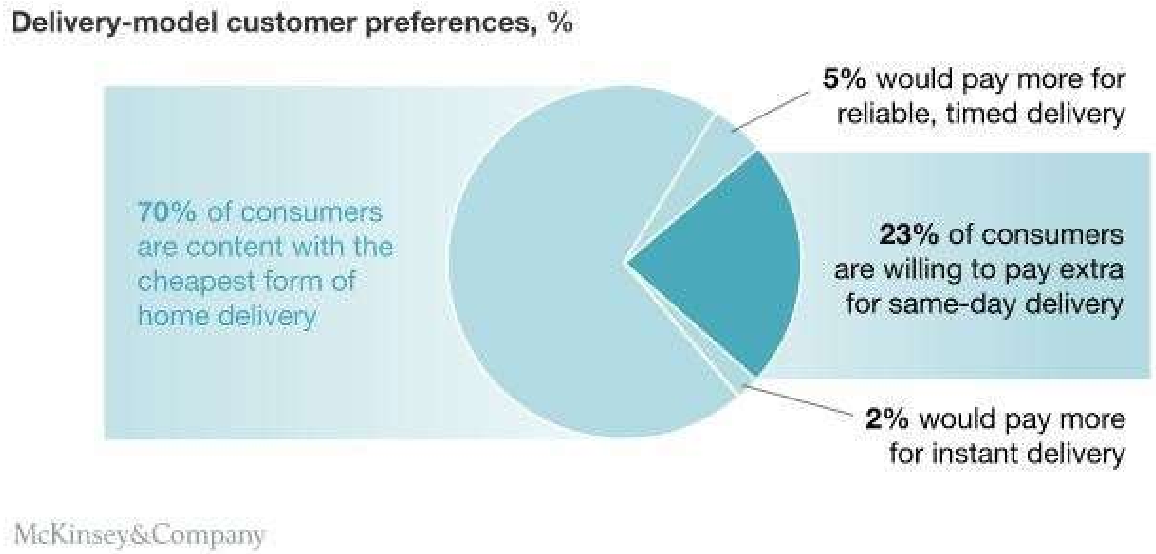


*FIGURE 2 DELIVERY MODEL PREFERENCE WORLD WIDE*

However, this paradigm shift has come up with a lot of challenges; many of them lie in last mile delivery. Last mile delivery is the final step of the supply chain which commences from the distribution hub to the final customer's doorsteps. The last mile delivery usually ranges from a few blocks to 50 or even 100 miles [2]. As much as 57% companies in America say that the last mile is the most inefficient in their entire supply chain, according to a latest Retail Insider report. As much as 30% of shipping expenses can be attributed to last-mile delivery operations alone according to study conducted by Mckinsey&Company. Year 2020 has created disruptions not just in our daily lives; sudden increase of e-commerce activities has made it more challenging for the businesses to meet logistics activities in the last mile.

## 1.3 Challenges in Last Mile Deliveries

- With 86% customers are ready to pay for expedited deliveries [3], it is still a difficult task for businesses to execute last mile deliveries in efficient manner. With Increasing demands and penalties for delayed deliveries, following strict ETA's has become another challenging task.
- Shopping habits of customers are changing with time. Earlier, waiting period of 4-5 days was considered normal; however, this is not the case in present times. According to study conducted by [2], 66% of millennial shoppers say that they want the e-Commerce companies to provide the 1-hour delivery option in metropolitan cities. 29% of the shoppers have changed the delivery time and location of their package. Furthermore, 50% would like to opt for it if that option is available. 27% of the shoppers in the US have canceled their order as there was no same-day delivery option available. 90% of the shoppers track the delivery status of their package and want their delivery to fit seamlessly with their schedule
- Volatility in demands makes last mile delivery extremely complex. The decision on how much inventory to keep, managing temporary staff and several such factors contribute to overheads.
- Incomplete or failed deliveries result in significant loss. Poor address quality impacts delivery profitability, 65% of retailers agree [4]. 1 in every 20 online orders is not delivered on the first attempt [4]. Failed deliveries can be caused by human error, incorrect address or bad quality address. These reasons are enough for a delivery professional to go on a complex maze.
- Smart transport of parcels in a city [5] is critical for Smart Cities efficient implementation. City logistics must consider the process of logistics optimization and last mile activities in an urban area taking into account three pillars: economic, social and environmental. Hence, Route planning is extensively confusing, mentally taxing and dependent on a various number of factors. Fuel efficiency, traffic congestion and environmental regulations are basic considerations that enterprise has to consider in advance.
- Cities have become highly urbanized and According to the Organization for Economic Co-operation and Development (OECD), in the 1950s the 50% of the population was urban, and by 2050 it is likely to reach the 85% [6].
- Freight vehicles typically represent 8-15% of total traffic flow in urban areas but, when they park to make collections or deliveries outside designated parking spaces, they can reduce road capacity and contribute to congestion [7].
- Diesel powered delivery vehicles are damaging to air quality and affect human health. EU commission has strict regulations on environmental degradation and companies may face strict fines if they violate those regulations, city authorities often regard improving air quality as a high priority [7].
- Maintenance of equilibrium between capacity and capability is difficult task to achieve. Managing certain number of deliveries in a particular area is a challenge. Locations of customers are diverse, and management has to somehow plan their activity accordingly. There are four use cases for this scenario.
    - Low-Density Short Distances

- Low-Density Long Distances
- Density Short Distances
- High-Density Long Distances

Considering size of parcel is different challenge. It adds more variables to this problem; hence, delivering parcels in different urban areas becomes two-fold.

Unpredictability of future occurrence is the most predictable. Either it is act of nature or act of man, the parcel delivery in progress is always a concern. Delays can be expected in case of such events. Traffic jams, strikes or any other kind of blockade causes unwanted delay of the last mile.

As a result of above challenges, Business Models for the Last mile delivery of parcels need to be innovative, fast, cheap, reliable and environment friendly. Enterprises has come up with several last mile delivery models in order to mitigate those challenges. we discuss these models in following sub section.

## 1.4 Last Mile Delivery Models

In recent years, many new and existing businesses have adopted a home delivery service model that allows customers to purchase goods online and have them delivered directly to their front door. Crossing this "last mile" provides an increase in service for customers, but also creates a logistics challenge for companies [8].

### 1.4.1 AHD- Attended Home Delivery

AHD is the most widespread model used last mile delivery model. It is a basic model in which company uses professional fleet of drivers to send goods to customer's doorstep, receive confirmation signatures and leave for the next delivery. With higher urban density, growing customer demands and restrictions from city administration, it has become inefficient mode to handle huge amount of orders. Many researchers have studied balance between customer satisfaction and delivery cost in AHD. [8] emphasized on usage of time slot incentives to reduce cost and improve profits. Hill [9] studied tradeoff between cost and short delivery time guarantees. Customers prefer narrow delivery time slots, but they lead to huge loss and affect routing efficiency.

Adoption of cargo bikes in AHD significantly reduces the environmental cost of the last mile delivery. They cut air and noise pollution, reduce greenhouse gas emissions, ease congestion in urban areas and improve safety. It is beneficial to economy as cargo bike companies create employment. In Copacabana, Rio de Janeiro (Brazil) the Associação Transporte Ativo (Active Transport Association) assessed the activity of the many cargo-cycle operators and concluded that they make a positive contribution to the creation of local jobs. In highly dense areas cargo bikes proves to be efficient [10]. Because in places like city centers, tourist areas etc. where vans and cars are not allowed, cargo bikes get the work done for the courier service.

### 1.4.2 Reception Box

With rising customer demand, AHD has become inefficient mode due to spatial dispersion of customers and higher number of failed deliveries [13] and cost of parcel delivery is high. Therefore, in order to achieve efficient last-mile delivery, various solutions have been proposed; among them are automatic delivery stations (lockers or reception boxes). Reception boxes can be personally installed by the customer at his/her home garage or home yard or they can be installed near customers for their shared use. Courier places parcel in the reception box and customer picks up the parcel in his/her convenience using messaged code. Reception boxes have the potential to reduce home delivery problems (such as missed deliveries) adding advantages such as flexible pick-up time, no missed-deliveries and less travelled kilometers for delivery service providers [14]. [15] Has found 60% cost reduction using reception box in comparison to AHD. In the study conducted by [10], multimodal last mile delivery approach is used in which lockers (reception boxes) are also adopted as delivery option. This study partly focuses on the comparison of different delivery modes. According to [10], adoption of lockers significantly improves the economic and environmental sustainability. However, their associated potential effects of increasing the number of private vehicles trips to collect the parcels [16] might make this mode inconvenient in highly dense areas due congestion issues.

### 1.4.3 Drone

With the limitations of above models, Drones are getting popularity as new last-mile delivery model. Thanks to the pioneering efforts of companies like Amazon, Drones are now being used to deliver parcels in a matter of minutes. Drones enable fast delivery to a specific, predefined point without much effort required: having no driver or truck costs, eliminating congestion costs, having less missed-delivery due to the very short delay, e.g. 30 min [16] between item dispatch and delivery, and is now the object of intense research. The convenience of sending packages to a client’s doorstep will create an improved customer experience [18]. However, it has some limitations as well for instance; regulation authorities can take only small parcels (up to 15kg).

### 1.4.4 Crowdsourcing

Shipping businesses are increasingly adopting third party delivery fleets as well as independent crowd sourced workers along with their in-house fleets. Hence, Crowdsourcing Is not a new concept. Crowd-shipping, or crowdsourcing, is “an app-based platform that connects the individual wanting to ship a packet with an individual willing to carry the shipment in the first or last mile logistics of urban areas [19]. ICT is evolving day by day and it enables current boom of Crowdsourcing. Every process in supply chain (e.g. getting customer orders, contacting crowd source, interaction among company management and crowd workers and their co-ordination, customer support, granting rewards to customers and workers, etc.) are supported by ICT and it has enabled the shipping companies to bridge time-location gaps [20]. In recent times, crowd sourcing has been adopted by several areas such as health care [21], journalism [33], public transport [34] etc. In logistics, the main objective is to deliver goods and/or information to the right addressee at the right place at the right time [18, 22]. The concept of ‘crowdsourcing’ may contribute valuably towards this objective [11, 20]. Crowdsourcing can be combined to the logistics, referred as crowd logistics. The idea of crowd logistics is to involve ordinary people in the delivery of packages to the final consumers. In a crowdsourcing project, there are typically two kind of stakeholder (outsourcing companies and crowd workers) and they have following objectives: (1) crowd worker’s goal is to maximize their income by choosing the task they have to complete. (2) Outsourcing companies wants to minimize the cost of last mile delivery by assigning parcel order to crowd workers. Availability of crowd workers at required time is also an issue if there is less number of crowd workers signed in for work. Hence, Crowdsourcing model requires offering incentives to crowd workers along with proper pricing, compensation schemes in extra ordinary situations (heavy rainfalls, snow, large distance deliveries) in order to engage the crowd for work. For example, a decade ago the most popular pricing scheme was bidding [23], while nowadays compensation fees are computed using numerous multipliers, which take into account, among others, workers’ flexibility and covering demand peaks [23,24]. On contrary, many crowdsourcing projects are successful without any monetary compensation for the participating crowd sources [35]. In those cases, where result-based compensations are involved, these are typically small monetary rewards, price incentives on products and services, or of non-monetary nature such as granting access to exclusive information [25]. From the crowd sources’ perspective, the mentioned monetary and non-monetary rewards represent incentives for participation in crowdsourcing projects [25].

The contribution of this paper is two-fold. Firstly, we propose modification in the framework initially proposed by [10] to address the dynamic and stochastic VRP with time windows (DS-VRPTWs) problem in the city of Turin. This framework allows to create real-time scenarios by describing and combining the requirements coming from different stakeholders. The framework generates new instance set and allocates delivery request to nearby crowd-worker. Secondly, we apply our framework to a case study focused on the online urban freight distribution in the city of Turin (Italy). This research highlights the adoption of crowdsourcing in last-mile delivery along with other delivery option (cargo-bikes and vans), its comparative economic, environmental effects and efficiency. Additionally, we compare the overall distance covered and request rejection trend among all the selected delivery options for the research.

This paper is organized as follows; In Section 2, we review the literature of existing studies regarding crowdsourcing in last mile delivery and its route optimization. Section 3 describes the methodology we propose in order to simulate the modified framework. Section 4 includes the case study of city of Turin and data collection method. We analyze the results in Section 5. Conclusions and future perspectives are discussed in Section 6.

# 2. Literature Review

The goal of this review is to identify the literature concerning crowdsourcing in last mile delivery. Our literature review follows two streams: impacts of crowd sourcing on last mile and academic models that focus on service as well as optimization of crowd sourced delivery. Most of the literature available has focused on the business models regarding crowdsourcing while little is available about the real world impacts of crowdsourcing; hence, we try to investigate the literature that is related to economic, environmental and social sustainability of the last mile using crowd sourcing strategy. We also try to investigate the availability of the literature that uses the optimization and real data to evaluate the impacts of crowd sourcing on last mile delivery as most of the studies concerned with last mile delivery are conducted using mathematical or academic data.

## 2.1 Literature on Impacts of Crowdsourcing on Last-mile

Study the use of in-store customers to deliver parcels to online customers to investigate the potential impacts of this strategy on retailer's economic aspects, [44] only focuses on economic impacts without considering environmental consequences. Furthermore, [45] has studied the case of Walmart in which in-store customers (crowd source) deliver the items to online customers. The purpose of this strategy is to guarantee same day delivery to online customers and allow professional company drivers to stay on hold for un-foreseen deliveries. This strategy can be counter-productive from city logistics perspective as it can increase the urban freight movement. In economic terms, sharing economy has indicated the substantial benefits for the businesses. Particularly in logistics, crowdsourcing provides customers access to wider range of goods [46], superior parcel delivery service by being faster [46,48], more flexible [47], more convenient [50], traceable in real time [49] and better priced [47,48]. Companies benefit from crowdsourcing due to its larger reach and it also require only light infrastructure that reduces investment in vehicle fleet, employees and maintenance [46,47,48,50]. The most important contribution of crowdsourcing is envisioned from environmental perspective by using existing flow of vehicles. Crowd sourcing leads to more efficient vehicle loads and routes [47] and reduces traffics, congestion and $CO_2$ emissions [47,50]

Propose four A's classification of sustainable city distribution of transportation based on their primary intention of: Awareness, Avoidance, Act and shift and Anticipation of new technologies. First, awareness of last mile and urban transportation is created by involving randomly unified crowd. It can reduce the high demand of parcel delivery generated by E-commerce sector and also ensure the successful received deliveries by increasing the employment opportunities among the citizens. Secondly, congestion in the urban transportation can be avoided by encouraging the citizens to use the free space for their trips [57]. In addition, integrating the crowd with other initiatives such as small load containers and pick-own-parcel stations potentially provides sustainability advantages in the future [58]. Third, because of the participation of the citizens in logistics activities, usage of delivery alternative modes increases considerably. The crowd can choose to deliver the goods on their daily routes independent of their transport mode. Fourth, crowd sourcing in logistics is an example of digitalization as it actually based on the mobile applications, geo-location technology and communication tools. Hence, these technologies connect the urban population.

Study a set of 42 papers and interview several logistics personnel [51]. The study reports three characteristics that affect the sustainability: crowd motivation (monetary benefits), third party involvement (involvement of third party which are professional) in case of in sufficient crowd and modal choice. For environmental perspective, modal choice is significant factor to consider. [56] Study the benefits of the using social network in last mile delivery. The researcher considers the results of the survey that aims to determine the readiness of the people to deliver the parcel to the friend on their way back to home. Then they develop logistic regression algorithm to compute the probability that a person is ready to deliver a parcel to his/her social network friend. This paper concludes that such model will prove to be beneficial in environmental terms as it reduces CO2 emissions and operational cost of the last mile.

## 2.2 Academic Models of Crowdsourcing

These were probably first to model the crowd sourcing in logistics by modeling VRP with crowd sourced drivers [52]. The research provides an extension of classical VRP by introducing the additional outsourcing module they call occasional drivers. Occasional drivers are in-store customers that are willing to deliver parcel on their way back to home. Static mixed integer programming model is used in this study and demand and availability of occasional driver is already known, moreover, it is assumed that one occasional driver with maximum one delivery task to avoid the routing considerations. The above parameters used by [52] make the problem oversimplified. To solve the problem, [52] proposes the multi-start heuristic that greedily assigns the task to occasional drivers by solving the multiple small scale integer programming problems to determine the customers that are served by occasional drivers. The tests are highly dependent on three factors: (1) the compensation scheme, (2) the ratio of customers to be served and the occasional drivers and (3) the flexibility of occasional drivers from their original route. [53] Later proposed an extension to this problem by introducing time-windows.

Gdowska [54] introduced crowd source delivery model as a bi-level stochastic problem. This research also refers to in-store customers to deliver the parcels as occasional drivers, but unlike the above reviewed papers, here the occasional drivers have the choice to accept or reject the delivery. The first level of the algorithm solves the stochastic model to determine the assignments to occasional drivers, then based on the number of rejected orders, the remaining orders are done by company's professional drivers by solving CVRP. The researchers also proposed a heuristic that computes the overall cost on the parcels delivered by professional drivers and then increases the number of customers to be served by occasional drivers until no more cost saving can be observed. This paper suggests the compensation scheme for the occasional drivers based on location and size of the parcel and that scheme is independent of the driver's final destination. Soto setzke [55] proposed an algorithm that matches the delivery requests and the driver's planned route. The researchers model the problem as a max flow min cost using a bipartite graph. if a request is feasible to driver's route then the arc exists on the graph. The cost of an edge determines the additional time of the route. The primary goal of the research is to propose an algorithm that provides optimal matches for the drivers to pick the delivery from any location not necessarily store or warehouse.

Crowd sourcing models in context of sharing economy has been largely studied. [26] Propose a potential collaboration between people transportation companies and online shopping companies where a set of taxi drivers are serving both people and parcels using homogenous vehicles. This study has its primary focus on the economic perspective of the crowd sourcing model. The researcher considers various last mile delivery terminals; inbound parcels are delivered by the professional drivers whereas the outbound parcel is done by shared transportation. The researcher also assumes that the shared drivers are always available. [26] Proposes the continuous approximation algorithm using OVRP (Open vehicle routing problem). The paper also proposes a wage that driver expects to deliver the parcels. This wage should be greater than or equal to compensation a driver expects to earn providing the shared ride to the people. This paper concludes that crowd sharing is not as scalable as traditional deliveries i.e. (van deliveries). In terms of economic cost; However, [26] concludes that crowdsourcing has positive effects in economic terms in lower dense areas. Major difference between [26] and our study is that [26] does not consider time window constraint as well as real time data.

It [57] presents the research on the use of ride-sharing platforms such as Uber, incorporated with van delivery system for last mile deliveries. Private drivers are encouraged to pick up bundles of packages from the warehouse and deliver them themselves, with any remaining packages at time T being delivered by the warehouse's van system He derives the exact result to get the number of packages that can be delivered in a given time horizon by solving single-variable continuous optimization problem. However, their study is purely based on two theoretical case studies. [28] study the problem of crowd sourcing parcel delivery from depot (from where parcels are picked up) to locations in a particular region, he proposes to sub divide the given region into number of sub-regions. Further, vans are used to deliver parcels among those sub-regions, and then use shared mobility for the last-mile delivery in each sub-region. The goal of the study is to determine optimal number of sub-regions, which is calculated using continuous approximation of the average cost. Routes for the delivering package are computed by solving open vehicle routing problem (OVRP).

The work presented in [29], discusses the benefits of using new alternative delivery options as opposed to conventional delivery modes (for instance, cars and vans). It also considers crowd shipping which aims at encouraging individuals to occasionally "carpool" a parcel – to pick-up and deliver goods on the way to their own destinations using stochastic model. They combine the delivery process in way that: if some parcels are not assigned to crowd worker, then it is assigned to professional driver. Consequently, it controls traffic congestion and society benefits from this approach. On the other hand, it helps enterprise to reduce their operational cost. [29] considers randomly generated instances of 1 depot and 15 customer locations, Coordinates of customers' locations, the compensation fee for serving each customer, and the probability of OCs' acceptance to serve each customer are randomly and uniformly distributed in [0,1].

It [30] proposes a novel robust crowdsourcing optimization model to study labor planning and pricing for crowd sourced last-mile delivery systems that are utilized for satisfying on-demand orders with guaranteed delivery time windows. They develop their model by combining crowdsourcing, robust queuing, and robust routing theories. Their study is also based on mathematical models and no real time data is used. [31] Considers an online crowd sourcing platform that continuously receives new delivery request. They use an event-based rolling horizon framework that repeatedly solves the problem. They run optimization for all active tasks to allocate delivery to active crowd drivers.

Our literature review highlights that most of the studies generally provides positive opinion for crowd sourcing regarding its economic, environmental and social impacts but some of those studies lack the holistic approach. [44] Only focuses on the economic implications of crowd sourcing, [45] uses the in-store customer to delivers same deliveries that can increase the road congestion. However, [46] [47] [48] [49] [50] provide potential benefits of crowdsourcing in logistics. [57] Has proposed 4 A’s that focuses on theoretical hypothesis and potential results of crowdsourcing. The study conducted by [51] is solely based on the questionnaires and study of previous papers; hence lacking the real repercussions of the crowdsourcing model. The first stream of our literature review provides potential benefits of using crowdsourcing model in logistics but some of the literature lacks in holistic view that takes economic, environmental and social consequences altogether; moreover, the papers are based on theoretical understanding and models and lack the real data for their results. In our opinion, no research has been conducted regarding crowd sourcing with realistic data-set. Our study introduces the simulation-optimization framework initially proposed by [10], with some modifications which provides deep insights on accurate impacts of crowd sourcing in urban areas. We will discuss this methodology in next section.

# 3. Methodology

This simulation-optimization framework is an extension of framework proposed by [10]. Here we have introduced crowdsourcing module in the simulation-optimization considering parameters for crowdsourcing from the literature. Simulation is implemented in python, whereas optimization is implemented using JSPRIT optimization library that solves VRPTW and it is based on ruin and recreates method. These optimization modules can be integrated as external ones. The framework consists of four modules.

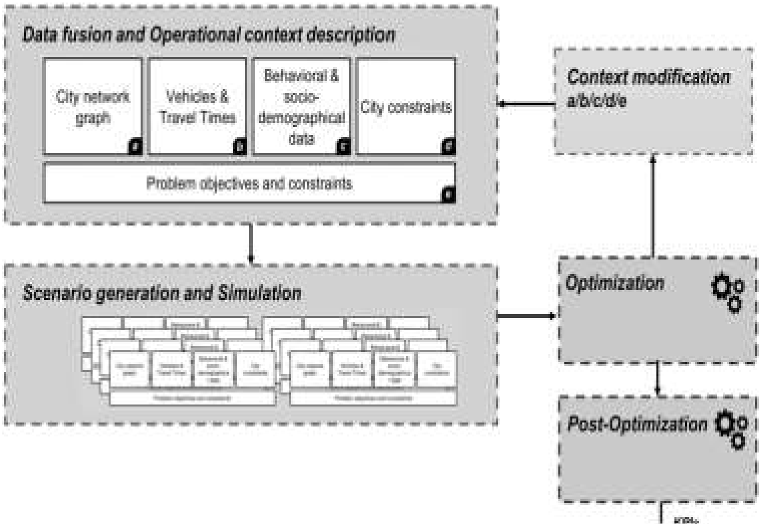


*FIGURE 3 SIMULATION-OPTIMIZATION FRAMEWORK*

## 3.1 Data Fusion and functional description

This phase describes the data gathering problem that may consider several data sources from where we can gather required information and problems related to functional description. Functional description can be defined using fives information sources: [10] city network graph, vehicles fleet and travel times, operational data (e.g. user's choice preferences), socio-demographical data and city constraints (e.g. limited traffic zones, specific restrictions for certain vehicles etc.) and problem objectives and constraints. Data can be stochastic and described by random variables for uncertain operational components i.e. service times or travel times. Then the problem is defined by the objectives and the constraints. Framework requires five types of data as input.

### 3.1.1 City and network graphs

Simulation is based in same city as of [10], we will use that data to get customer locations and depot locations. We consider a $2.805 \times 2.447$ km$^2$ area in Turin which includes the center of the city and a semi central area as in [8] (see Fig. 2). List of depots and likely customers are considered inside in that area; location of crowd workers are generated using heuristics. For bikes and crowd workers, satellite facility is used. A list of road segments is needed and it is arranged as network and network is defined as sequence of the connected points. Average speed of vehicle is calculated by speed sensors. Every element has distinct identification and coordinates.

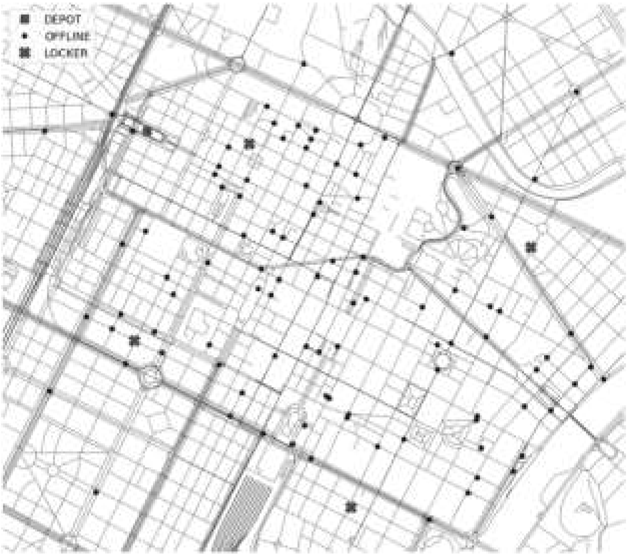


*FIGURE 4 AREA CONSIDERED IN THE CASE STUDY. NOTE THAT IN THIS FIGURE, THE MOBILE DEPOT (SQUARE) AND A SET OF OFFLINE CUSTOMERS (CIRCLES) AND LOCKERS (CROSSES) ARE REPRESENTED*

### 3.1.2 Vehicle Fleet

It includes vans and cargo bikes for the professional drivers of the company. It has certain capacity, $CO_2$ emissions, speed and fuel consumption etc. Every type of vehicle has its own travel time and cost. These are provided by companies along with other sources such as sensors spread all over the city. We consider three types of parcels, 0-3 kg these are small parcels, 3-6 kg these are medium and more than 6kg are large parcels. We consider vans for crowd worker. The expected numbers of parcels for each class, expressed as a percentage of the total number of parcels delivered, are shown in Table 1.

### 3.1.3 Operational Data

It consists of the data of final customer's behavior for specific market. It captures customer demands i.e. time windows, product demand and locations. We consider 9:00 to 17:00 working hours, unit of time is 1 minute. Demand of each potential customer is provided along with time window request. Customer's expectations of HVRPTW are described, for every location of customer $i$, and for every time unit $t$ of time horizon, request appears for location $i$ at time $t$.

### 3.1.4 City Regulations

There are some laws imposed by city administration such as access time windows, forbidding trucks during day hours and weight constraint for a specific vehicle type.

### 3.1.5 Objective and constraints

Objective is to minimize the travel distance of the last mile delivery and reduce number of rejected requests.

# 4. Case Study: Urban Freight Collection in Turin

We adopt the case study of the city of Turin. The aim of our analysis is to analyze the impact of crowd sourcing with multimodal delivery options to face the demands generated by e-commerce.

## 4.1 Scenario generation and simulation

Once above factors are defined, set of different scenarios can be generated and each scenario can describe an operational day. *Monte Carlo* method is used to generate instances; users can define a scenario by setting their inputs. Its methodology is as follows: simulation module generates the following process repeatedly, for provided number of times. The simulator generates the different scenarios. The optimization module performs its task for each scenario. Aggregated results are obtained for each iteration and optimization is performed. Extreme and unrealistic conditions are checked on basis of gathered information. Georeferenced module is responsible to get more accurate travel times and cost. Additional KPIs e.g. $CO^2$ emissions, travel times etc. would be computed by another module after optimization.

## 4.2 Benchmarks

• **Benchmark 1 (B1):** Only in-house traditional vehicles (i.e. fossil-fueled vans) are used to manage all the parcel delivery in urban areas.

• **Benchmark 2 (B2):** In this benchmark, we consider vans and cargo bikes. Outsourcing of classes of parcels to green carrier subcontractors (i.e. they use bikes and cargo bikes) is a common practice to obtain operational and economic efficiency and customer proximity while reducing the environmental impact of logistics activities [34]. Thus, in the B2 we consider that a green subcontractor delivers the parcels up to 6 kg in the central and semi-central areas of Turin. On the contrary, the traditional carrier manages all remaining parcels.

• **Benchmark 3 (B3):** We consider vans and crowd workers. Outsourcing of parcels to Crowd workers is new model. Crowd workers with cargo bikes are requested to deliver a parcel, which they can accept or decline. We consider that crowd workers deliver small size parcels (up to 5kg). Traditional carrier manages all remaining parcels.

Table 1a defines the parcel types as expressed in [37], the data specified in this table is heterogeneous in terms of parcel size. The parcels are classified as "mailer" (0-3kg), "small parcel" (3-6kg), and "large delivery" (>6kg). Mailers cover the largest portion of parcel distribution. In our study, we assign mailers and small parcels to cargo bikes and crowd workers. Table 1b defines the capacity of the vehicles used in this study. We use two types of vehicles in our study: traditional vans used by professional drivers employed by the company, and cargo bikes used by professional cargo bike rides employed by the company and crowd workers. Traditional van can deliver 100 parcels at a time with maximum parcel size of 70kg, whereas cargo bikes can deliver 10 parcels with 6kg maximum parcel limit. Table 1c specifies speed limits of the vehicles used in this study, traditional van can achieve maximum speed of 40km/hour in urban area due to city traffic rules, and cargo bikes can attain 20km/hour speed at maximum. Table 1c also shows setup time of traditional vans. Setup time refers to the loading time of parcels into the vehicle. Table 1d shows the average service time in minutes of each parcel type with respect to each vehicle type. Traditional vans take 4 minutes to deliver mailer and small parcel, whereas it takes 5 minutes to deliver large parcel. Cargo bikes only deliver small parcel and mailer; it takes 2 minutes for both types of parcels.

## Table 1 Input Data

| Input Data | | | |
|---|---|---|---|
| **Class** | Weight range (kg) | Classes of parcel | **Percentage on total parcels, %** |
| **Mailer** | 0–3 | | **57** |
| **small delivery** | 3–6 | | **13** |
| **Large Delivery** | **>6** | | **30** |

## Table 2 Capacity

| Capacity | | |
|---|---|---|
| **Vehicle** | Maximum parcel size in coverage delivery (kg) | Capacity |
| **Van** | 70 | 100 |
| **Bike** | 6 | 10 |

## Table 3 Speed-Setup time

| Speed-Setup time | | | |
|---|---|---|---|
| **Speed in urban area** | | | **Setup time** |
| **Vehicle** | Speed (km/h) | | **15 min** |
| **Van** | 40 | load bikes at | **15 min** |
| — | — | mobile depot | — |
| **Bike** | **20 km** | — | — |

## TABLE 4 SERVICE TIME

| Service time to deliver each class of parcels | | | |
|---|---|---|---|
| **Vehicle** | Mailer, min | Small delivery, min | Large |
| **Van** | 4 | 4 | 5 |
| **Bike** | 2 | 2 | - |

Functional description can be used to describe likely customers in city and offline customers out of likely ones and ratio of premier members. We have three functional descriptions of 550,350 and 150 likely customers respectively with 70% offline customers and remaining ones are premier. Customers are arbitrarily chosen from list of input data. Then it is trivial to calculate the distance between customer and depots on the map by using dijkstra's shortest path. From computed distance matrix it is possible to get the travel times of the customers and depots by using input data obtained from the speed sensors. Degree of dynamisms for online requests for each day are 15,30 and 45%. For each degree we generate n Poisson random variables for n instance sample with parameter λ subject to dynamism. For each scenario, optimizer solves the HVRPTW with respect to requests received along with revealed time and day. Every instance is created in terms of benchmarks presented above. This information derives from interviews with Chief Executive Officer and logistic director of an international parcel delivery company and of an e-commerce company operating in Turin. For further information about these data, the interested reader could see [36]. Moreover, the tests are conducted using real data concerning the customer distribution and daily volumes of deliveries in Turin between 2014 and 2015, provided by the international parcel delivery company that operates in Italy and is involved in the urban electronic logistics [37].

## 4.3 Optimization Module

As already mentioned above, we propose the extension of the simulation-optimization framework proposed by [10]. We have included crowd workers along with professional fleet of drivers. The problem is defined as follows: we have a depot location and n set on customers, it can be defined as $R = \{1, \ldots, n\} \times \{1, \ldots, h\}$ of likely requests, that means for each time t, and for each customer location we have a single request. The probability of every request is assumed to be known along with demand, time window and service time. Optimizer will try to allocate the arrived request to crowd worker if it won't be adequate for professional fleet in terms of travel distance and cost. In case of request rejected, a function $c: R \rightarrow \mathbb{R}+$ defines the penalty cost inquired whenever a request $r \in R$ is rejected.

# 5. Results and Analysis

In this section, we describe the computational test of simulation-optimization framework. The results are based on set of randomly generated test runs. For each benchmark and each operational context, independent runs are performed, so we have obtained 270 solved instances by our optimizer. We have considered different KPI's as following.

## 5.1 Economic Sustainability

Economic sustainability pertains to financial profits for the enterprise. B1 comprises of Vans that can be managed by company itself or it can be externally managed by subcontractor [12]. In case of external fleet management, cost increases by 15%. Typically, contract schemes in logistics systems converts cost per kilometer to cost per stop. For crowdsourcing benchmark, we consider cost per parcel.

Cost per stop (internal): in case of internal fleet management.
Cost per stop (external): in case of external fleet management.
Cost per parcel (crowdsourcing): cost of the single parcel delivered by crowd.

For further details about the computation of operating costs and each cost item, see [37].

## 5.2 Environmental sustainability

The goal of the enterprises is not limited to achieve economic sustainability only, city administrative regulations has made it obligatory for companies to plan their last mile deliveries to mitigate pollution and greenhouse gases. Environmental impact of adopting crowdsourcing is evaluated by comparing CO2 savings as the kilograms of CO2 (CeKg) in B2 and B3 in comparison to B1. We express the CO2 emissions in monetary terms by apply carbon tax based on the average price paid for CO2 emissions [12]. Note that according to the regulation ISO/TS 14067:2013, we consider the total amount and costs of greenhouse gases emitted directly or indirectly by the overall parcel delivery chain.

## 5.3 Operational sustainability

It is related to the performance and efficiency of each actor involved in the last-mile delivery process. We compute the efficiency in terms of number of parcels delivered per hour (Nd/h), Kilometers travelled by vans in a day (Km/d) the number of request rejected per day (Nr/d).

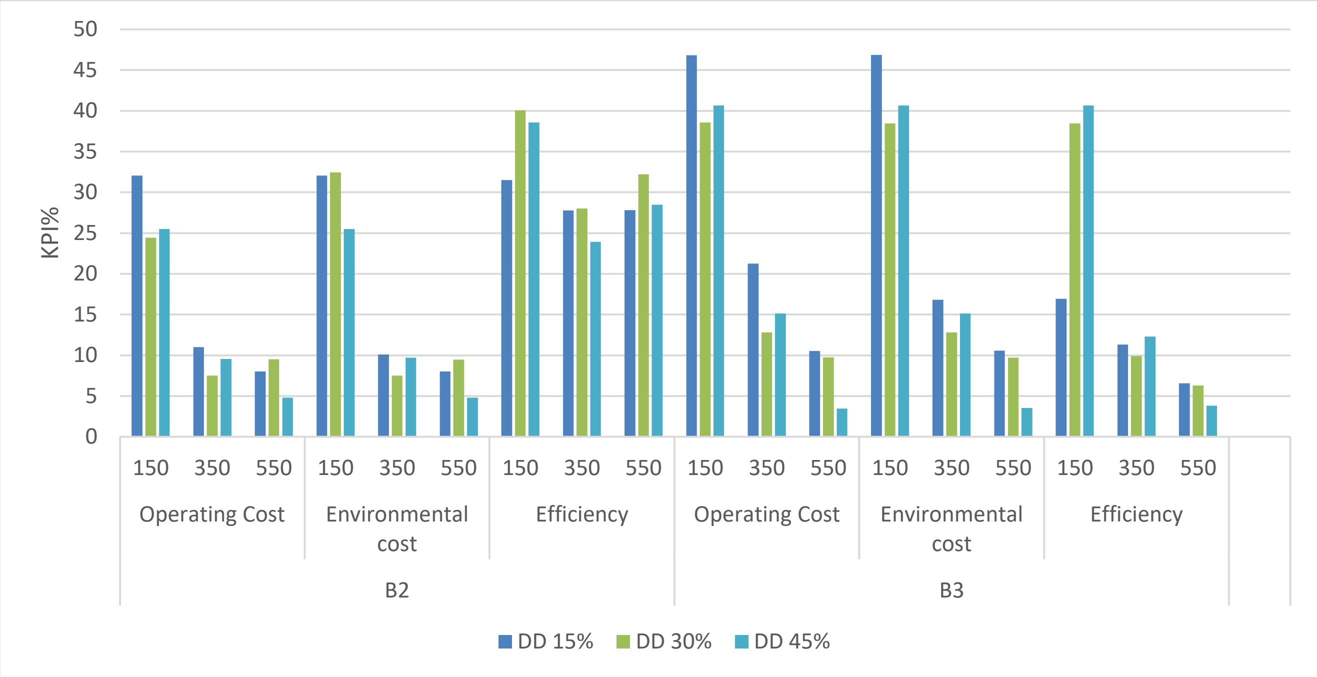


***FIGURE 5 PERFORMANCE OF THE TRADITIONAL CARRIER WHEN CARGO BIKES AND CROWDSOURCING ARE ADAPTED***

The above figure depicts the performance of benchmark B2 and B3 in comparison to traditional courier i.e. B1. The values are computed as percentage variation of each KPI with respect to the value of the same KPI in benchmark B1. Δ operating cost highlights the cost savings; Δ environmental shows the environmental cost savings. In particular, the Δ operating costs and Δ environmental costs show the percentages of costs savings, both operating and environmental, that the traditional carrier obtains when the parcels up to 5 kg are outsourced to the cargo bikes or delivered by a crowdsource worker. While the item Δ efficiency represents the loss of efficiency that affects the traditional vans due to the reduced number of deliveries and the high saturation of vans. Fig. 3 depicts the improvement of both economic and environmental costs when green carrier (B2) and crowd workers (B3) delivery option is adopted. Particularly, in B3 the adoption of crowd workers and optimization of routes lead to a cost saving by 22% due to reduction of 15% of van usage; similarly, reduction of CO2 emission on average of 673kg is registered, leading to reduction of environmental cost by 21%. Maximum benefits in Δ environmental and Δ operating in B3 are reported when the number of customer's location to serve are lowest i.e. 150, reduction of both cost by 42%. One reason for this result is that Crowd workers are assumed to use cargo bikes; Hence, B3 results 15% of reduction in van usage, consequently leads to reduction of environmental and operating cost. Another reason that crowd workers are assigned request dynamically, and due to low number of customer locations, request pool is manageable by using limited crowd source drivers with route optimization.

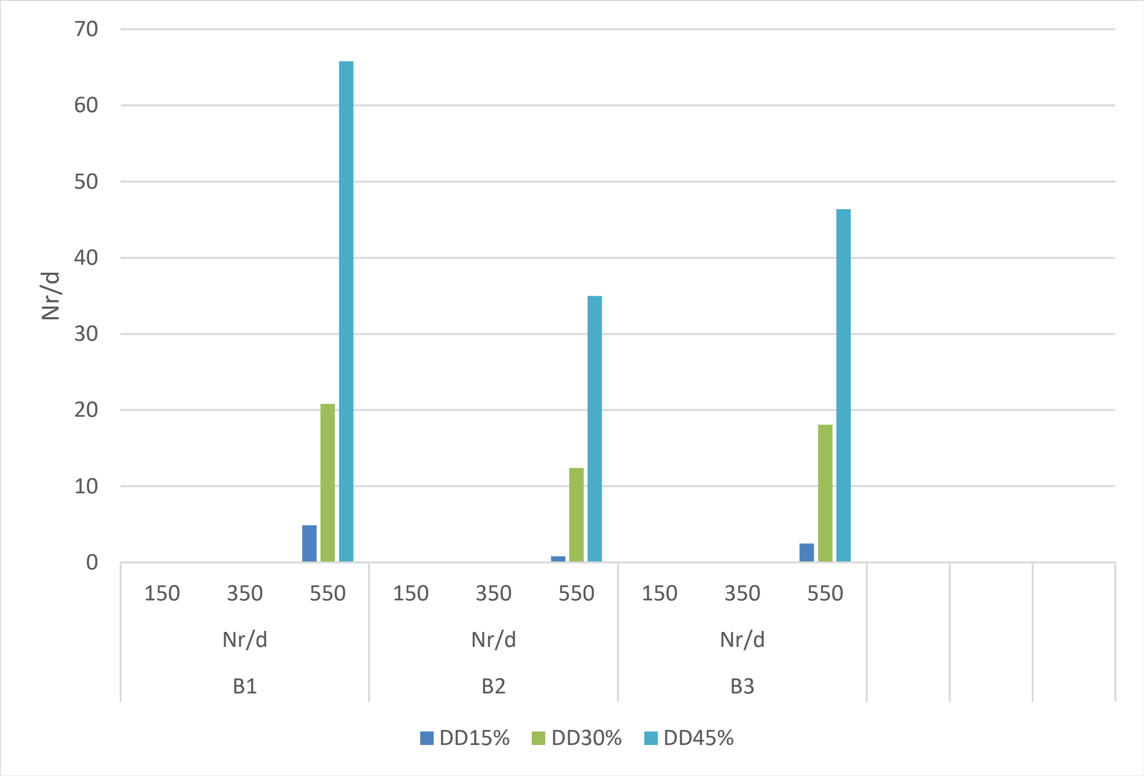


***FIGURE 6 AVERAGE NUMBER OF REJECTED REQUESTS A DAY***

The above figure reports the comparison of average number of rejected request in the operational context when there is highest number of customer locations i.e. 550, also segmenting the results according to the degree of dynamism. The number of requests rejected is particularly higher when degree of dynamism is 45% in every benchmark; high number of online request along with 550 customer locations is difficult task to handle. B2 has the lowest number of rejected request; whereas, there is highest number of rejected request in benchmark B1. Crowd workers has the choice of acceptance or rejection of parcel delivery, crowd worker can reject the request for several reasons like long distance delivery and low monetary compensation, fault in the vehicle or bike or simply he or she is not willing for no reason. On the contrary, professional bike riders are obliged to work and deliver the parcels and they have no authority to reject the delivery by themselves. Adoption of cargo bikes with vans in benchmark B2, leads to reduction of 47% of rejected request and adoption of crowdsourcing with vans B3 leads to reduction of 25% of rejected request.

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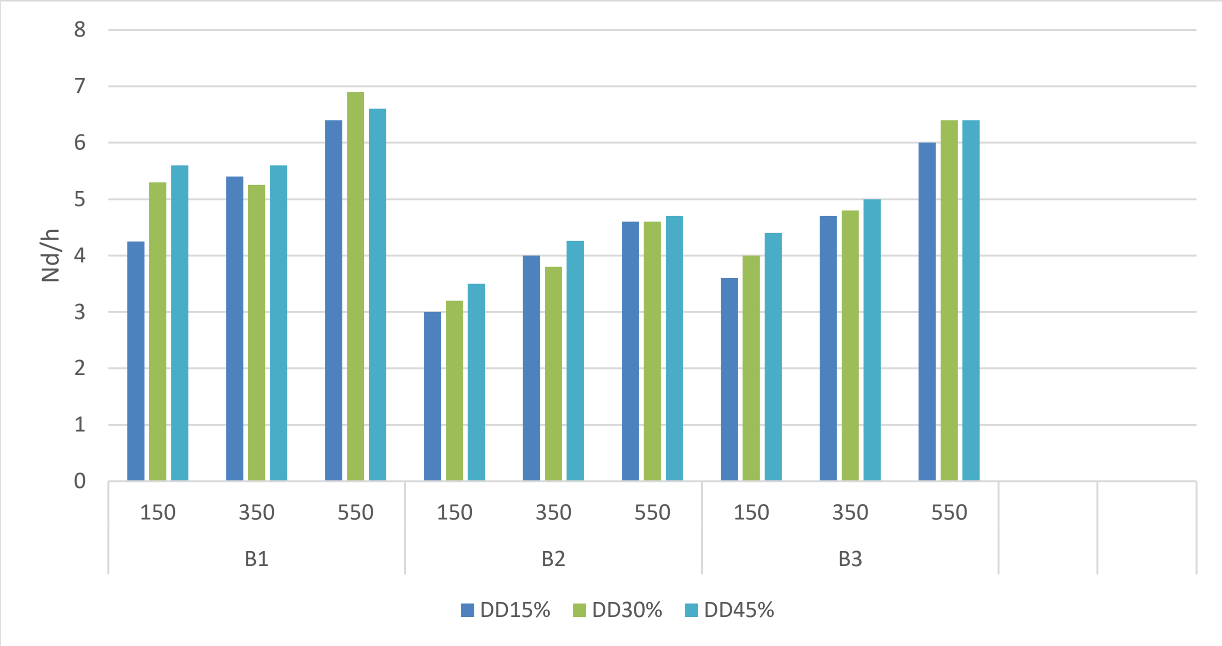


**FIGURE 7 NUMBER OF DELIVERIES PER HOUR (ND/H) FOR EACH BENCHMARK**

Fig. 7 reports the number of deliveries per hour of all the delivery options adopted in the different operational contexts, segmenting the results according to the number of customers in the scenarios and the degree of dynamism. Combined working hours of traditional vans and bikes are assumed in B2, similarly number of deliveries done by crowd workers is combined with the traditional couriers. [12] figures out that outsourcing small parcels and mailers to green carriers results in 80% percent loss in efficiency, hence Fig. 5 depicts the poor performance of B2 in comparison to traditional vans (B1). B2 results in 29% reduction of parcels delivered in comparison to B1. On contrary, introduction of crowd workers has provided better results in terms of performance, especially when customer locations are higher i.e. 350 and 550, the performance of B3 is identical to B1. The reason for this is that online requests are dealt by crowd workers, because Professional drivers have a scheduled day, abundant availability of crowd workers enable dynamic dispatch of parcels when degree of dynamism is high. One more factor that distinguishes the performance of crowd worker and professional worker is that professional drivers are experts in delivering parcels at faster pace, crowd workers are occasional couriers so there is possibility of unwanted delays. In our study, Nd/h in B3 reaches to its lowest when customer locations are lowest i.e. 150.

Moreover, for low density areas, where customer locations are distant, crowd sourcing has its limits. Crowd workers want maximum number of orders in minimal time in order to get as much monetary compensations as they can, but in low density areas, there are lower number of orders and possibly large distant deliveries that discourage the crowd workers to work.

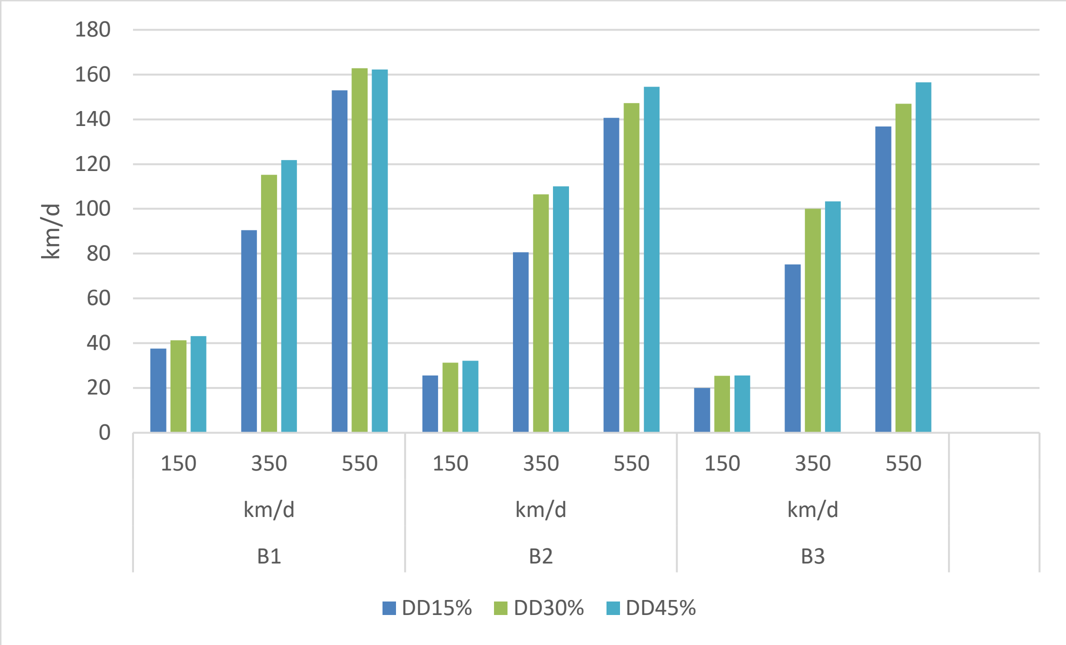


***FIGURE 8 DISTANCE COVERED BY TRADITIONAL CARRIER IN EACH BENCHMARK***

Fig. 8 highlights the Average distance covered by the vans in each benchmark in different operational contexts, the results are segmented according to degree of dynamism. B1 has worst figures of all benchmarks as only internal van fleet is used and the all the parcels are delivered using vans as traditionally last mile delivery process is done in AHD. In comparison to B1, benchmark B2 results in 11% of less distance travelled; whereas, benchmark B3 results in 15% reduction in total distance travelled. There is significant difference of 40% between the distance travelled between B1 and B3 when customer locations are 150; however, when customer locations are 550, there is negligible difference between B1 and B3 as traditional carriers have to travel over larger distance to complete their task.

# 6. Conclusion

This research topic is inspired from the work of [10] where author proposed the realistic benchmarks for the VRP in city logistics applications. As the title of the thesis is the impacts of crowdsourcing, here simulator-optimizer framework proposed by [10] is used and slightly modified to analyze the impacts of crowdsourcing in urban logistics by introducing crowd-sourcing module. The main limitation of the study on crowd-sourcing is its data collection method The novelty of our contribution is that the realism of case study is guaranteed by the introduction in the framework of different real data sources and stakeholder requirements. Simulation and optimization has been performed to observe and analyze the economic, environmental and operational impacts of crowdsourcing in the urban context of the city of Turin. In addition, we considered the integration of different deliveries modes (traditional vans, cargo bikes), reflecting the current practices in the city, which are devoted to the adoption of green delivery options. The experiment highlighted that the switch to crowd sourcing could lead to operational efficiency and better online service delivery within urban areas. Moreover, crowd sourcing with environmentally friendly vehicles could result in benefits in terms of $CO2$ emissions reduction. The loss of efficiency, when crowd sourcing is adopted with traditional vans, is lower than the integration of traditional vans and professional cargo bike employees. An important outcome obtained is that a multimodal last-mile delivery achieved by means of adoption of crowd-sourcing allows reaching the highest levels of economic sustainability when the number of the customers are low/medium. On the contrary, vans and bikes represent the most appropriate means to deal with high demand, while still pursuing environmental benefits.

With current lack of space and human resource, the future of last-mile delivery is in crowd-sourcing that enables companies to adopt crowd-workers in their supply chain. In order to properly manage the ever-growing customer online demands, companies have to adopt this approach to mitigate capacity shortage in company owned vans and trucks. Furthermore, crowd-sourcing also proves to be sustainable in terms of economic benefits. Vehicle ownership and maintenance is not managed by the company, also fuel cost is managed by the crowd worker, feasible monetary compensation can attract more and more crowd workers to offer their services. Furthermore, crowd-sourcing also helps reducing traffic congestion as number of cars and trucks deployed by logistic companies also reduce; hence, administrative fines and restrictions can be avoided by adopting crowdsourcing. It is essential for the businesses that offer last-mile delivery to use technology to cut cost and $CO2$ emissions, reduce inefficiencies, and improve customer experience.

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