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„Crowdsourced Delivery: An Alternative to In-House Delivery“

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Abstract

The last-mile delivery is facing new challenges resulting from the rise of e-commerce, consumer expectations regarding shorter delivery times and urbanization. The new, alternative solutions are being implemented to face these challenges, and one of them, coming from the rise of sharing economy is crowddelivery.

In this thesis, a model is constructed to evaluate if incorporating private individuals as carriers can be considered an option in the local delivery. We consider a setting where pedestrians serve as carriers and in-house vehicles as a back-up to cover all order requests. The results are compared to the pure in-house delivery with regard to distance reduction. Furthermore, the sensitivity of the proposed model to factors regarding maximum carry weight and maximum cover radius of crowdsource is investigated. The results show that both factors, especially carry weight, increase the number of assigned tasks to crowdsources and thereby have a certain effect on reducing distances travelled of in-house vehicles.

Abstrakt

Die Last-Mile-Lieferung steht vor neuen Herausforderungen, die sich aus der Zunahme des elektronischen Handels, den Erwartungen der Verbraucher in Bezug auf kürzere Lieferzeiten und der Urbanisierung ergeben. Neue alternativen Lösungen werden implementiert, um diesen Herausforderungen zu begegnen. Eine davon, die aus dem Aufstieg der Sharing Economy resultiert, ist die Crowd-Lieferung.

In dieser Thesis wird ein Modell erstellt, um zu beurteilen, ob die Eingliederung von Privatpersonen als Lieferanten als mögliche Alternative für die örtliche Lieferung in Betracht gezogen werden kann. Dabei betrachten wir eine Umgebung, in der die Fußgänger als Träger fungieren und die hauseigenen Fahrzeuge dafür vorgesehen sind, alle restlichen Bestellanforderungen abzudecken. Die Ergebnisse werden hinsichtlich der Entfernungsreduktion mit der reinen hauseigenen Lieferung verglichen. Darüber hinaus wird die Sensitivität des vorgeschlagenen Modells bezüglich Faktoren wie dem maximalen Tragegewicht und des maximalen Abdeckungsradius der Crowdsource untersucht. Die Ergebnisse zeigen, dass beide Faktoren, insbesondere das Tragegewicht, die Anzahl der zugewiesenen Aufgaben für Crowdsources erhöhen und dadurch einen gewissen Einfluss auf die Entfernungsreduktion der zurückgelegten Entfernungen von hauseigenen Fahrzeugen haben.

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List of Abbreviations

B2B : Business-to-Business
B2C : Business-to-Consumers
C/C Ratio: Customer/Crowdsource Ratio
CEP : Courier, Express and Parcel Market
CVRP : Capacitated Vehicle Routing Problem
CVRPTW : Capacitated Vehicle Routing Problem with Time Windows
EAV : Electric Autonomous Vehicles
GPS : Global Positioning System
KPI : Key Performance Indicators
MILP : Mixed Integer Linear Problem
MTVRP-RD : Multi-Trip Vehicle Routing Problem with Release and Due time
TSP : Traveling Salesman Problem
VRP : Vehicle Routing Problem
VRPB : VEhicle Routing Problem with Backhauls
VRPTW : Vehicle Routing Problem with Time Windows

1 Introduction

Not only that global e-commerce sales have more than doubled in the last five years, but predictions are that expansion in near future will be even higher (eMarketer, 2018). With rise of e-commerce, consumer needs and expectations have also shifted, especially regarding duration of delivery. They expect shorter delivery times, same-day delivery and even delivery to be made in specific timeframes. According to a survey by McKinsey (2016) 23% of all consumers are willing to pay additional fees on top of standard delivery fare for same-day delivery, 5% for delivery in a specified time window and 2% for instant delivery.

With that kind of pressure caused by online trade and consumer expectations, new logistic solutions have been constantly developing. One such option is the employment of private individuals as carriers in last-mile delivery where benefits are two-sided. From the retailer perspective, savings are made mainly because the compensation paid to a crowd carrier is significantly lower than costs for carrier companies, or when delivery is conducted with own resources. On the other hand, a crowd carrier receives compensation for doing an additional task usually alongside their daily activities by utilizing existing resources.

The core of this study is to explore if crowdsourced same-day delivery can be considered an alternative to the in-house delivery. Simulation is performed to investigate if using crowd for delivery service leads to cost reduction and to identify significant factors. According to McKinsey (2016) same-day delivery, especially instant delivery is applicable solely in urban city environments due to two reasons. First, instant delivery for distances larger than 5-10km is not cost-effective. Second, the time necessary to travel to distant locations makes such short-term requests hardly achievable. The same study also suggests that bikes as a mode of transportation would be the best option. Accordingly, this thesis is also focused on high-density urban environment. In particular, we are considering a part of urban city area, a square of $4km^2$ in size and pedestrians as a crowdsource. Analysis is done from business entity perspective, in particular one store located in the center of the examined region.

This thesis is organized as follows: in Chapter 2 the concept of last-mile delivery is explained and alternative delivery solutions are presented. Then we focus on incorporation of the crowd into the delivery process. Thereby, benefits and limitations of using a crowd are discussed. In Chapter 3 literature essential for construction of our model is analyzed and a methodological overview is provided. In Chapter 4, the examined problem is stated, and the two-stage solution is presented. Input data generation and relevant parameters are illustrated in a computational study in Chapter 5. In Chapter 6 the results of the simulation are analyzed, followed by conclusions in Chapter 7.

2 Theoretical Framework

2.1 Last-mile Delivery

The last phase in e-commerce, whereby cargo is transported from a depot to an end customer, is called last-mile delivery or final mile. Depending on the type of customer, we differentiate between business-to-business (B2B) and business-to-consumers (B2C) delivery. The last mile in B2C, which is the least efficient stage in the whole supply chain (Rodrigue, 2017; Y. Wang, Zhang, Liu, Shen, & Lee, 2016), can account up to 75% of the total supply chain costs (Gevaers, Van de Voorde, & Vanelslander, 2009). High costs in B2C segment are caused by the fact that substantial volume of individual parcels needs to be transported to various locations, whereby due to traffic uncertainty and congestion problems the planned routes can be altered. This occurrence is partially caused by the inability to deliver named parcels when customers are not at home and delivery attempt need to be repeated. In comparison to B2B, the other form of delivery, B2C is characterized by a lower volume of parcels and by the fact that a substantial number of consumers with usually one parcel need to be visited. Having in mind that every consumer has a unique location, the sum of traveling distances in order to visit numerous locations can be substantial. This can also be seen in the analysis made by American Transportation Research Institute (2016) which shows that labor costs make up 38% of total operational logistics cost, followed by the costs for fuel which accounts for 25%. How significant and extensive the last-mile in delivery is, tells the fact that 71% of all full-time jobs in Germany's courier, express and parcel (CEP)[1] market is incorporated in this segment (see Figure 1).

Another important factor influencing costs of last-mile delivery is the population density of the area that needs to be covered. In their research Gevaers et al. (2014) calculated the average B2C last-mile delivery cost of 3,87€ per unit delivered. Depending on the level of urbanization, costs can even double and vary between 2,75€ for highly populated area (more than 1500 inhabitants/km^2) and 7,75€ for rural area (less than 50 inhabitants/km^2). Other than that, deliveries with different time windows are also analyzed. In highly populated urban areas costs are between 2,75€ for same-day delivery without time windows and 5,77€ for narrowest, one-hour time windows. In contrast, costs for same time spans in rural areas are significantly higher and lie between 4,17 and 8,75€.

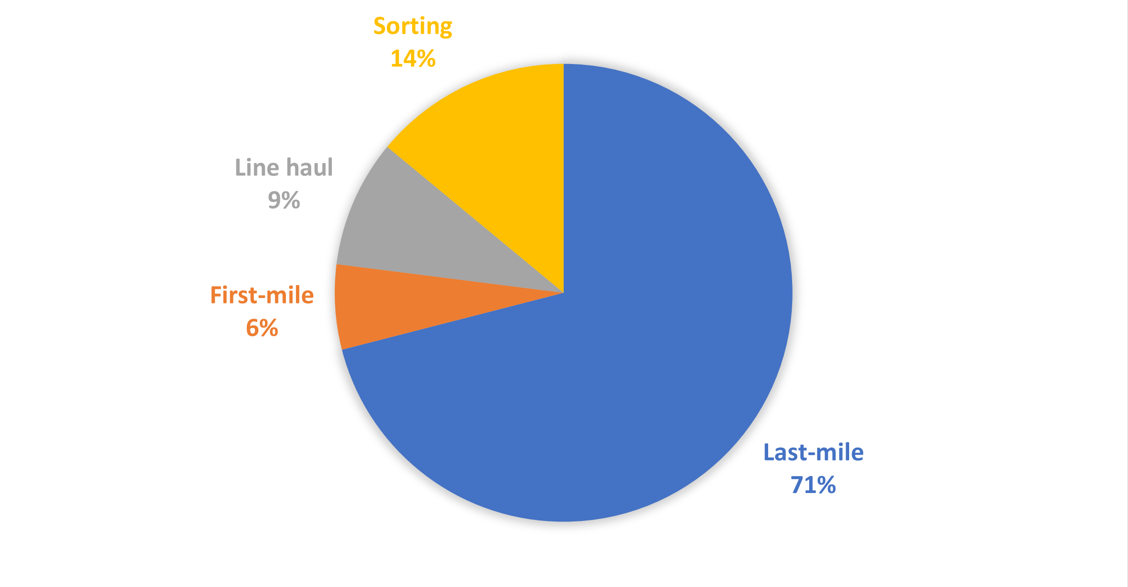

Figure 1: Distribution of full-time employees in CEP Market (in Germany). Source: Manner-Romberg, Kille, & Müller-Steinfahrt (2017)

For years the B2B segment has been dominant part of the CEP market. Despite the fact that the B2B segment remains an important source of income in delivery industry,

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[1] CEP or courier, express and parcel market includes parcels with weight between 1 – 30kg (Accenture, 2015)

in the last decade, the given share of B2C continually grows. This shift from B2B to B2C dominance in parcel delivery market is caused by e-commerce expansion (McKinsey, 2016). Since 2009 the B2C share in CEP market in Germany rose by 16% and is expected to increase even further (see Figure 2). In the North American market, the rise is even higher. Figure 3 represents forecast for 2019 which indicates that B2C market share will reach 48,8 billion US dollars, a rise of 24,4% compared to the year of 2015.

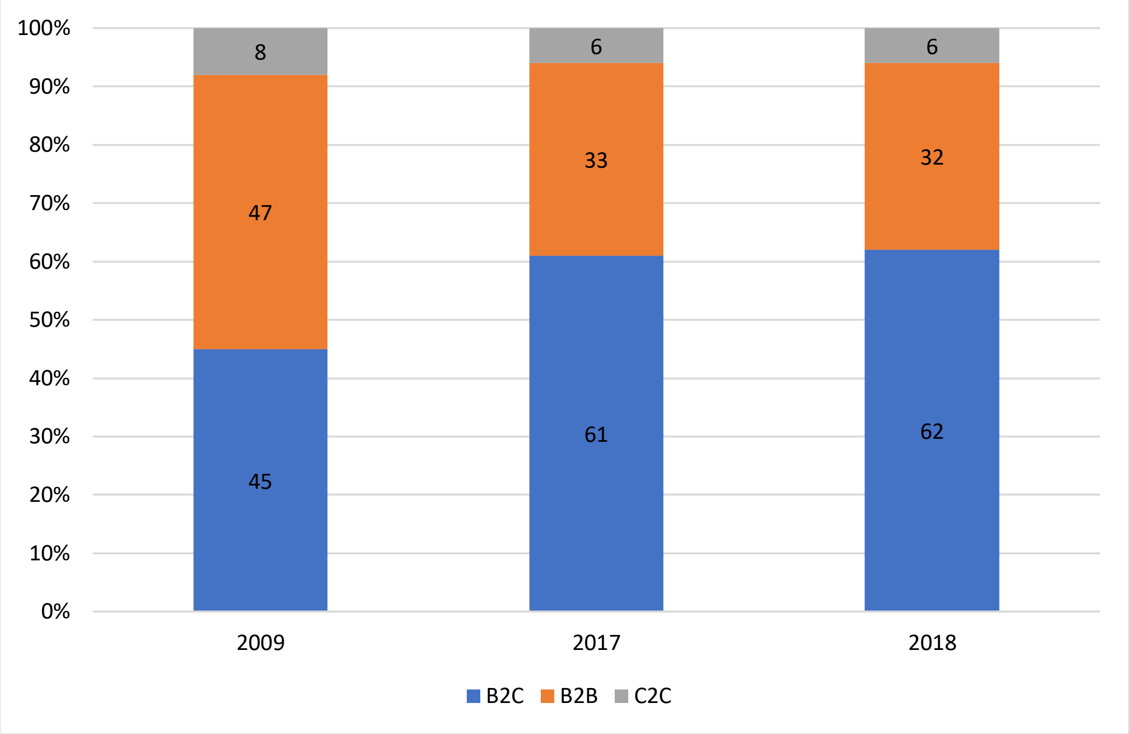


Figure 2: Market size of parcel services courier, express and parcel (CEP) market for period 2009 – 2018 by business segment (in Germany). Source: BIEK (2018)

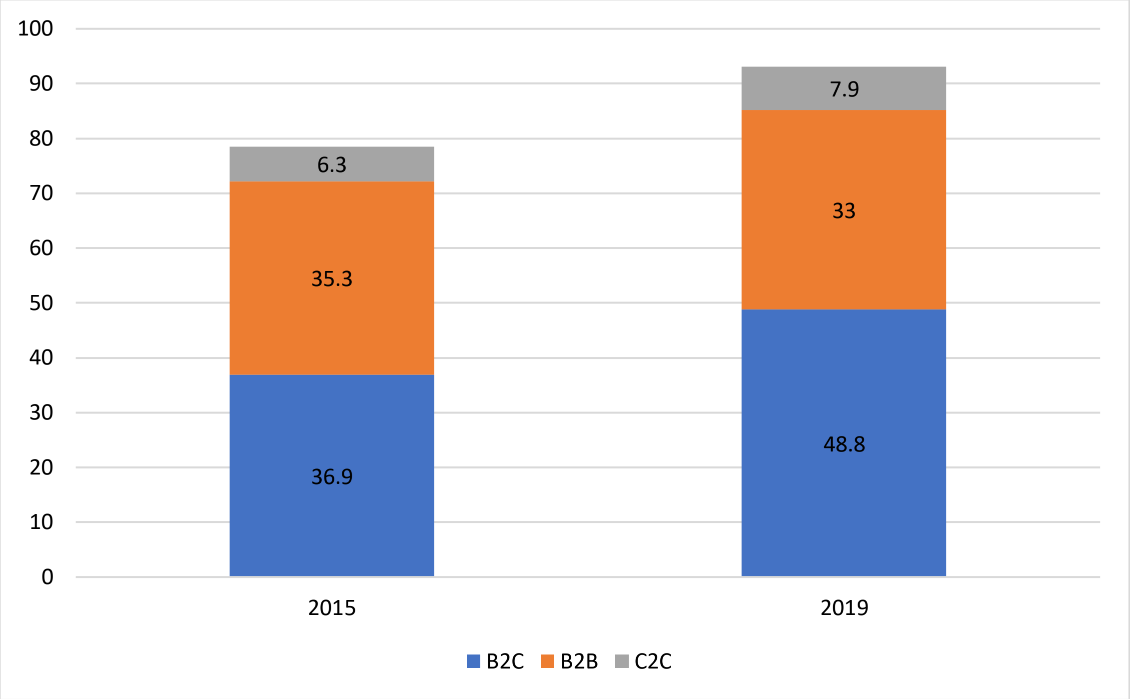


Figure 3: Market size of parcel services in the United States in 2015 and 2019, by segment (in billion U.S. dollars).
Source: ATKearney (2017)

2.2 City Logistics

Urban environments highly depend on efficient city logistics. It is inconceivable for such complex surrounding to be functional without it. Their impact on human lives is monumental, in positive as well in the negative way (Savelsbergh & Van Woensel, 2016). However, with the evolution of mankind and technology, city logistic is also changing. Six global megatrends are identified by leading consulting agencies Siemens, PwC, Ernst & Young, McKinsey and Zukunftsinstitut: digitalization and technology change, demographic change, climate change, urbanization, globalization and individualization (Kunze, 2016). Savelsbergh and Van Woensel (2016) distinguish six fundamental trends affecting the urban transportation industry, that are listed below in the following two excerpts with an emphasis on technological advancements.

2.2.1 Crucial Trends Affecting City Logistics

Changes in last-mile delivery, especially in a context of city logistics are caused by the perpetual change of society, economy and environment. In their work Savelsbergh and

Van Woensel (2016) compiled six biggest trends that are causing the evolution of city logistics.

- **Population growth and urbanization –** According to UN DESA (2017) world population had been growing with a constant increase of average annual rate of population change until 1970s when it reached its peak of 2,05%. Since then it still continues to grow but with a slight decreasing rate, until it dropped to 1,19% in 2015. Furthermore, urbanization rate has been constantly increasing since 1950 when 29,6% of world population used to live in urban areas. Today urban population makes up 55,3% of global population and it is anticipated to reach 68,4% in 2050 (see Figure 4). Along with an increased pace of urbanization it is inevitable that new demands in urban logistics are and will be appointed.

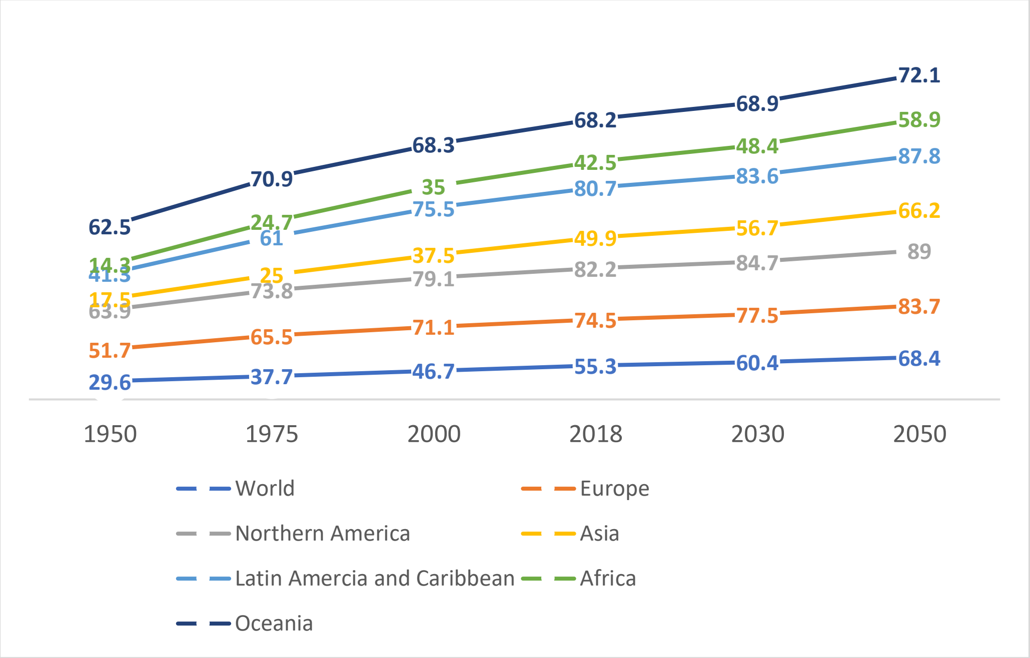


Figure 4: Population living in urban areas worldwide (in percentage). UN DESA (2018)

- **E-commerce growth:** The global e-commerce sales reached $2.304 trillion at the beginning of this year, which equals to 10,2% of total sales in retailing sector (eMarketer, 2018). The same study estimates that by the year 2021 this number will more than double to $4.878 reaching 17,5% of total retail sales. One of the main contributors to the rise of internet sales in the last decade is the development of mobile technologies. Out of all sales, a significant portion (58,9% of the total e-commerce sales in 2017) are conducted using mobile devices, e.g. mobile phones or tablets (eMarketer, 2018). This expansion of online shopping leads to new challenges in logistics and is partly responsible for the enlargement of the B2C segment which has already been discussed into in the previous part. Accenture (2015) suggests that due to e-commerce growth and mobile technology advances, logistics providers need to focus on the recipient in order to retain market share, lower the costs and boost revenue.

- **Desire of speed.** CEP market consists of three segments: courier, express and parcel. Since courier end express shipments are aimed at short delivery spans delivery is made during the same-day or even within a couple of hours. Delivery time in parcel segment is usually between 24 and 72 hours for national shipments conducted through traditional delivery channels offered by Deutche Post or DHL (Manner-Romberg et al., 2017). Recently, however, logistics providers have started to offer shorter delivery options, e.g., delivery in 1, 2 or 4-hour time. Offering a variety of delivery options it is a way for logistics provider to distinguish themselves from competitors and to attract more customers (McKinsey, 2016). The same study also shows that the majority of consumers chose the cheapest option of home delivery, whereas approximately 30% of respondents are willing to pay an additional fee for a faster delivery.
- **Sharing economy:** It has been a decade since platforms Airbnb and Uber had been founded. That was the beginning of the sharing economy where human consumption is shifted to collaboration. Nowadays, not only that accommodation and different transportation resources are shared, but also clothing, electric appliances and even services, human capital and intellectual property (Goudin, 2016). Besides the consumption domain, collaboration is also present between business subjects. Logistics carriers are co-operating by sharing their resources and infrastructure, which leads to increased capacity utilization, reduced costs and carbon emissions, and better service quality for their consumers (Chung, Gesing, Chaturvedi, & Bodenbenner, 2018).
- **Climate change and sustainability.** Freight transportation in urban environment is responsible for roughly 20 to 30% of all vehicle movements in a city (Rodrigue & Dablanc, 2018). As a result, city logistics is major influencer of global warming, and of human health. The biggest issues of logistics are air, noise and water pollution, traffic congestions, accidents, greenhouse gases emissions and land

use (Demir, Huang, Scholts, & Van Woensel, 2015). One way to reduce these negative influences is by enforcing regulations associated with transportation standards and gas emission levels. The other way is to use alternative, more environment-friendly solutions for transportation like electric vehicles, bicycles, drones. Even warehouses can be more green by turning to hydro and solar power sources, and by using motion sensors to cut unnecessary power use (Chung et al., 2018).

2.2.2 Technological Advances Impacting City Logistics

The logistic chain is a highly complex system. An immense amount of data needs to be processed in short time and in a highly dynamic surrounding. The global trends already addressed in previous section are leading to constant growth of transportation requests and customer expectations. Logistics is facing many new challenges with technology playing an important role. In the following part, advances in technology essential for city logistics are presented, grouped in three clusters by Savelsbergh and Van Woensel (2016).

- **Digital connectivity, big data and automation.** Nowadays all logistics providers use telematics to monitor their fleet of vehicles. Everything is connected and traced, from information about vehicles to details regarding every parcel that is being transported. Logistics systems are operating with big data, which require state of the art technology in order to keep up with real-time information in the supply chain. Speed is crucial to improve accuracy and utilize capacities in a more efficient way. Not only that data processing must be done in real-time, but also predictive analytics are used to plan upfront inventory on specific locations where they can be ready for shipment in shortest time possible. Forecasting of demand, capacity and labor with big data analytics improves utilization of all resources, quality of services and reduce costs in the whole supply chain (Chung et al., 2018). Specific algorithms are used to make real-time decisions, e.g. dynamic route optimization and adaptation on the go. Such new technologies and analytics are necessary to meet customer expectations and short time requests (ATKearney, 2017).

- **Automotive technology:** technological advancements in automotive industry most relevant for urban logistics are associated with type of fuel that is used and self-driving vehicles. The use of alternative fuel vehicles in logistics can be an important factor to reduce greenhouse gas emissions and noise. Effects can be immense considering that urban logistics make up to 30% of all traffic movements (IKEM, 2017; Rodrigue & Dablanc, 2018). Electric vehicles are being used for years now and decent supporting infrastructure for charging has been already put in place in certain geographical regions.

  Autonomous vehicles and ground drones are self-driving vehicles, that do not require human presence and thus can operate continuously without interruption. In logistics they are at present being used mainly in highly controlled environments, like warehouses (Chung et al., 2018) and distribution centers for, e.g., moving and packing operations. First prototypes of ground drones which are able to perform last-mile delivery to customer locations had been designed in 2013 and as of 2015 pilot programs have been launched. First one was "SideWalk" delivery robot developed by DHL in 2015 in Lithuania, followed by "Carry" robot launched by Dispatch in China in 2016, and a pilot program in London initiated by Starship in 2017 (Lee, Chen, Gillai, & Rammohan, 2016). The biggest potential of self-driving cars lie in the fact that they operate without human presence, so that labor costs can be significantly reduced. According to McKinsey (2016) future last-mile delivery in B2C segment will be completely conducted by self-driving vehicles, particularly in developed countries with high labor costs.

- **Unmanned aerial vehicles –** usually known as air drones with a storage unit sufficient to carry one single, small package per route. They can be crucial for urgent, time sensitive deliveries and deliveries to locations which are hard to reach by cars, e.g. islands, mountains etc. In urban areas they are used to avoid traffic congestion. In areas with low population density and small volume of orders, drones can be used as an option to conduct same-day or even time-window delivery request (McKinsey, 2016). First drone prototypes had been developed in 2005 and as of 2014 pilot programs with commercial purpose have been launched (Lee et al., 2016).

2.3 Traditional Delivery vs. Alternative Delivery Solutions

The term traditional delivery is associated with postal and delivery companies (e.g., ATPost, DHL, DPDgroup) when the delivery time for parcels is not guaranteed and usually takes 2-3 days for national shipments. The main advantage of traditional delivery comes from long historical presence. Along the way a substantial infrastructure has been built, which is crucial to handle large volume of orders typical for B2B services. The focus of traditional delivery was to provide services for business entities, also B2B. As already described in Chapter 2, B2B was a prevailing segment of the CEP market for decades, until the rise in e-commerce led to the B2C expansion. McKinsey (2016) anticipate that alternative delivery solutions like drone delivery will dominate in CEP market, whereas traditional delivery will account for 20% of all of the CEP market. Traditional delivery will still be required in order to handle large volume orders in the B2B segment and deliveries that need to be attended by humans. One of the main problems in traditional delivery regarding individual, small volume orders are failures to deliver parcels (Sampaio, Savelsbergh, Veelenturf, & Van Woensel, 2017), usually caused by absence of receivers during delivery time. To reduce costs caused by failed deliveries and also to be more competitive, new technologies and solutions are continuously being implemented in traditional delivery settings. DPDgroup currently uses geotracking of the parcel in the last-mile. Their future plans involve employment of autonomous vehicles by partnering up with Renault employing the concept car EX-PRO for last-mile delivery and as a mobile locker (DPDgroup, 2018). The Austrian Post office offers two different alternatives for parcel pick-up, namely lockers at customer residences and over 2000 service centers in specific locations in Austria with a possibility to pick-up and drop-off parcels around the clock. They operate the largest e-vehicle fleet in Austria and have been using electric vehicles for last-mile delivery since 2014 (Austrian Post, 2014). Another company, GLS Austria has recently launched a test project in cities of Salzburg, Linz and Graz where an electric scooter of 750l capacity and an operational range of 100km called eScooter is used for parcel delivery (GLS-group, 2018).

2.3.1 New Forms of Delivery

At this point in time, city logistics are primarily conducted with trucks and vans. They are gradually being replaced with alternative, technologically more advanced solutions. In the following, a summary of new delivery forms is presented, with the focus on main positive and negative characteristics. As a reference the overview by Kunze (2016) is used, complemented by additional findings from a number of other studies and reports, e.g., WIK (2016); Lee et al. (2016); Ranieri, Digiesi, Silvestri, & Roccotelli (2018); Chung et al. (2018).

- **Electric vehicles**: the main advantage of electrically powered vehicles is that they can completely replace fossil-fuel vehicles, which leads to substantial reduction of CO2 emissions. Thereupon, they have immense positive effect on environment and sustainability. Disadvantages are short battery life, limited recharging infrastructure, a driver presence, the fact that they are pricier than classic vehicles and space consumption in city traffic.
- **Bikes and scooters** are better alternative to trucks and vans used in traditional delivery given that they are easier to navigate in cities and avoid traffic congestion, they take up less parking space (Kunze 2016), they are environment-friendly, and they are easier to park. Drawbacks are reflected by smaller cargo capacity and the fact that they also require a driver, unlike autonomous vehicles. Additionally, bad weather conditions can have significant influence on executing a task and there is a safety risk for cyclists on busy streets (Dablanc et al., 2017).
- **Autonomous electric vehicles (EAV) or ground drones** are superior to human operating vehicles since they do not require a driver, have a lower accident rate and represent an environment-friendly option. On the other hand, their movement can be relatively slow and they are hard to navigate on congested streets and sidewalks. Low speed can be a hindrance in case of longer distances, but according to Kunze (2016) for EAV it is possible to enter public transportation vehicles in off-peak hours in order to cut traveling time to the given destination.

Furthermore, loading and unloading can be difficult without human presence and there is a risk for the parcels to be stolen. They require a precise GPS data of road infrastructure to coordinate, or else they can cause accidents and pose a risk for other drivers and pedestrians.

- **Air drones** – great way to avoid traffic congestion and obstacles on the road, therefore unreachable locations can be accessed. Since their speed can be greater in comparison to classical vehicles, even up to 128km/h (Giles, 2018), they are a better alternative for emergency shipments. They possess a loading and unloading mechanism, so that human assistance is not necessary for pick-ups and drop-offs. Different government regulations can pose restrictions. Those might be issues such as air-zone restrictions due to airport proximity, operation licenses, or a trained supervisor/conductor must be present at all times. There is also a risk of wrong delivery location, in case of inadequate geo-mapping information or failure in algorithm. Ever rising costs of acquisition of drones and freight capacity are also constraints to consider.
- **Cargo pipelines and tubes**: The parcels are placed in special capsules and transported through pipelines and tubes, similar to a small metro system (Turkowski & Michalak, 2016). It is the best viable way to avoid traffic congestion and it is environment-friendly, since it uses electricity for transportation (Chung et al. 2018). Other than that, it is secure and reliable since moving of parcels is done in completely controlled and isolated environment (Egbunike & Potter, 2011; Turkowski & Michalak, 2016). The biggest downside is that they require substantial initial investment, since infrastructure needs to be completely built from scratch.
- **3D printers** can be seen as alternative to traditional delivery in a way that products are printed at remote locations immediately after printing data is acquired instead of delivering them from seller to a customer. They support individualization, since it can be easy to adapt minor changes to the product (Kunze 2016). However, printing can be very time consuming. Keeping that in mind, they are not universal, a certain type of printer can’t use variety of printing materials (Chung et al. 2018). Printers are expensive and require a license to print specific products (WIK 2016).

- **Crowdlogistics** is a delivery approach where private individuals are acting as carriers in exchange for a compensation where their own transportation source is used, e.g. car, bicycle or public transportation. Additional transportation resources are not necessary, and it is an environment-friendly solution (Kunze 2016). Since delivery is done on planned routes with minor detours, a trip exclusively dedicated solely for a specific delivery is not performed. Negative sides reflect in the fact that, in order to make a crowdlogistic solution lucrative, a large user network must be built, which usually takes plenty of time. Also, it is hard to guarantee service quality when private unknown and non-professional individuals serve as drives (Kunze 2016).

2.4 Crowdsourced Delivery

Crowdsourced delivery or crowdlogistics is a concept based on the social trend of sharing and collaboration. After Uber and Airbnb, the concept of sharing is copied to other businesses and logistics is certainly one of them. It is a solution to address increasing expectations of customers in terms of speed, individualization and more economical delivery service. In their research Buldeo Rai et al. (2017) defined crowdlogistics as *"an information connectivity enabled marketplace concept that matches supply and demand for logistics services with an undefined and external crowd that has free capacity with regards to time and/or space, participates on a voluntary basis and is compensated accordingly"*. In other words, an online platform plays a role of a marketplace where sender posts a transportation requests that need to be delivered to a receiver. Transportation request includes information about delivery, like, e.g., weight and size of an item, delivery time, delivery location. The crowdsource, or private individual willing to make a delivery is matched by the platform with a delivery request and in return receives certain compensation for provided service. According to Buldeo Rai et al. (2017) there are five stakeholders which are included in crowddelivery:

- **Sender and receiver,** both can be business subjects or private individuals. The receiver buys an item from the sender, which then is transported by a crowdsource to the receiver. For one crowdlogistics business to be successful in the long run, it is essential to build a sufficiently large network of customers (Frehe, Mehmann, & Teuteberg, 2017).

- **Logistics service provider:** due to uncertainty of the crowd mass, in order to ensure continued service, a third party carrier needs to be involved (Frehe et al., 2017). Those are usually subcontractors, already employed in other carrier companies which serve as backup, in case there are not enough crowdsources to cover all transportation requests.
- **Platform provider** is usually an independent business unit, responsible for designing, hosting and managing the technical platform.
- **Crowd** or individuals willing to serve as carriers. They are willing to accept task when it is convenient, usually to accompany an already planned journey and receive some benefits along the way. Alternatively, they conduct a delivery as a side job in their free time, so-called non-professional dedicated carriers. The Crowd is the most important resource for business success of crowddelivery (Rougès & Montreuil, 2014). The bigger the existing crowd network, the smaller is the need to involve third party logistics providers.

From a technological point of view, the most important factor in crowdsourcing is a platform used to connect all stakeholders. Such a platform is used by the customers and the crowd as a communication medium with the purpose to coordinate demand and supply for transportation services. In designing a platform, there are few aspects to consider. Firstly, the platform must be able to grow, as the network of customers and crowdsources increases (Frehe et al., 2017). Secondly, which method should be used to assign delivery requests to crowd carriers. One way is to use a smart matching algorithm which calculates the routes of carriers and matches them with transportation requests (Schreieck et al., 2016). An example of such algorithm is proposed by Setzke et al. (2017), whereby routes are being calculated with a goal to minimize costs and match as many requests as possible. Another option is that a customer chooses an offer from crowdsource, from a list of submitted requests based on an auction model (Mladenow, Bauer, & Strauss, 2015). Kafle et al. (2017) designed a platform with bidding mechanism, whereby the offer with the minimal cost is chosen by the platform. Thirdly, what revenue model type to calculate transportation fees should be used. Rougès and Montreuil (2014) state five different types of compensation:

- Fixed price per delivery item, with eventual surcharges for faster deliveries, bulkier parcels, longer distances etc.
- Negotiated price between sender and carrier, which results from a bidding process.
- Financial and matching fees are negotiated between a sender and a carrier, whereas platform provider acts as an escrow transferring the payment to carrier only upon delivery.
- Resale margin, where a fee is already included in the price of an item. For every order the carrier receives a commission which is variable and depends on the delivery specifications.
- Membership – grants free delivery to customers for a certain annual fee.

Lastly, a rating system for carriers should be included in order to provide transparency and security. The fact that the job is assigned to non-professionals can result in hesitation of end customers, to accept service provided by unknown private persons.

Depending on a size of a company there can be two types of crowd service provider, larger logistic companies who also build whole crowddelivery systems and smaller companies, like start-ups (Frehe et al., 2017). According to McKinsey (2016) analysis of a start-up scene connected to the last-mile delivery, the majority of start-ups belongs to the food delivery service segment and local commerce, with 27% each. Interesting is also that food delivery service start-ups are the youngest, with the average founding year of 2012. Whereas those in local commerce have a longer historical presence, founded around 2003. Moreover, food delivery services and food delivery platforms receive most attention from investors, whereas biggest portion of capital is invested in local commerce.

2.4.1 Crowdsourced vs. Traditional Delivery

As already described, crowddelivery typically is a more environment-friendly option and has lower operating costs than conventional delivery. In their study, Wang et al. (2016) point out that lower operational costs, CO2 emission and traffic congestion are the result of high level of parallelism and communication in crowd delivery systems. Hence, a number of deliveries is simultaneously conducted due to a vast number of individual carriers, who perform deliveries, having their own already existing resources. Usually one or few tasks is assigned to a carrier. As a result, an eventual delay in one task has a minor impact on a successor. In addition, every carrier is connected to the relevant customer over the platform, and they can communicate and make adjustments, e.g., to alternate a delivery location or postpone it. In the traditional delivery, larger volume of orders is assigned to a carrier and they need to be delivered successively. Thereby, an eventual delay during a route affects all the following tasks and can even lead to failed deliveries, due to lack of time.

Carbone et al. (2017) points out differences between crowd based and traditional logistics from the strategic, organizational and operational level, represented in the following excerpt.

From a strategic point of view, we have business subject versus crowd as provider of services, whereby crowdlogistics is focused primarily on the crowd and uses outsourcing as a back-up to secure delivery. The motivation in traditional delivery is pure economical, whereas crowd, besides earning potential, has also multidimensional non-economic factors that act like motivators: environmental impact, social interaction, altruistic and even political factors (Carbone et al., 2017; Mladenow et al., 2015). Yet another difference is that traditional is of large-scale, whereas crowd is involved in small-scale operations, with shorter delivery radius and smaller weights. Ultimately, from a philosophical point of view, traditional delivery is aimed at consolidation of large-scale operations. Crowdlogistics, on the other hand, is focused on the symbiosis of transportation needs and available logistics assets.

At an organizational level, there is centralized traditional delivery with their own platform, whereby wide range of activities are performed by professionals. Whereas crowdsourced logistics is based on distribution of basic services to private individuals and uses platform only for market mediation.

From an operational point of view, traditional delivery uses specific assets with standardized procedures, the information system is specialized and consists of complicated procedures and algorithms. Finally, performance is quantitatively measured based on various key performance indicators. In crowdlogistics no specific assets are required, carriers use their own cars, bikes and means of public transportation or simply deliver on foot, no specific procedures need to be followed, and jobs are done ad-hoc. Individuals use mobile devices to connect to the platform and performance is measured based on feedbacks from other customers.

2.4.2 Crowddelivery Benefits

Using a crowd for deliveries has positive economic, social and environmental outcomes. In the following passages, benefits for every type of stakeholders are described, followed by advantages for the whole society.

1. **Customers as receivers of service** have economic benefits since the fee paid for crowd delivery is usually lower than the one for express delivery by business carriers. In some cases, the fees for the same-day delivery involving crowd are the same as for standard shipping done in 2-3 days through traditional channels. The price is the key decision criterion since more than 50% of all on-line consumers choose the type of delivery entirely based on a fee range (McKinsey, 2016). Secondly, crowddelivery is an on-demand solution, where an item is shipped immediately. According to the PWC (2017) survey, when asked how important the delivery time of the parcel is, 41% of online shoppers found it to be important, whereas, for 18% of those who participated in the survey find this feature to be very important. Taking into consideration the survey by McKinsey (2016), 27% of respondents quit online shopping of groceries and medications due to longer delivery time. Thirdly, crowddelivery has a higher level of

personalization, customers can choose the time of delivery and easily rearrange the delivery location or postpone the delivery by communicating directly with carriers trough platform (Rougès & Montreuil, 2014). Lastly, they have access to products that are sold by retailers who do not offer delivery service or when the products are sold on distant location (Rougès & Montreuil, 2014). The issue of accessibility to products is of great importance to consumers with reduced mobility (WIK, 2016).

2. **Crowd individuals as providers of service** acquire compensation for their service, such as monetary rewards, price incentives on products and services (Mladenow et al., 2015); this can partly cover the costs of journeys (Rougès & Montreuil, 2014). At the same time, better utilization of resources is accomplished (Das, 2018). Also it is a convenient additional job opportunity due to customizable working schedule, hence it can be performed ad hoc in free time (Rougès & Montreuil, 2014).
3. **Retailers** – for a small and medium-sized businesses, crowddelivery is a way to reduce delivery costs, since own, in-house delivery could be inefficient due to small volume of shipments and it is impossible to achieve positive effects of economies of scale (Schreieck et al., 2016). Additionally, simply including delivery option increases customer reach. Lastly, shorter delivery times may induce competitive advantages (Dablanc et al., 2017).
4. **Society**: almost the entire literature that covers this topic has one thing in common, the positive effects of crowddelivery on the environment and human health. It reduces air and noise pollution, traffic congestion and resource use. These benefits are achieved by using already planned routes to make deliveries and bicycles as a mode of transportation (Rougès & Montreuil, 2014). Furthermore, use of spare capacity in public transportation vehicles for freight transportation and better utilization of free capacity by using vehicles already on the route (Savelsbergh & Van Woensel, 2016). Apart from that, crowddelivery results in new job opportunities (Dablanc et al., 2017).

2.4.3 Limitations of crowddelivery

Most articles addressing crowd concepts, state that the most important factor for its sustainability is the necessity to obtain a critical mass of customers. Rougès and Montreuil (2014) and Frehe et al. (2017) state that it is a chicken-and-egg problem. Customers as receivers are attracted with inexpensive, fast prompt and flexible service, which is assured with critical mass of carriers. But to attract individuals to participate as carriers, critical mass of submitters is essential. Thus, it can take up to several years for a platform to become profitable (Frehe et al., 2017). How open customers are to delivery conducted by private individuals, a survey conducted by PWC (2017) attests. Entirely open to the crowddelivery is 7% of the population polled, 31% will probably accept but most of the population 39% is totally reluctant. There are different factors that encourage acceptance or serve as motivators in crowdsourced delivery. Besides economic benefits and a service reliability (Sampaio et al., 2017), private individuals can be motivated by other factors. Mladenow et al. (2015) state that social factors, like interaction with other individuals, and sustainability awareness can play an important role. Punel et al. (2018) conducted a study to find out what are the most important motivators of crowd shipping users. Results confirm that economic benefits are not the main motivators, and environmental concerns play an important role as well, whereas sense of community is not that important.

Other than building a sufficient network of customers, there are some other factors that represent hindrance in crowddelivery concepts.

- **Service quality –** concept of a crowd is based on recruiting private, nonprofessional individuals as carriers, which comes with a risk of low-quality service. Finding reliable occasional drivers who are going to stick to one provider can be difficult due to presence of competitors (Dablanc et al., 2017). Some crowd platforms use predominantly professional carriers or dedicated drives to ensure quality of service (Rougès & Montreuil, 2014). Others are implementing rating systems in order for receiver to gain more insight in carrier behavior.
- **Trust and transparency.** Trust is a major factor influencing potential customers willingness to participate (Rougès & Montreuil, 2014) and is fundamental for the

success of a crowd concept (Schreieck et al., 2016). According to the questionnaire by Dörrzapf et al. (2016), 59% of participants would accept a delivery request if they personally knew the person requesting a service, whereas only 14,8% would do so if there are not personally acquainted. The risk of theft, damage or a missing parcel can be reduced by enforcing rigorous controlling mechanism (Buldeo Rai et al., 2017; Rougès & Montreuil, 2014) and rating systems (Schreieck et al., 2016). Some providers encourage direct communication between a carrier and a receiver (Rougès & Montreuil, 2014).

- **Liability insurance** – since delivery items are not owned by a crowd provider, and the carrier is only a middleman, it is hard to determine who is responsible in case of theft, loss or damage (Mladenow et al., 2015). The only clarification to this issue is to get an insurance, which in return represents additional costs for the crowd provider.
- **Privacy concerns** – as already described, transparency is vital to attract users, but in case of a delivery, private information regarding location is publicly accessible, which can be a major drawback for certain customers.
- **Workforce Protection** – since occasional drivers are not legally employed as carriers, they have no benefits and are not insured. Even as an independent contractor, it is difficult to achieve a minimal salary (Das, 2018). Due to lack of official regulations for business in sharing economy, certain companies have been sued, such as Uber in Vienna recently. Some countries are working on regulations for the crowdsourcing segment. Case in point is Belgium, where private individuals are allowed to make up to 5000 euro(s) annual profit providing crowd services.

3 Relevant Literature

The topic of crowdsourcing has gained popularity in the last decade. Therefore, there is a large amount of literature examining the issue. Crowdlogistics and especially concrete solutions regarding designing of a system that can be used for simulation and testing are, on the other hand far less covered by research and literature. One reason for that is that the use of crowd for delivery of items has been in place for a short time only which can be perceivable from the fact that literature reviewed in this section hails from the time span of the last few years.

In order for crowdsourcing to be a successful enterprise, a critically large number of participants is needed (Agatz, Erera, Savelsbergh, & Wang, 2011). It takes substantial time to be accepted by wider population and create a critical mass of customers. Even then, crowdsourced last-mile delivery needs to be supported by backup delivery vehicles in order to guarantee a certain level of service and cover all requests. In the crowddelivery concept, arrived delivery request is to be assigned or matched to a suitable crowd carrier from a pool of available crowdsources, with regard to predefined requirements, like, e.g., planned route, weight of the order, distance length. For the matching process an algorithm is usually constructed, in which case process is done automatically by the platform. If there is no interested individual for a delivery request or a successful match between an order request and crowd carrier cannot be made, then the task must be carried out by a backup vehicle. Therefore, construction of a crowddelivery solution usually consists of two stages:

i. matching of orders to in-store customers and
ii. routes generation for in-house vehicles and eventually for crowd carriers, in case of a single crowdsource delivering multiple orders per route.

The application of such two-stage method where a matching is performed first followed by route generation can be seen in Arslan, Agatz, Kroon, & Zuidwijk (2016); Dayarian & Savelsbergh (2017). For assigning of orders to customers Rougès and Montreuil, (2014) recommend to use matching algorithms, whereas for routing part different extensions of VRP, TSP and PDP models are applied depending on the problem setting.

This study considers delivery from the local shop, located in an urban area, and assumes that customers visiting the giving store are willing to serve as crowd carriers in their available time and with respect to a specified time window for delivery. To solve our problem a static and deterministic model is constructed, where all information about crowdsource arrivals and transportation requests are known in advance. As a reference for construction of the model we used the static variant designed by Dayarian & Savelsbergh (2017) and the static variant from Arslan et al. (2016), which they used to get reference values for comparison with the dynamic variant. Real crowd concepts are highly dynamic, hence requests and crowdsources are arriving randomly throughout the day. However, we believe that a static solution is a good method for a simulation and examination, since Arslan et a.l (2016); Dayarian & Savelsbergh (2017); Kafle et al. (2017); all used a static version as a benchmark to validate constructed dynamic algorithms for large-scale problems. Whereas, Archetti et al. (2016) in their research considered solely a static problem, where all information about customers is known in advance.

In the first stage of our model, delivery requests are assigned to crowd carriers and for that a matching algorithm is constructed. Our problem is only local, limited to a $4km^2$ city area with a store in the center and pedestrians as crowd carriers. Kafle et al. (2017) also used walking, besides cycling as a mode of transportation, whereas P. Chen & Chankov (2017) opted for all three transportation modes, walking, cycling and driving. Walking as a mean of transportation has certain limitations: the distance and the weight of a package pedestrian is willing to accept. We also decided that a crowd carrier can only perform one task per delivery route, which is also implemented by P. Chen & Chankov (2017); Dayarian & Savelsbergh (2017); and Setzke et al. (2017). Furthermore, carrier is available at certain point in time and every delivery request has its time window for delivery. Constructed matching algorithm takes all mentioned limitations in consideration, distance, weight, time windows and one task restriction; and conducts matching with a goal to assign as many orders as possible, whereby delivery requests with a maximum distance from the store are prioritized. The most similar matching solution is the one presented by Dayarian & Savelsbergh (2017) with not only the longest distances being prioritized, but also tasks which are most urgent.

After all possible delivery requests are assigned to crowd carriers, unmatched requests need to be delivered with backup vehicles and for this issue a model for the routing problem is created. According to Wang and Kopfer (2015) the type of mathematical model that can be used to solve a routing problem is determined by the following facts:

- if a single or more vehicles are considered,

- if vehicle capacities are limited,
- by the type of customer requests (pickup, delivery or both),
- if are pickup or delivery regarding each request are directly connected to the depot.

A single, uncapacitated vehicle is used in TSP, where all customers are visited in one route. The case where pickup and delivery requests are allowed in between customers is PDP. Whereas VRP can only have set of deliveries which originates from a depot or set of pickups that need to be delivered to a depot. A special case of VRP is Vehicle Routing Problem with Backhauls (VRPB) with both pickup and delivery requests, however first delivery requests are served following with pickups. Keeping in mind that crowdsources are not included in regard to the route generation in the second stage, our problem belongs to classic Capacitated Vehicle Routing Problem (CVRP) (Archetti et al., 2016). More than that, time windows are also employed and thus the problem is an extension of the CVRP called Capacitated Vehicle Routing Problem with Time Windows (CVRPTW). Most similar to our model is the one proposed by Dayarian and Savelsbergh (2017) using calculations only for in-house vehicles in the second stage. They constructed a Multi-Trip Vehicle Routing Problem with Release and Due time (MTVRP-RD). Ready and due times serve almost the same as time windows, where ready times represent release times, hence earliest time when vehicle can start a route, whereas due times have the same function as delivery end time.

Theoretically, our proposed two-stage solution is not mathematically optimal, since two options, crowd carriers and in-house delivery are not considered simultaneously. The ideal model would calculate routes for crowd carriers parallel with vehicle routes to find an optimum. However, in solving our problem we were led by the assumption that using crowd as carriers is always a cheaper option than using an in-house employee and own vehicle. For that reason, our solution prioritizes the use of a crowd over in-house delivery and utilize as much as possible crowdsources with respect to given limitations mentioned in the previous paragraph. The same principle is applied in the study done by Dayarian & Savelsbergh (2017). For the rest of orders, that are unassigned and need to be delivered by the in-house vehicles, the model is constructed and solves a VRPTW to the optimum.

Lastly, a simulation is conducted to test what kind of an effect, in terms of distances travelled by carrier, a delivery incorporating crowd has in comparison to a pure in-house delivery. Similar as in P. Chen & Chankov (2017) the following Key Performance Indicators (KPI) have been applied: Crowddelivery Service Level that indicates portion of delivery requests conducted by crowdsources; and Crowd Utilization or portion of crowdsources successfully matched with a delivery request. Furthermore, carry-weight and willingness to travel a certain distance of a crowdsource as parameters have been adjusted in order to measure the grade of their influence exercised on the overall problem.

4 Model Formulation

4.1 Problem description

The aim of this study is to test if implementing crowddelivery has a positive effect on cost reduction and if it can be considered as an alternative to the delivery done solely by a business subject, the store. The considered problem is solved from a perspective of a local store, where the goal is to minimize the distance travelled which poses as costs. We consider same-day delivery from a local store positioned in an urban, highly populated city area, which covers a city area equal to $4km^2$ with the store in the center of it. The considered store receives order requests, which are firstly assigned to interested in-house customers, with respect to predefined conditions, regarding order weight, distances and time windows. Every order request is to be delivered within a specified time window, chosen by the customer. The rest of orders, that are not successfully assigned are to be delivered by the store. We consider only pedestrians as a crowdsource. Crowdsources are in-store customers willing to carry out additional delivery for other customers, located in the same neighborhood. To avoid confusion in the following part of the paper we refer to a customer who made an order request simply as a customer, in contrast to an in-house customer who serves a carrier, namely a crowdsource. We consider only one store which serves as a depot, where all inventory to fulfill orders is kept and which also represents the starting point for both crowdsources and backup vehicles. All received orders need to be delivered during the day, and for that to be assured, the store uses its own fleet of vehicles as a backup. Since there is a certain level of uncertainty regarding the availability of crowdsources, a backup fleet is a necessity to guarantee that all orders will be fulfilled. Otherwise, a business subject can be seen as unreliable and reputation will be ruined. The vehicle fleet is uniform, and every vehicle has a limited capacity. For the orders that are delivered by the store, CVRPTW model is used to calculate optimal routes, which guarantees that minimum distances are travelled, and all customers are served. Order requests and availability time of crowdsources are known in advance, this way, all the decisions and calculations can be done at the start of the day. Locations of customers and crowdsources are unique, e.g., there are no overlappings.

Furthermore, we are adding assumptions which have major influence on the model:

- Each crowdsource can carry only one order, which as a result simplifies our problem in a way that we only need to calculate routes for backup vehicles,
- Every crowdsource is willing to carry an order for a certain distance, therefore only customers with locations in specified radius θ are considered,
- The carry-weight of crowdsource is limited,
- Each customer can only have one order request,
- Every vehicle has to start and end the route in the same store.

4.2 Matching of Orders and Crowdsources

As outlined in Section 3, we divide our problem in two stages in order to solve it. In first phase orders are assigned to carriers based on a priori received information. Every crowdsource submits information about availability time and his home location, whereas for orders location, time window and weight of an order are known. After the matching system has assigned orders to customers it is assumed that a crowdsource accepted the proposed match.

The algorithm which matches customers and crowdsources with a goal to primarily cover orders with longest distances is designed and depicted in Table 2. In that way, we have the highest effect on cost reduction in phase two, where a routing model aiming for total cost minimization is solved.

As in Dayarian and Savelsbergh (2017) we assume that it is always cheaper to use crowdsources then our own vehicles, mostly due to the fact that fixed and operational costs for a vehicle fleet are much higher than compensation paid to crowdsource to deliver the order. We also want to employ every possible crowdsource to make a delivery with a respect to following conditions:

1. Every crowdsource is allowed to carry only one order at a time,
2. Maximum carry-weight of an order is $5kg$,
3. Crowdsource accepts only order with delivery location in θ radius from his home,
4. Only orders which can be delivered in preplanned time window are assigned to crowdsource.

To best depict the path of solving the matching problem we use the following algorithm. For customer $i \in C$ we first check if the order fulfills Condition 2, if this is not the case, we assign it to an unassigned set. Then we check if conditions regarding cover radius and time window are upheld, and if the distance between customer i and store has a maximum value. If that is the case, customer i and crowdsource l are matched, i gets an assigned order status, whereas the corresponding distance is set as best distance. If for the same crowdsource l another customer i who fulfills all conditions is found, corresponding distance is compared to the best distance and if the latter is better, the old matched set is updated, and best distance gets a new value. At the end set with unassigned customers is created in order to be used in phase two.

Notation	Definition
$\mathcal{C} = \{1, \dots, n\}$	Set of customers, index i
$\mathcal{M} = \{1, \dots, m\}$	Set of crowdsources, index l
d_i	Distance between customer i and store
d_{il}	Distance between customer i and crowdsource l
t_i	Travel time between customer i and store
e_i	Earliest delivery time for customer i
l_i	Latest delivery time for customer i
r_l	Ready time for crowdsource l
q_i	Weight of an order for customer i
θ	Maximum distance between crowdsource and customer

Table 1: Parameters and Variables for Matching Algorithm

Algorithm: Matching of customers and crowdsources

Precondition: Customer i, crowdsource l
Postcondition: Set of unassigned orders for second stage

```
for $l \in \mathcal{M}$ do
    $bestAssignement \leftarrow \emptyset$
    $bestDistance \leftarrow \emptyset$
    for $i \in \mathcal{C}$ do
        if $q_i \leq 5$ then
            if $i \,!\, in\ assignedOrders$ then
                if $d_{il} < \theta$ then
                    if $t_i + t_l > e_i$ then
                        if $t_i + t_l < l_i$ then
                            if $d_i > bestDistance$ then
                                $bestAssignement = i$
                                $bestDistance = d_i$
                            end if
                        end if
                    end if
                end if
            end if
        end if
        else
            if $i \,!\, in\ unassignedOrders$ then
                $i = unassignedOrders$
            end if
        end else
    end for
```

Table 2: Matching Algorithm

4.3 Formal Definition of Routing Model

Our model is formulated as static and deterministic, where all information regarding orders and crowdsource arrivals are known in advance and stay unchanged over time.

This is similar to static variant used by Arslan et al. (2016) and static variant in Dayarian and Savelsbergh (2017). We use following notation to construct our CVRPTW model.

The CVRPTW can be defined as a directed graph $\mathcal{G} = (\mathcal{N}, \mathcal{A})$ where $\mathcal{N}$ is a set of all nodes in the graph and $\mathcal{A}$ is set of al arcs connecting all the respective nodes. In VRP problems, every route must start from, and end in a depot. If we have a subset of customer nodes $\mathcal{C} = \{1, \dots, n\}$ and depot which serve as a start and end node $\mathcal{D} = \{0, n+1\}$, then start of every route is at node 0, whereas node $n+1$ represents the end of a route. Our set of all nodes $\mathcal{N} = \{0, \dots, n+1\}$ consists out of customer and depot subsets $\mathcal{N} = \mathcal{C} \cup \mathcal{D}$. Let $\mathcal{A} = \{i, j\}$ represent an arc between nodes i and j. Every arc has corresponding distance d_{ij} and travel time t_{ij}. Every customer $i \in \mathcal{C}$ has corresponding order weight q_i and service time s_i. Furthermore, each customer needs to be visited in pre-specified time window $[e_i, l_i]$, where e_i represents earliest delivery time at node i, whereas l_i is latest delivery time. If a vehicle arrives at customer before e_i it needs to wait to serve the customer and delivery must be served before l_i. We also have a set of identical vehicles $\mathcal{V} = \{1, \dots, v\}$ with a limited capacity of Q. Lastly, two sets of variables are in use, binary variable x_{ijk} which takes value 1 if vehicle $k \in \mathcal{V}$ serves an arc $(i, j) \in \mathcal{A}$ and 0 otherwise. Continuous variable a_{ik} which represents arrival time of vehicle $k \in \mathcal{V}$ at node $i \in \mathcal{C}$.

Notation	Definition
$\mathcal{N} = \{0, \dots, n+1\}$	Set of all nodes, index i, j
$\mathcal{C} = \{1, \dots, n\}$	Customer subset of nodes, index i, j
$\mathcal{D} = \{0, n+1\}$	Depot subset of nodes, index i, j
$\mathcal{V} = \{1, \dots, v\}$	Set of vehicles, index k
Q	Vehicle capacity
d_{ij}	Distance between nodes i and j
t_{ij}	Time between nodes i and j
s_i	Service time at node i
e_i	Earliest delivery time at node i
l_i	Latest delivery time at node i
w_i	Weight of an order at delivery node i
x_{ijk}	Binary variable equal to 1 if vehicle k travels from node i to node i, j 0 otherwise
a_{ik}	Time vehicle k starts to serve customer at node i

Table 3: Parameters and Variables for CVRPTW

4.4 Route Generation Model

We formulate our model as general mixed integer linear problem (MILP) based on VRPTW formulation found in Cordeau et al. (2007). Our VRPTW model represented bellow includes two types of variables:

- Binary variable x_{ljk} equal to 1 if vehicle k serves an order i between nodes i and j, and 0 otherwise
- Continuous variable a_{ik} represents arrival time of the vehicle k at node i

$$\text{minimize} \sum_{i,j \in \mathcal{N}} \sum_{k \in \mathcal{V}} d_{ij} x_{ijk} \tag{1}$$

subject to

$$\sum_{j \in \mathcal{C}} \sum_{k \in \mathcal{V}} x_{ijk} \leq 1 \qquad \forall i \in \mathcal{N} \tag{2}$$

$$\sum_{i \in \mathcal{C}} \sum_{j \in \mathcal{N}} w_i x_{ijk} \leq Q \qquad \forall k \in \mathcal{V} \tag{3}$$

$$\sum_{j \in \mathcal{N}} x_{0jk} = 1 \qquad \forall k \in \mathcal{V} \tag{4}$$

$$\sum_{i \in \mathcal{N}} x_{ihk} - \sum_{j \in \mathcal{N}} x_{hjk} = 0 \qquad \forall h \in \mathcal{C}, \ \forall k \in \mathcal{V} \tag{5}$$

$$\sum_{i \in \mathcal{N}} x_{i(n+1)k} = 1 \qquad \forall k \in \mathcal{V} \tag{6}$$

$$e_i \leq a_{ik} \leq l_i \qquad \forall i \in \mathcal{N}, \ \forall k \in \mathcal{V} \tag{7}$$

$$a_{ik} + t_{ij} - M(1 - x_{ijk}) \leq a_{jk} \qquad \forall i \in \mathcal{N}, \forall j \in \mathcal{N}, \ \forall k \in \mathcal{V} \tag{8}$$

$$x_{ijk} \in \{0,1\} \qquad \forall i \in \mathcal{N}, \forall j \in \mathcal{N}, \ \forall k \in \mathcal{V} \tag{9}$$

$$a_{ik} > 0 \qquad \forall i \in \mathcal{N}, \ \forall k \in \mathcal{V} \tag{10}$$

The objective function (1) minimizes total costs for all routes, where distances travelled represent the costs. Furthermore, following constraints are given:

(2) Make sure that each customer is visited only once.

(3) Vehicle capacity constraint.

(4) Makes sure that each vehicle starts a route from store, hence node 0.

(5) Flow conservation constraint, after arrival at customer vehicle must leave for the next customer. This constraint makes sure that customers locations are visited consecutively, in a route, before the route ends at the store.

(6) Each vehicle must end the route at the store, where end node is $n+1$.

(7) Time window constraint makes sure that vehicle serves customer after earliest delivery time and before latest delivery time. In case vehicle arrives at node i before beginning of the time window, it must wait until the beginning of the time window to serve a customer.

(8) Linearized time constraint which assures that between visiting node i and j time travel for that particular arc and a service time at node i are included. Where M represents a constant and can be calculated as $M = \max\{l_i + a_{ik} - e_i\}$ for $\forall i, j \in \mathcal{N}, \ \forall k \in \mathcal{V}$.

Runtime of a calculation can be accelerated by adding additional constraints (W. Chen, Mes, & Schutten, 2017). In set of nodes $\mathcal{N}$ we have pairs $(i, j) \in \mathcal{N}$ where $i = j$ and we eliminate them from calculation by adding constraint (12).

$$x_{iik} = 0 \qquad \forall i \in \mathcal{N}, \ \forall k \in \mathcal{V} \qquad (12)$$

5 Computational Study

Testing is performed on 2,5 GHz Intel Core i5 with 4 GB DDR3 RAM. Code is implemented in Java programming language and CPLEX 12.8 Solver is used to solve CVRPTW to the optimum.

5.1 Instance Generation

As a reference for instance size generation we used information regarding online shopping and delivery in grocery industry in Vienna. The chain of Merkur supermarket had approximately 100 online requests per day and 10-15 orders are carried out per in-house vehicle (Etschmaier, 2017). Other than that, they also have had two depot locations from where online orders have been shipped to the whole of Vienna region.

Since we analyze the problem on a smaller scale, where only part of a city area is taken in consideration, we created three main groups of instances with 10, 20 and 30 customers and labeled them A, B, C respectively. Furthermore, for every instance group we created three scenarios with different number of crowdsources based on Customer/Crowdsource Ratio (C/C Ratio). Similar to Supply/Demand Ratio applied in P. Chen & Chankov (2017) for C/C Ratio we used values 0,5; 1; 1,5. Therefore, for instances from group A we have three scenarios with 5, 10 an 15 crowdsources and we named them A1, A2, A3 respectively. Analogous scenarios for remaining instances are generated.

C/C Ratio **Number of customer**	**C/C Ratio = 0,5 (50%)**	**C/C Ratio = 1 (100%)**	**C/C Ratio = 1,5 (150%)**
10	A1	A2	A3
20	B1	B2	B3
30	C1	C2	C3

Table 4: Simulation Scenarios

For every customer the following information is generated:

- Location given as Xcoord and Ycoord,
- Earliest and latest delivery time, with time window equal to $120min$,
- Weight of an order in kg.

Generated information regarding crowdsource:

- Location (Xcoord, Ycoord),
- Ready time,
- Maximum weight willing to carry,
- Maximum distance willing to travel from his home location to location of a customer (θ radius).

Locations of customers and crowdsources are generated randomly on a 100×100 square graph, which represents a $2km \times 2km$ geographical region with a store at the center $[50,50]$. We consider time horizon of 8 hours working day, or $480min$ for the store. Having in mind that traveling time between store and customer needs to be included before arriving at delivery location, we set time horizon for earliest/latest delivery time and ready time of crowdsource between $30min$ and $450min$. Time values are also generated randomly in mentioned time horizon, where every customer has a time window of $120min$. Weight of orders are chosen randomly between 1 and $15kg$, whereas maximum weight crowdsource is willing to carry is equal to $5kg$. Coverage area from crowdsource home location to delivery location is defined with radius $\theta = 500m$.

Travel times are calculated based on Euclidean distances. We used average pedestrian speed of $1{,}3m/s$ (Steierwald, Künne, & Vogt, 2005) and $30km/h$ as a vehicle speed based on speed limitation valid for streets in reduced-traffic area (Wien.gv.at, 2018). Our vehicle fleet consists out of five identical small transporters with carrying capacity of $500kg$.

6 Numerical results

Table 5 represents the results from nine instances with maximum carry weight of a crowdsource which equal to $5kg$ and with cover radius of $500m$. For performance evaluation three categories of indicators are used:

- **Crowddelivery service level** which presents a portion of order requests delivered by crowdsources, denoted in the following table as orders match rate.
- **Crowd utilization** showing percentage of crowdsources matched with order requests, in table denoted as crowdsources match rate.
- **Distance saving** for in-house vehicles, defined as a difference between delivery involving crowd and an option when no crowd is included where all delivery tasks are performed solely with in-house vehicles.

	#customers	#crowdsources	#matched orders	Match rate (%)		Total distance		Distance saving (%)
				Orders	Crowdsources	With crowd	NoCrowd	
A1	10	5	1	10	20	4935.77	5205.75	5.19
A2	10	10	1	10	10	5965.04	6149.4	3
A3	10	15	1	10	6,67	6122.06	6122.06	0
B1	20	10	3	15	**30**	10174.53	10594.03	3.96
B2	20	20	4	20	20	10705.11	11782.39	9.14
B3	20	30	2	10	6,67	10267.55	10598.12	3.12
C1	30	15	3	10	20	12568.26	12833.57	2.07
C2	30	30	6	20	20	11283.68	12424.46	9.18
C3	30	45	7	**23.33**	15.56	10979.86	13075.63	**16.03**

Table 5: Results for generated instances

The results display that every instance has at least one matched delivery request but regardless of that, in case of instance A3, no savings are obtained. This can be the case when the location of order in question is on the direct route to a subsequent location and no detour is made by the vehicle. Crowddelivery resulted in the highest saving of 16,03% in the case of instance C3, with the highest customer/crowdsource combination. It can also be observed that the larger number of customer request there is, the bigger matching rate of orders is achieved. Whereas similar conclusion about the effect on crowdsource matching rate cannot be drawn.

The impact of the customer/crowdsource ratio on the matching rate is depicted in Figures 5 and 6. It can be observed that different C/C ratios have no effect on instances with 10 customers, whereas in cases of 30 customer instances, it is clear that the bigger C/C ratio is, the greater matching rate for orders can be achieved. The larger pool of order requests in combination with larger pool of potential crowd carriers allows for an algorithm to find more order request fulfilling the given requirements for successful assignment. On the contrary, mentioned C/C ratio has an opposite effect on the crowdsources matching rate for all size instances, which is consistent with results obtained in the study performed by P. Chen & Chankov (2017).

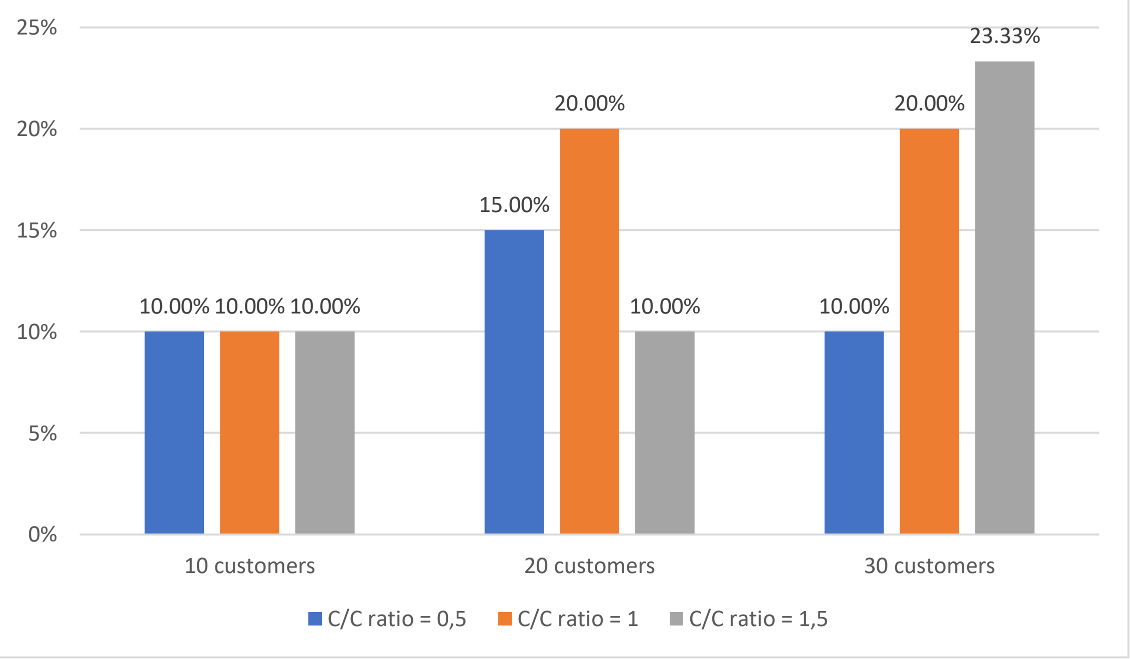


Figure 5: Impact of different C/C ratio on Crowddelivery Service Level

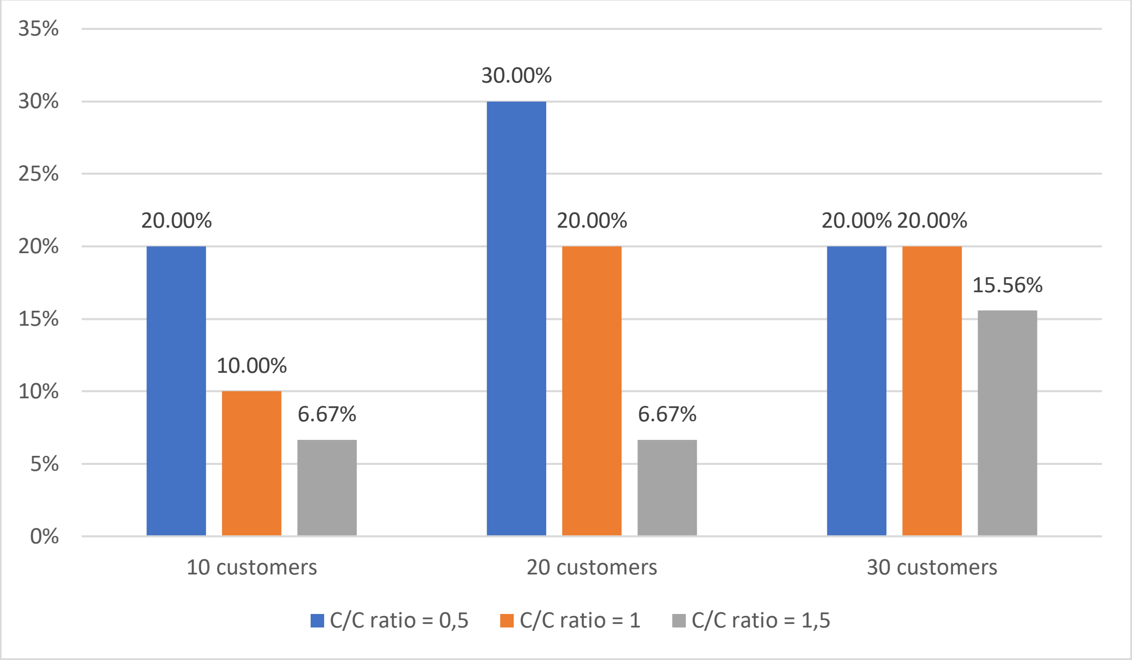
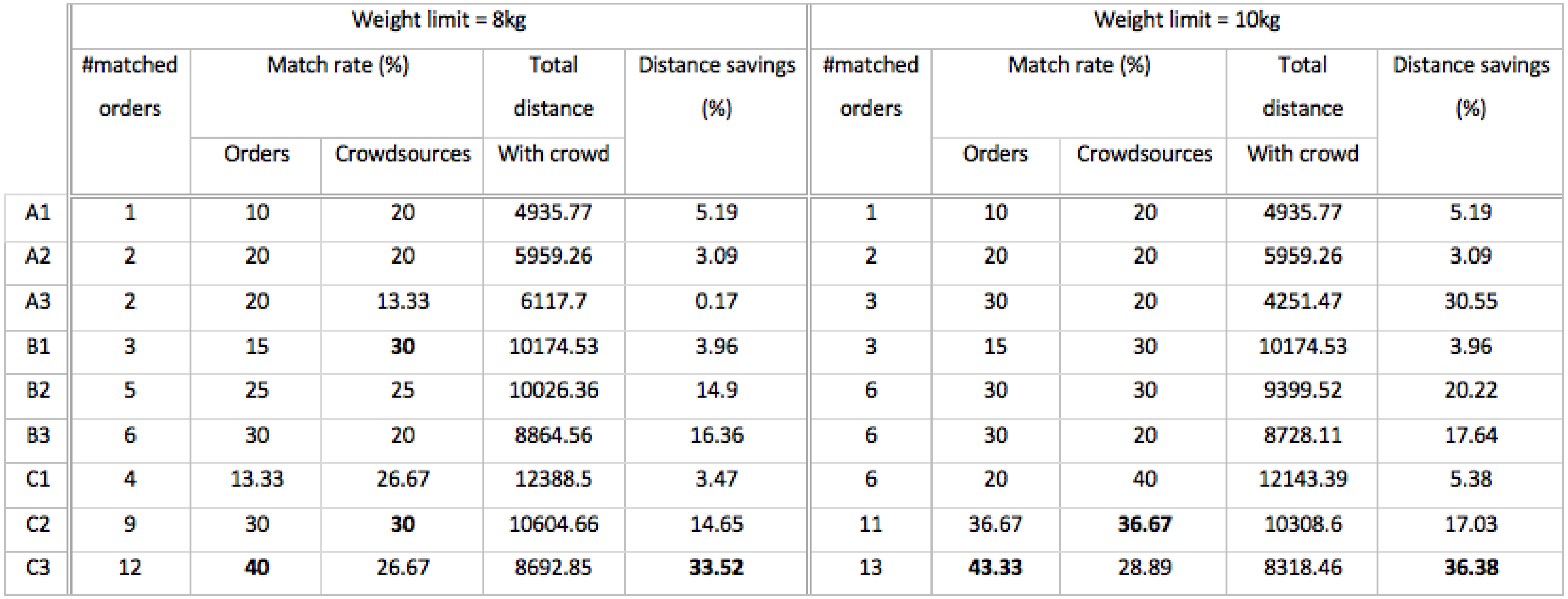


Figure 6: Impact of different C/C ratio on Crowd Utilization

6.1 Impact of Weight Limit of Crowdsource

In order to examine the influence of the influence of the maximal carry weight of a crowd carrier on the overall performance, the same set of instances is tested with weight limit parameter adjusted to 8kg and 10kg respectively, whereas cover radius remains constant. Results are given in Table 6. Compared to the case with 5kg weight limit, number of matched orders has increased in most cases, except in A1 and B3 instances. As expected, the order match rate increases more, when crowdsources are willing to accept orders up to 10kg, which is illustrated in Figure 7. In all three cases, the highest matching rate of orders is achieved in instance C3 with largest pool of customers and crowdsources. Once again this confirms a positive effect on successful assignment of orders by synergy between a bigger instance size and a higher C/C ratio.

The match rate of crowdsources is also elevated in the same seven instances, but at the same time 10kg limit is superior to an 8kg limit in five of those seven instances. In the case of 10kg limit, better utilization of crowdsources is attained in instances with 30 customers, in the C1 case where the highest rate achieves 40%. In contrast to the previous case, where the C/C ratio had an impact on the matching rate of crowdsources, the C/C ratio effect has no influence on matching of crowdsources changing the given 5kg weight limit parameter.



	Weight limit = 8kg					Weight limit = 10kg				
	#matched orders	Match rate (%)		Total distance	Distance savings (%)	#matched orders	Match rate (%)		Total distance	Distance savings (%)
		Orders	Crowdsources	With crowd			Orders	Crowdsources	With crowd	
A1	1	10	20	4935.77	5.19	1	10	20	4935.77	5.19
A2	2	20	20	5959.26	3.09	2	20	20	5959.26	3.09
A3	2	20	13.33	6117.7	0.17	3	30	20	4251.47	30.55
B1	3	15	**30**	10174.53	3.96	3	15	30	10174.53	3.96
B2	5	25	25	10026.36	14.9	6	30	30	9399.52	20.22
B3	6	30	20	8864.56	16.36	6	30	20	8728.11	17.64
C1	4	13.33	26.67	12388.5	3.47	6	20	40	12143.39	5.38
C2	9	30	**30**	10604.66	14.65	11	36.67	**36.67**	10308.6	17.03
C3	12	**40**	26.67	8692.85	**33.52**	13	**43.33**	28.89	8318.46	**36.38**

Table 6: The results with varying weight limits

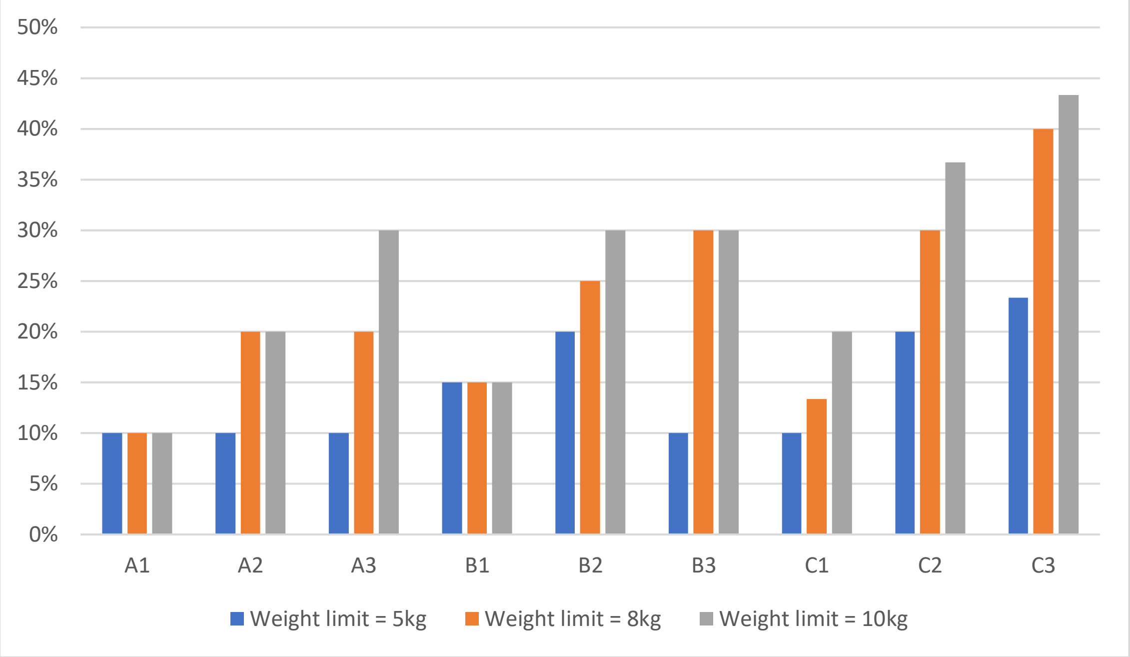


Figure 7: Delivery service level for different weight limits

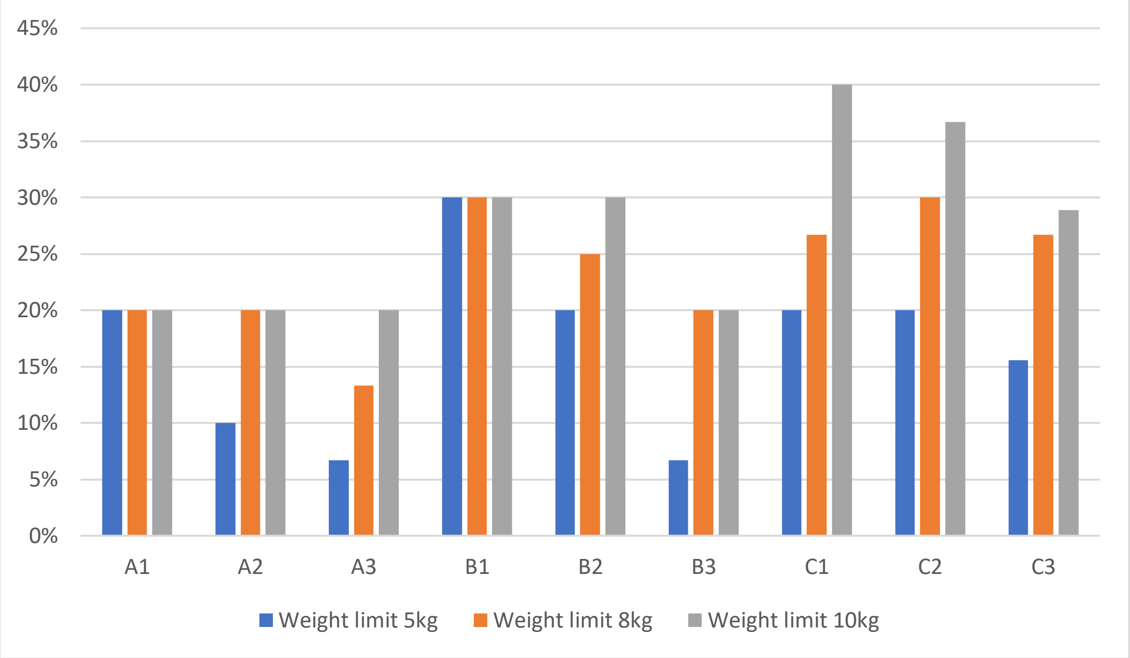


Figure 8: Crowd Utilization for different weight limits

The distance savings are greater in all instances except described A1 and B3 cases, whereby in case of 8kg limit the highest saving of 33,52% is achieved in instance C3, and for the same instance a 10kg scenario generated savings of 36,38%. Comparative overview of distance savings for all three weight limit cases are presented in Figure 9. In both cases with 8kg and 10kg weight limit, savings are greater in 7 out of 9 instances compared to the basic case with a weight limit of 5kg. Overall, the greatest influence on savings is achieved in scenario with 10kg weight limit, which comes from the fact, that by shifting the weight limit, more order requests are included in consideration.

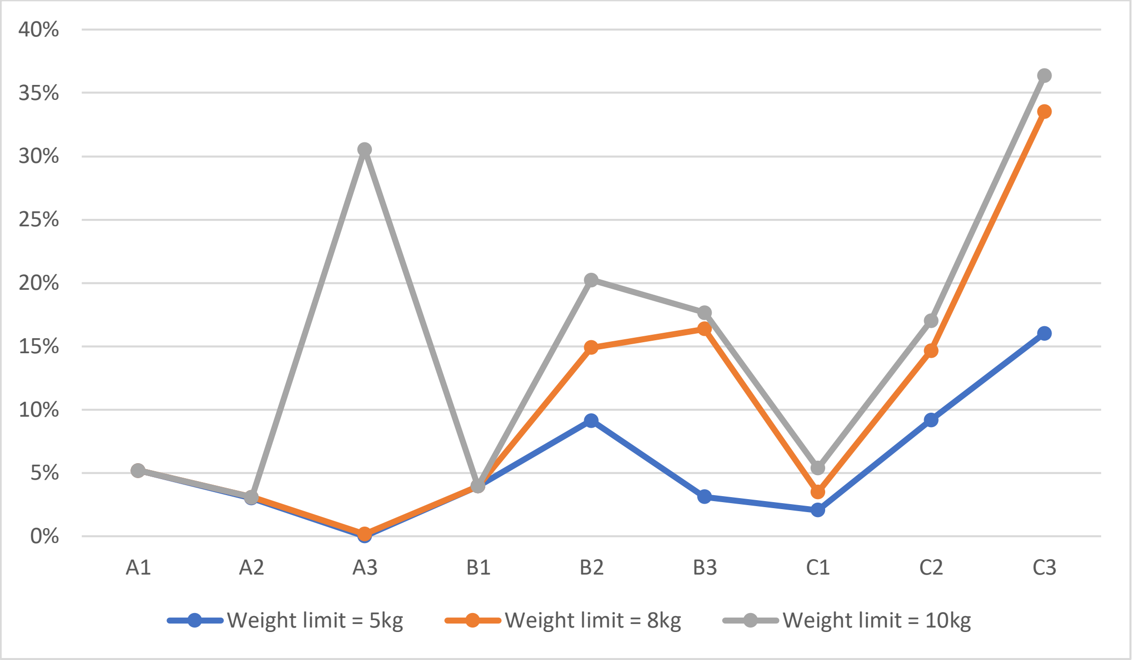


Figure 9: Distance saving for different weight limits

6.2 Impact of Coverage Area of Crowdsources

In Table 7 results are presented for same nine instances whereby cover radius of crowdsource is set to 750m and 1000m respectively. In all but two instances (A1, A3 and B1), matching rate of orders is improved, whereas changes in distance savings are noticeable in all except A1 and A3 instances. Overview of order match rates values for all three varieties of cover radius is visualized in Figure 10. In comparison to the 500m case, the 1000m case and 750m case both, generated a better order matching rate to the original case in 6 instances, whereas in the remaining 3 instances there is no change in the order matching rate. Furthermore, the specific four instances out of these 6 in the 1000m case, display a better order matching rate than those of the 750m case. This same effect can be seen in Figure 11, this time for the matching rate of crowdsources. However, in opposition to the previous cases tested, the highest matching rate is no longer achieved in the instance C3 if cover radius is set to 750m. Therefore, we cannot conclude that the bigger pool of customers combined with highest C/C ratio provides

	Cover radius = 750m					Cover radius = 1000m				
	#matched orders	Match rate (%)		Total distance	Distance savings (%)	#matched orders	Match rate (%)		Total distance	Distance savings (%)
		Orders	Crowdsources	With crowd			Orders	Crowdsources	With crowd	
A1	1	10	20	4935.77	5.19	1	10	20	4935.77	5.19
A2	2	20	20	4897.32	20.36	3	30	30	3005.84	**51.12**
A3	1	10	6.67	6122.06	0	1	10	6.67	6122.06	0
B1	3	15	30	9642.35	8.98	3	15	30	9642.35	8.98
B2	7	**35**	35	9253.35	**21.46**	7	35	35	9253.35	21.46
B3	4	20	13.33	9642.35	9.02	4	20	13.33	9642.35	18.16
C1	6	20	**40**	12191.83	5	7	23.33	**46.67**	12118.58	5.57
C2	7	23.33	23.33	10993.33	11.52	9	30	30	10582.15	14.83
C3	8	26.67	17.78	10830.04	17.17	10	**33.33**	22.22	10377.46	20.63

Table 7: The results for different cover radius

best results. Furthermore, C/C ratio has no uniform effect on the order matching rate nor for the crowdsource matching rate.

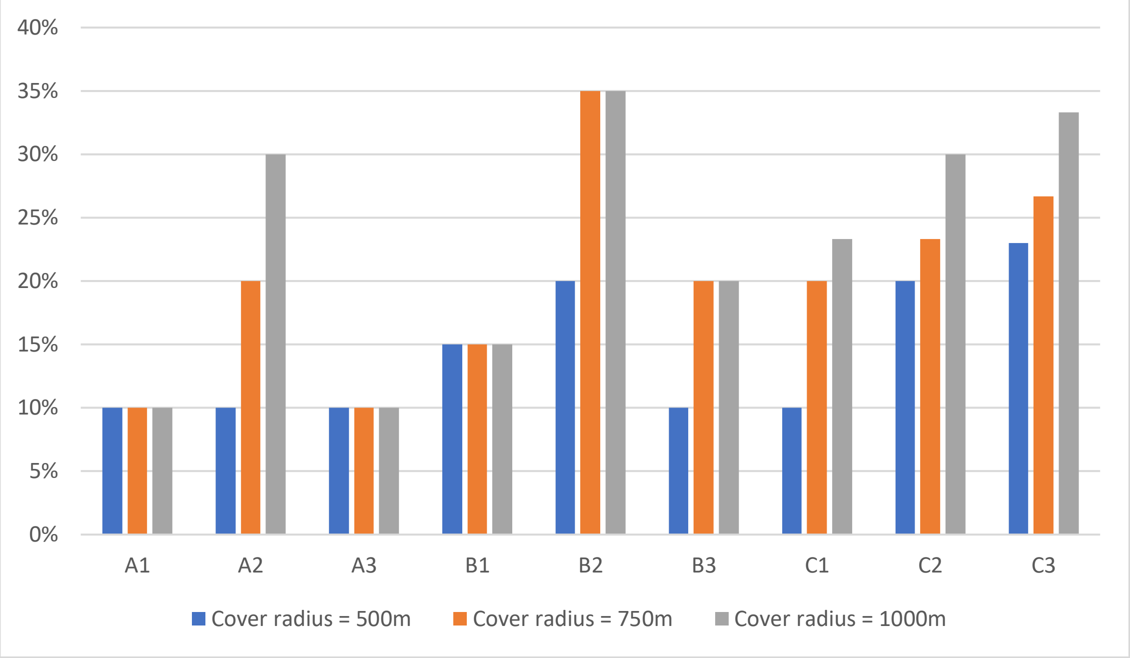


Figure 10: Crowddelivery service level for different weight limits

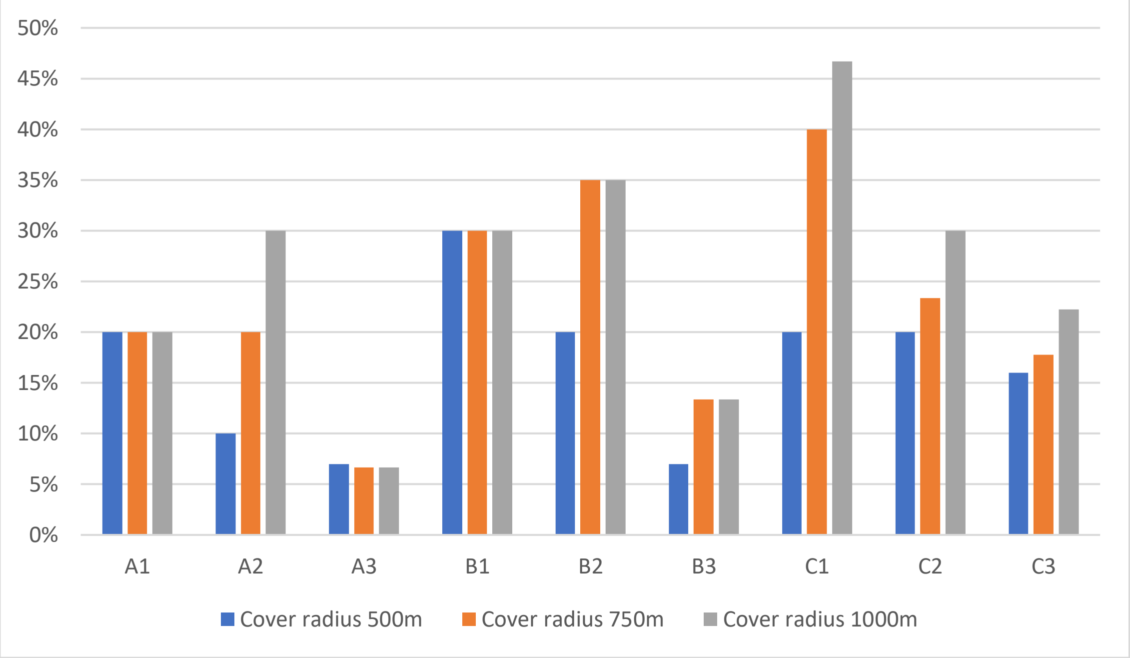


Figure 11: Crowd Utilization for different cover radius

By increasing the cover radius, distance savings are also generated, not only in cases where more orders are matched, but also in the instance B1 where the matching rate is the same as in case of 500m radius. This comes from the fact that a different order request is matched to a crowd carrier, which provides better end result. In Figure 12 can be seen that changes in distance savings occur when new orders are assigned. Similar as in the case with adjusted order weight, the bigger the change of parameter is, the greater savings can be achieved. In the instance B2, distance saving of 21,46% is attained, which is the highest achievable value in conducted experiments, in the case when cover radius parameter is set to 750m. In the 1000m radius case, the biggest saving peaked at 51,12% in the instance A2, portraying the highest value in this category.

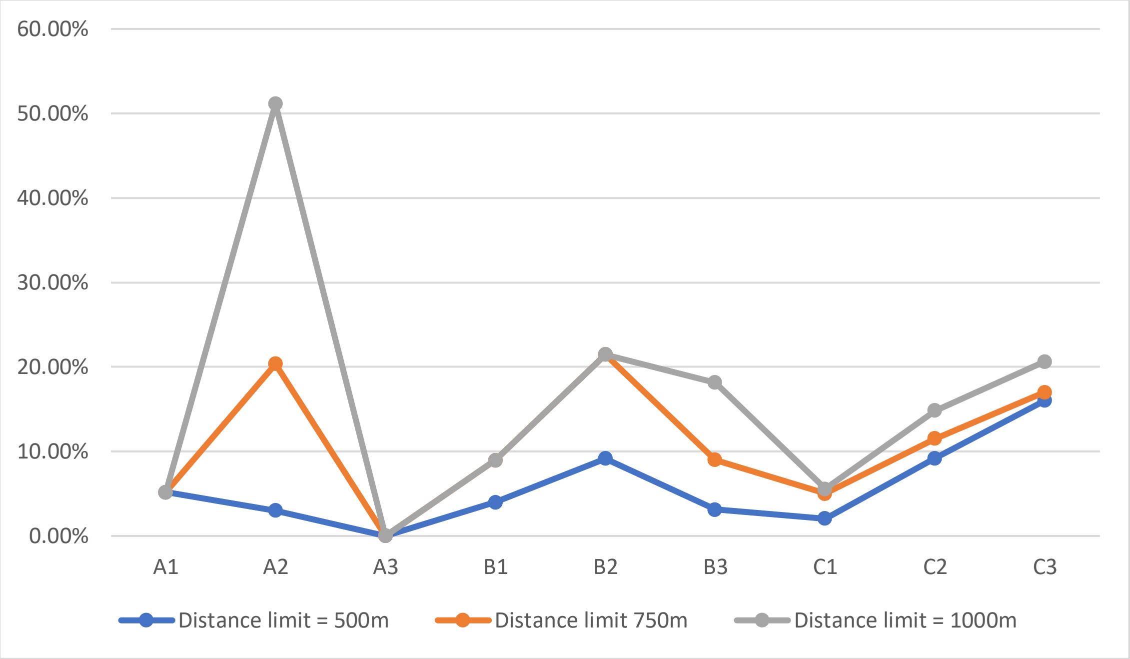


Figure 12: Distance saving for different cover radius options

7 Conclusion

In this thesis an option of employing private individuals for local delivery is examined. For the purpose of this simulation, a model is created which assigns the orders to crowdsources and calculates optimal routes in order to minimize travel distances. Since we consider only pedestrians as crowdsources, limitations parameters regarding maximum carry weight and coverage radius are applied. Furthermore, time windows and a one order one carrier constraint are also applied.

The constructed model solves the problem to optimality, based on randomly generated nine instances with different customer sizes and with different number of available crowdsources. To analyze effects of crowddelivery, the obtained results are compared to those of a delivery solely performed with in-house vehicles. The results show that in the case of crowddelivery, total distance can be reduced up to 16,03%, which is achieved by a successful matching of 23,33% of order requests. The influence of two parameters is also examined, namely carry weight and cover radius of crowdsources. This results in a significant increase in orders assigned to crowdsources and distance savings. In the original set of instances and in the case when the weight parameter is adjusted, best results are achieved in the particular instance consisting of the highest number of both customers and crowdsources. This outcome only confirms the economies of scale character of crowd concept. Since the tested instances are randomly generated and are of smaller size, it is advisable to conduct the testing on a bigger sample set to validate achieved results.

The problem of local delivery can further be investigated by incorporating other means of transportation, such as bicycles and cars. Furthermore, a new cost calculation can be applied instead of the solution illustrated in this thesis, with distances posing as costs. Likewise, different strategies for a matching process can be considered, such as assigning customers to crowdsources based on a bidding process.

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