A

Appendix: Scientific paper

An agent-based approach to simulate strategical effects of crowdshipping in the Netherlands

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Changing logistic demands let companies search for innovative shipping possibilities. One of these innovations is 'crowdshipping', parcel delivery done by the crowd instead of conventional delivery companies. The goal of this study is to explore the interactions between travellers and parcel shipments in various strategic crowdshipping contexts and assess their impact on transport use in the Netherlands. For this, an agent-based model was built with interactions between the customer, crowdshipping platform, traveller and occasional carrier. Results show a large increase in passenger transport kilometres compared to the decrease in freight transport. The passenger transport increase is equally divided between car and bicycle traffic. The service seems viable with an average compensation lower than the price of conventional delivery and a high number of delivered parcels. Experiments show that these results highly depends on the platform's strategy.

Keywords: crowdshipping, agent-based, simulation, case study

1. Introduction

Logistics has been changing massively in the recent decades; the world is more globally connected, people increasingly live in urban areas and technological innovations cause an exponential rise in e-commerce. The sales are currently doubling every five years which expected continue for the next five years as well (Clement, 2020). Besides, the recent coronavirus pandemic gave an additional boost the growth (Ali, 2020). These increasing e-commerce sales subsequently lead to increasing parcel transport, something noticed in the Netherlands as well. The largest parcel delivery service, PostNL, noted an volume increase of 29.6% in the last quarter of 2020 (PostNL, 2021). At the same time, consumers seek for more flexibility in delivery channels and times (DHL, 2013). Consumers expect logistics services to be smoothly integrated in their daily routine activities, deliveries should be right on time, delivered any time a day at any location.

Unfortunately, parcel delivery leads to various negative effects. These effects mostly consist of congestion in urban areas, air, and noise pollution (Demir et al., 2015). Companies therefore seek innovative solutions for their parcel transport. One of these innovations is "crowdshipping", parcel delivery done by the crowd instead of conventional delivery companies. By making use of existing passenger transport rather than a specially dispatched driver to ship parcels, it is promised that shipping will be economically and environmentally more sustainable (Punel et al., 2018 & Rai et al., 2017).

The impact of crowdshipping, however, is hardly examined in literature. Research has been based on case studies (Paloheimo et al., 2016), quantitative data of start-up crowdshipping firms (Ermagun and Stathopoulos, 2018, Rai et al., 2017), small scale hypothetical data (Macrina et al., 2020) and survey data (Punel et al., 2018). These researches result in small scale analysis which lacks integration of the above mentioned various crowdshipping implementations. This is substantiated by a recent review by Le et al.

(2019). This integration is necessary to assess the impact of crowdshipping on the transport systems. The knowledge gaps are defined as a lack of strategic analyses of the impact of crowdshipping on all actors in the transport systems, and crowdshipping has not yet been integrated into transport models.

To address these knowledge gaps, the goal of this research is to explore externalities of different crowdshipping strategies and assess their potential.

This structure of this paper is as follows; first, the state of the art literature is discussed. Following, the method is described. Next, the results are given and finally, the conclusion is given with possibilities for future research.

2. Literature

Crowdshipping could take place in various ways and the definition varies ambiguously over literature (Mehmann et al., 2015, Rai et al., 2017, Punel et al., 2018). Therefore, the following definition will be used in this report ”Crowdshipping is the transport of parcels done by an undefined and external crowd which is coordinated using an information platform”. Within this definition, various implementation methods are possible. At first, the route options will be discussed, followed by infrastructure usage, compensation schemes, carrier selection method and finally other dependencies will be elaborated.

Route options

Walmart experiments with their employees who at the end of their working day deliver packages around their homes (Lore, 2017). Archetti et al. (2016) also assume that the carrier has the same origin as the parcel, yet assumes the opportunity that customers could be carriers as well. Lee and Savelsbergh (2015) suggest that occasional carriers (crowdshipping carriers) should not necessarily have the same origin as the parcel. This results in a larger group of potential carriers. Instead of a full trip made by the occasional carrier, Wang et al. (2016) see an opportunity where crowdshipping is only done for a certain part of the parcel transport. This could be done using pick-up points where conventional parcel service takes care of most part and the ’last mile’ will be done by the occasional carrier.

Crowdshipping where carriers and the consignor have the same origin, is a variant from the implementation where both the origin and destination are different for carrier and parcel. The former has an advantage that the detour to pick-up the parcel falls away.

Infrastructure usage

Most literature assumes crowdshipping is done by private vehicles (Rougès and Montreuil, 2014), here the modal choice of the occasional carrier determines the used infrastructure. Yet there are a few pilots where existing passenger transport infrastructure is used for crowdshipping. Both Li et al. (2014) and Chen and Pan (2016) review cases where taxis are shared by parcel and passenger transport. van Duin et al. (2019) and Schäfer (2003) describe case studies with the usage of busses to transport parcels. Quadrifoglio et al. (2008) suggest using the tram for crowdshipping. Finally, Trentini and Mahléné (2010) propose an idea where all transport is shared for both passenger and freight transport.

Compensation

As described in the first chapter, the crowd participates voluntarily, but will be compensated for their effort. There are four main options for the compensation; First is the simplest form to compensate for the distance to be travelled by the parcel, independently of the origin and destination of the occasional carrier. This has the practical advantage that the crowdshipping company does not need to know the route of the carrier, yet it does not take into account the extra effort by the occasional carrier (Archetti et al., 2016). The second option is thus to compensate for the extra time/distance the occasional carrier has incurred to deliver the parcel. Third, the platform may choose to set a fixed compensation for all parcels, or base the amount on shipment characteristics. Finally, a variable compensation could be provided based on supply and demand (Rougès and Montreuil, 2014).

Matching

When a parcel needs to be shipped, a consideration needs to be made for which passenger may transport this parcel. There are three matching procedures described in literature to select the occasional carrier; At first, Wang et al. (2016) describe an assignment method where the system finds the most feasible occasional carrier who then must accept the job. If the carrier refuses the job, the system will look for the next best candidate and so on. Another method is given by Kafle et al. (2017), they describe a bidding process where potential occasional carriers place their bid on available parcels and the system selects the best option. The third and final method is to apply the simple first-come, first-serve principle. Here travellers could ’claim’ certain parcel shipments and the first to claim may do the shipment.

Other dependencies

These four themes are widely covered in literature, yet there are more implementation variations which would probably determine the success of the crowdshipping implementation. First, Ermagun and Stathopoulos (2018) note that not only **shipping characteristics**, but also the **socio-economic and built environment** characteristics of both the trip origin and the trip destination affects the availability of crowd-resources. Secondly, it should be considered that crowdshipping is an alternative service for parcel delivery and would most likely work side to side with conventional delivery services. On this matter, **integration and corporation** with conventional parcel delivery should be taken into account. Next, the **delivery time window** could impact success. The time window varies from same-day delivery (Dayarian and Savelsbergh, 2020) to long term pre-specified time windows (Dahle et al., 2019). Finally, some **preconditions** are mentioned by Varshney (2012), mostly related to privacy and reliability concerns. Rai et al. (2017) add criterion related to the platform provider and crowd.

3. Method

To address to the previously stated research goal, an agent-based model is developed to simulate the interactions between the agents in the system. For this agent-based model, first, the involved actors and the crowdshipping process are identified. Following, this process is conceptualised into a system with interacting agents. This conceptual model is finally implemented in a Python based simulation model using a supplementing transport model.

The involved actors are the following. The most important actor is the public administration since this is the problem owner of the possible externalities. Secondly, the crowdshipping platform manages the matching of supply and demand from both the consignor and the traveller, which are both actors in this system as well. When a match is made, the traveller becomes an occasional carrier. Next, customers are an actor in this system since they place the orders and decide for the delivery method. Finally, the conventional delivery service provider takes over the parcels for which no match could be found. Furthermore, the impact of crowdshipping is compared to conventional delivery, where this actor has a key function.

For the conceptual model, only the customers, crowdshipping platform, travellers and occasional carriers are considered as agents. The other actors have no direct relevant interactions in the crowdshipping process. Between these four agents, the following interactions takes place. At first, the customers place their orders at the platform. After this process, a few interactions take place back and forth between the travellers and the platform. First, the traveller communicates their planned trip after which the platform searches through the orders and calculates the optimal ones for this particular traveller. These optimal shipment offers are communicated back to the traveller. Now the traveller may pick their favoured offer and accepts this delivery offer, or denies them all. When an offer is accepted, this is communicated back to the platform and the traveller becomes an occasional carrier who now will make their trip with an additional detour. A schematic overview of these interactions could be found in figure A.1.

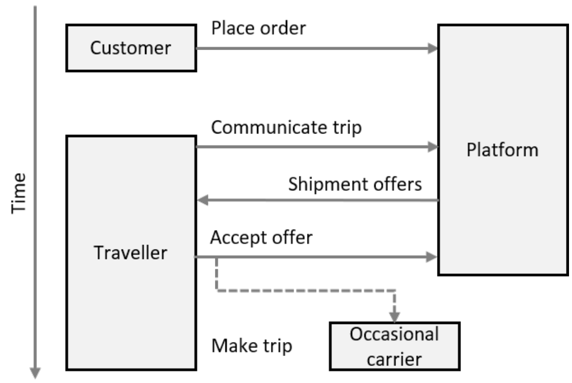

Figure A.1: Agent interactions

The simulation model is implemented using the Python Programming Language. In the simulation, first the parcel demand and travellers supply are generated. Following, a loop iterates over all travellers for which the optimal parcels are calculated. The input for this simulation comes from three sources. First, the conceptualisation of above mentioned agents comes with various states which were studied in literature. Secondly, agent-based simulation model 'Mass-GT' provides this research with parcel demand data as well as outcomes on conventional delivery performance (de Bok and Tavasszy, 2018). Thirdly, the Verkeersmodel Metropool Regio Rotterdam Den Haag (VMRDH) provides this research the spatial demarcation (Goudappel, 2018). The case study will be applied to the study area of VMRDH, which is the province of South Holland in the Netherlands.

Four output indicators were defined for this simulation. First, the difference in driven distance compared to the reference case. This consists of the increase in passenger kilometres through detours made by occasional carriers, and the decrease in freight transport kilometres through lower demand for conventional parcel delivery. The second indicator is the mode in which the detour is taken. From the modality use, the sustainability of the concept could be derived. Thirdly, the average provided compensation to the occasional carriers is calculated to determine the viability of the platform. The fourth indicator is the percentage of delivered parcels, again relevant for the platform's viability.

4. Data & Results

Study area

The study area covers most of the province South Holland in the Netherlands with an area of 1,125 square kilometres. This area is divided over 5925 zones with geographical as well as socio-economical data for each of them. The geographical data includes their zone location and a skim matrix for the travel distance between the zones as well as the travel time for car travel. For the socio-economical data, the household data is most important; in the study area, 2.3 million residents live spread over 1.1 million households.

Within the study area, over 220,000 parcels are ordered each day. Of these parcels, about 6% is eligible for crowdshipping which is about 13,000 parcels. The parcel demand must be matched with the traveller supply. About 4.1 million trips are made each day within the study area by car or bike. 30% of these travellers are willing to carry a parcel which are about 750,000 willing travellers who enter the model. The output of the model are the difference in driven distance compared to the reference case, the mode used for the detour, the average provided compensation, and the percentage of delivered parcels.

Results

To understand the crowdshipping results, the reference case is described first. The reference case is a scenario where no crowdshipping takes place. In the passenger transport system, 4,1 million trips are made. 57% of these trips are made by car and the other 43% by bike. The car trips accounts for a total driven distance of 15.5 million kilometres (6.6 km/trip). The driven distance by bike is significantly lower at almost 7 million kilometres (3.9 km/trip). In freight transport system, this research only focuses on parcel transport. In the reference case, 221,125 parcels are ordered daily. To deliver these parcels, 1,240 tours are made for 28,200 trips. The total driven distance by the delivery vans is 68,200 kilometres. This only includes the last mile of the parcel transport from the distribution centre to the customer.

The base case is a scenario with crowdshipping. In the base case, the system is modelled with the input parameters as found in literature. Of the 220,000 daily ordered parcels, slightly more than 13,000 are eligible for crowdshipping. A reduction of 2,300 kilometres by delivery vans is found through the decrease in regular delivery demand. On the other side, the passenger transport increased with 31,400 kilometres, which contains the detours made by the occasional carriers. Of these passenger kilometres, about half is driven by bike, which does not impact the congestion and emissions, yet the other half is driven by car. The average provided compensation is €2.32, which is below the average price consignor currently pays for delivery services (of €3.35). Furthermore, for most parcels, a suitable occasional carrier could be found. For 97.5% of all ordered crowdshipping parcels, a match is made.

An overview of the most interesting model results can be found in table A.1

Decreasing detour distances

As the above-described figures show, the passenger transport increase is 14 times the decrease of conventional delivery kilometres. Experiments were performed to make crowdshipping more efficient. The platform has two levers to decrease the taken detour by the travellers: the provided compensation and their relative detour threshold. Lowering either of these, causes the detour to decrease yet on the other hand the percentage of delivered parcels drops as well. A trade-off must be found between a low detour and high percentage of delivered parcels. Experiments show that lowering the detour threshold is more effective in decreasing the taken detours, while maintaining an acceptable percentage of delivered parcels.

Furthermore, in tuning the levers, the platform may force occasional carriers to make negative detours. This is caused since travellers usually choose the fastest route, which is not always the shortest one. When a parcels gets offered on a shorter yet slightly more time-consuming trip, the driver could take a shorter route to deliver a parcel. Based on the current outcome indicators, these trips score good. However, these shorter routes with lower travel speeds may however be undesirable because of higher usage of local roads.

Run scenario	Percentage delivered	Average compen-sation	Freight km decrease Delivery van	Passenger km increase Bike	Car	Total (avg)
Base	97.52%	€2.32	2,261	14,900	16,490	31,400 (2.45)
Detour threshold -0.9	55.07%	€2.34	1,000	620	-2,130	-1,510 (-0.21)
Ratio 6.8 110,000 parcels	87.33%	€2.29	19,078	68,910	135,720	204,630 (2.12)
Ratio 6.9 13,000 parcels	64.87%	€2.24	1,379	6,400	12,210	18,610 (2.18)
Fixed compensation €2.50	95.66%	€2.50	2,168	15,380	11,760	27,140 (2.16)
Based on traveller's detour trip length	93.74%	€1.94	2,269	11,480	15,350	26,830 (2.37)
no pickup points	98.64%	€2.35	692	3,100	5,700	8,810 (2.89)
1 pickup point	99.09%	€2.21	570	2,440	4,720	7,150 (2.34)
3 pickup points	99.42%	€2.09	565	3,710	2,060	5,770 (1.88)
6 pickup points	100%	€1.98	603	3,880	710	4,590 (1.50)

Table A.1: Results experiments

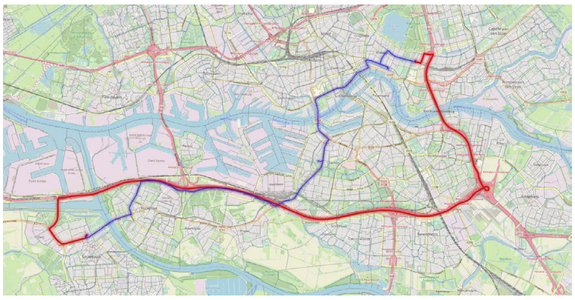

Figure A.2: Example negative detour. In red the planned traveller's trip, in blue the 'detour' trip for crowdshipping delivery

Distribution of parcels and travellers

Another experiment was done to inspect the impact of the ratio travellers per parcel. In the base case, 750,000 travellers were willing to carry 13,000 parcels, 57 travellers per parcel. With this ratio, the percentage of delivered parcels was at 97.5%. The ratio could be decreased in two ways; increasing the number of parcel orders, or decrease the number of travellers. When increasing the number of parcel orders, the percentage of delivered parcels was not affected significantly. However, lowering the number of travellers, the percentage of delivered parcels dropped.

These observations could be explained by the fact that a certain distribution of parcels and travellers is needed for the system to work properly. To get a better understanding of this, visualise a system of 5 travellers and 1 parcel in a confined area. Here, it would be a 'case of luck' to find a suitable parcel to ship. When this number goes up to 50 travellers and 10 parcels (same ratio), travellers are more likely to find a suitable parcel. This is tested in the small-scale environment, see figure A.3. For the first scenario (5 travellers, 1 parcel), in only 27% of runs this parcel gets delivered. In the second scenario (50 travellers, 10 parcels), on average 74% of parcels gets delivered.

5 travellers, 1 parcel: 50 travellers, 10 parcels:

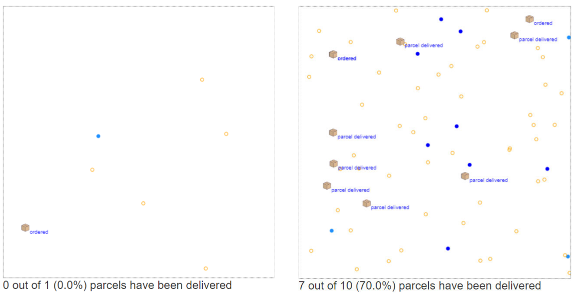

Figure A.3: Small scale experiments ratio travellers per parcel

Pick-up points

The final experiment covers the use of pick-up points. For these experiments, a smaller part of the spatial demarcation is used to perform better qualitative assessments. The use of pick-up points is examined in The Hague. Model runs are performed with 0, 1, 3 and 6 pickup points. The detour decreases from 2.89 km (without pickup) to 1.5 kilometres at 6 pickup locations. At the same time, the percentage of delivered parcels increased up to 100%.

In these experiments, the number of pick-up points and their locations were not optimised. Adding pick-up points would bring extra operating costs, so a trade-off must be made between decreased detour and total cost of operations. Furthermore, Wang et al. (2016) and Serafini et al. (2018) suggests placing pick-up points at public transport hubs. In this research, public transport data was lacking so this placement of pick-up points could not be tested.

5. Conclusion

This research assessed the externalities and viability of crowdshipping. The base case shows a large increase in passenger transport kilometres compared to the decrease in freight transport. The passenger transport increase is equally divided between car and bicycle traffic. The service seems viable with an average compensation lower than the price of conventional delivery and a high number of delivered parcels.

The experiments show large fluctuations in outcomes between the different experiments. The base case makes clear that crowdshipping without interventions could turn out worse for the environment and congestion. Even while these problems were the initial motive to seek for innovative solutions for parcel delivery. In some experiments, the negative externalities were limited while maintaining perspective on viability. This research affirms the findings by Simoni et al. (2019) that limiting the deviation of crowdshippers' delivery trips from their original trips is a necessity to reduce negative externalities. It is advised for the public authority to set boundaries for the platform and stimulate strategic matching choices based on these possible externalities.

Future research

Future research could be done on four areas. At first, the negative detours raise need for more extensive research in the spatial distribution of occasional carriers' detours. This would consist of two parts. At first to determine which routes are preferential to take. And secondly to find out how the platform could strategically compulse travellers towards the preferred routes, while maintaining their viability.

Secondly, more research could be done on the externalities of crowdshipping including public transport, especially in the case of pick-up points. Furthermore, to better determine effects per modality, more extensive stated preference research to travellers' willingness per mode would be needed. This new stated preference study should pay attention to the sample size and getting a representative sample.

Thirdly, an conceptually interesting concept is to optimise for collaboration between conventional and crowdshipping delivery. This would especially helpful combined with the use of pick-up points. Certain parcels could be chosen strategically to transport using occasional carriers because these would be more costly or environmentally worse using conventional delivery.

Finally, this research showed that implementing crowdshipping leads to an increase in driven mileage and possibly emissions. The problem owner of these externalities, the public administration, might set policies to limit the effects. Two shortly suggested methods of interventions are stimulating the platform to consider environmental impacts in their matching strategy, and limiting certain detours. However, future research could study other, better suited, interventions and corresponding legal possibilities.

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