Assessing the Impacts of Public Transport-Based Crowdshipping: A Case Study in Nørrebro District in Copenhagen

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SHORT SUMMARY

This paper proposes a public transport-based crowdshipping concept as a complementary solution to the traditional parcel delivery system, where public transport users utilize their existing trips to carry out crowdsourced deliveries. To analyze the impact of public transport-based crowdshipping, we conduct a case study in Nørrebro district in Copenhagen using real-world data. Three scenarios with varying percentages of crowdshipped parcels are developed to be compared with the traditional distribution mode. For each scenario, the distribution of non-crowdshipped parcels is formulated as a capacitated vehicle routing problem and solved by the adaptive large neighborhood search metaheuristic. Results show that applying public transport-based crowdshipping could reduce the total vehicle kilometers traveled, the total working time of drivers, and the number of used vans (drivers) to perform last-mile deliveries. Moreover, public transport-based crowdshipping has great potential to reduce the total costs including driving costs, external costs, labor costs, and compensation.

Keywords: City logistics; Last-mile delivery; Crowdshipping; Impact assessment.

1. INTRODUCTION

Facing the exponential growth of E-commerce, both logistics service providers (e.g., DHL) and E-retailers (e.g., Amazon) have experimented with crowdshipping as a complementary solution to provide efficient last-mile delivery. In such a system, ordinary people utilize their free capacity regarding time and/or space to perform parcel delivery with monetary compensation.

Crowdshipping can be implemented in different ways. The main body of prior research and practical applications related to crowdshipping has focused on private personal vehicle use, where dedicated trips or detours are more or less unavoidable (Allahviranloo and Baghestani, 2019; Punel and Stathopoulos, 2017). Such personal vehicle-based concepts often entail rebound effects resulting in emission increases instead of decreases (Buldeo Rai et al., 2018). Meanwhile, sharing economic concepts has often been criticized for undermining workers' rights and creating a 'gig-economy' precariat (Paus, 2018).

To balance these considerations, this paper proposes a public transport (PT)-based crowdshipping concept (see Figure 1). In PT-based crowdshipping, automated parcel lockers (APLs) are

installed in some PT stations to store small parcels. A proportion of parcels are transported from the depot to PT stations by trucks and then delivered by crowdshippers. The crowdshippers are PT users, who pick up the parcels from APLs installed in the PT stations at PT users' origins before starting their PT trip and deliver the parcels to APLs installed in the PT stations at PT users' destinations. The final recipients take the parcels from the APLs in the stations near the parcels' destinations. The crowdshippers are compensated with credit for the transit system. This could ensure that only trips that would be taken anyway are utilized and that the task of crowdshipping cannot evolve into creating a new precarious job market lacking workers' rights.

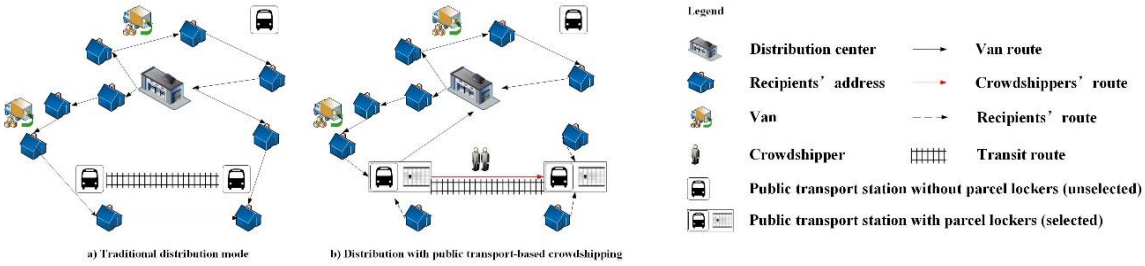

Figure 1 Comparison of traditional distribution mode and public transport-based crowdshipping

Three studies have examined the potential impacts of such a novel last-mile delivery system. All of them found that PT-based crowdshipping has positive impacts on reducing greenhouse gas emissions, vehicle kilometers traveled, etc. The PT-based crowdshipping concept in Gatta et al. (2018) and Karakikes and Nathanail (2022) is the same as our idea presented in Figure 1. Zhang et al. (2022) proposed another type of PT-based crowdshipping where PT users pick up parcels from APLs located in metro stations and deliver the parcels to the parcel's end destination instead of an APL in the PT user's destination stop.

Different from Gatta et al. (2018) and Karakikes and Nathanail (2022) which consider only installing APLs at metro stations, our study investigates a PT-based crowdshipping system with a denser network of APLs by extending the APLs network to some major bus stops so that more parcels could be delivered by crowdshippers. We determined the bus stops to install APLs and the vehicle routes to deliver the packages unserved by crowdshippers by solving a set covering problem and capacitated vehicle routing problem, respectively. The impacts of the PT-based crowdshipping were evaluated using real-world data in Copenhagen.

2. METHODOLOGY

To assess the impact of PT-based crowdshipping, three crowdshipping scenarios with varying percentages of crowdshipped parcels are simulated to be compared with the base scenario. The study area in this research is Nørrebro district in Copenhagen, the capital of Denmark. Nørrebro is located northwest of the city center, with an area of 3.82 km^2 and a population of 71891. It has a high population density and good public transport coverage.

Demand

The parcel delivery data is provided by PostNord – the largest logistics service provider in Denmark. The study period is from October 11th to October 17th, 2021, representing a normal

operation week. On average, 864 parcels with 492 delivery points are delivered per weekday and 480 parcels with 146 delivery points are delivered on the weekend.

The demand for crowdshipped parcels is influenced by many factors, e.g., goods' attributes (category, weight, size), recipients' social demographics (age, job), etc. Unfortunately, we do not have this information from the parcel data. Thus, we randomly select a certain number of parcels as crowdshipped parcels to reflect the ultimate effects of various influencing factors on demand for crowdshipping. When a sender places an order, he/she should specify whether the item to be delivered is a home parcel, collect parcel, or crowdshipped parcel.

Supply

Parcels distributed to Nørrebro are sorted in Brøndby distribution center, from where vans with small capacity depart, visit customers in Nørrebro, and finally return to the distribution center. The geographic distribution of the Brøndby distribution center and the study area is illustrated in Figure 2.

Figure 2 Study area

- Location of APLs

The main public transport means in Denmark include bus, metro, S-train, and train. S-train serves the Copenhagen metropolitan area. It has 86 stations that connect the suburban and urban areas. The S-train system carries more than 357000 passengers a day. Two S-train stations near Brøndby distribution center, i.e., Glostrup station and Brøndbyøster station, are selected to install APLs for crowdshippers to pick up the parcels. Crowdshipped parcels are placed in the APLs installed in the two stations before 7:30 am and will be completed on the same day.

We assume recipients only accept crowdshipped parcels delivered at PT stations within 500 meters of their original delivery addresses (i.e., home address of home delivery parcels and collect points of collect parcels). APLs are available at eight railway stations (i.e., S-train and metro stations) within or near Nørrebro district. Since the eight railway stations cannot serve all recipients, seven bus stops are selected, by solving a set covering problem proposed by Toregas et al. (1971), to serve recipients that railway stations cannot serve.

The capacity of APLs at each selected PT station is unlimited by installing sufficient APLs. This assumption makes sense considering the following reasons. First, APLs are easy to install – one person can complete them in several minutes. Second, APLs are inexpensive. The long-life battery inside the APL could work for ten years.

- Crowdshippers

The supply of crowdshipping is influenced by many factors, e.g., goods' attributes (category, weight, size), crowdshippers' social demographics (age, job), compensation, and extra time needed to perform delivery. Based on data from the Danish Rejsekort and the national Danish traffic model, around 400 daily trips are made from Brøndbyøster station and Glostrup station to Nørrebro. Although an additional effort is required to determine the number of trips to the selected PT stations where APLs are installed, this provides an estimation of the overall volume of passenger traffic. According to Fessler et al. (2022), when the compensation is 10 DKK per parcel, a passenger's probability of bringing a parcel is more than 30%. Increasing the compensation would attract more passengers working as crowdshippers and encourage crowdshippers to bring more parcels on their trips. To estimate the maximum potential benefits of PT-based crowdshipping, we assume that all crowdsourced parcels could be performed by crowdshippers by allowing crowdshippers to bring multiple parcels on their trips and increasing the compensation.

Scenario description

In the base scenario (S0), all parcels are distributed by the logistics companies using their vans. In the crowdshipping scenarios S1, S2, and S3, 10%, 20%, and 30% of the parcels are randomly selected and assigned to crowdshippers, while the rest are distributed by the delivery vans. The routes of the vans are determined by solving a standard capacitated vehicle routing problem using the adaptive large neighborhood search (ALNS) metaheuristic (Ropke and Pisinger, 2006). We generate 15 samples for each scenario of the daily parcel data to eliminate the stochastic effects of randomly selecting crowdshipped parcels. S1 is easy to achieve when most crowdshippers bring one parcel and the compensation is 10 DKK per parcel, while the realization of S2 and S3 requires more passengers to bring multiple parcels or more compensation paid to crowdshippers.

3. RESULTS AND DISCUSSION

Using the methodology introduced in section 2, we simulate the delivery operation of PostNord under different scenarios. Three indicators, vehicles kilometers traveled per day (including the travel distance of trucks that deliver crowdsourced parcels from the depot to selected PT stations), total working time of drivers (time spent by the driver from departure to return to the distribution center), and the number of used vans to serve Nørrebro, are used to describe the performance of each scenario. It is worth noting that the simulation result of the base scenario is validated by PostNord, which means the aforementioned three indicators obtained from our simulation are close to their actual operation on those days. The value of each indicator for each scenario is equal to the average value of the 15 samples of the scenario.

- Impacts on vehicle kilometers traveled

Figure 3 presents the percentage change of vehicle kilometers traveled during the study period under different crowdshipping scenarios. All the signs are negative, indicating that using PT-based crowdshipping as a complementary solution to last-mile delivery could reduce the vehicle kilometers traveled to deliver the parcels, even if some distances are needed to transport the crowdsourced parcels from the depot to PT stations. Moreover, the more parcels delivered by crowdshippers, the more percentage reduction of vehicle kilometers traveled occurred. First, it is shown that the average percentage reduction of vehicle kilometers traveled is 6%, 11%, and 20% under scenarios S1, S2, and S3, respectively. Second, the percentage reduction of vehicle kilometers traveled on the weekdays (8%, 14%, and 25% for scenarios S1, S2, and S3, respectively) is more significant than that on the weekend (2%, 4%, and 6% for scenarios S1, S2, and S3, respectively).

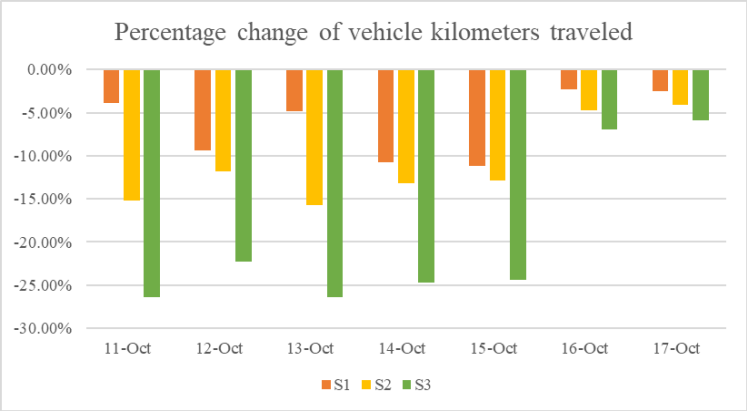

Figure 3: Percentage change of vehicle kilometers traveled under different scenarios

- Impacts on total working time of drivers

Figure 4 demonstrates the percentage change in drivers' total working time under different scenarios. On average, drivers' total working time could be reduced by 11%, 20%, 30% on weekdays and 7%, 15%, 21% on the weekend under scenarios S1, S2, and S3, respectively. This could reduce the increasing labor intensity of drivers.

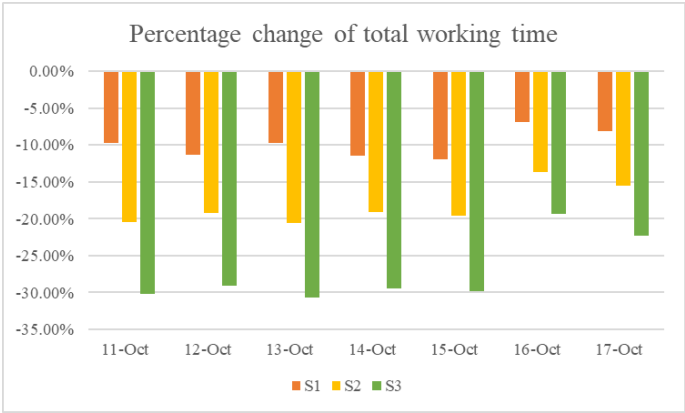

Figure 4: Percentage change of total working time under different scenarios

- Impacts on the number of used vans

Figure 5 shows the change of the number of used vans to serve Nørrebro. The simulation results are in line with our intuition that when some parcels are transferred from vans to crowdshippers, the number of used vans should be less than or equal to that in the base scenario. The reduction of used vans on weekend is zero, because only one van is used in the base scenario. The parcels cannot be completely delivered by crowdshippers. Therefore, one van is still used in crowdshipping scenarios. The number of used vans keeps unchanged in S1 on October 11th and October 13th. This indicates that the number of required vans (drivers) could be saved only when enough parcels are removed from vans to crowdshippers. Generally, if 20% of the parcels could be delivered by crowdshippers, one van (driver) is released. If the percentage of crowdsourced parcels reaches 30%, two vans (drivers) are released.

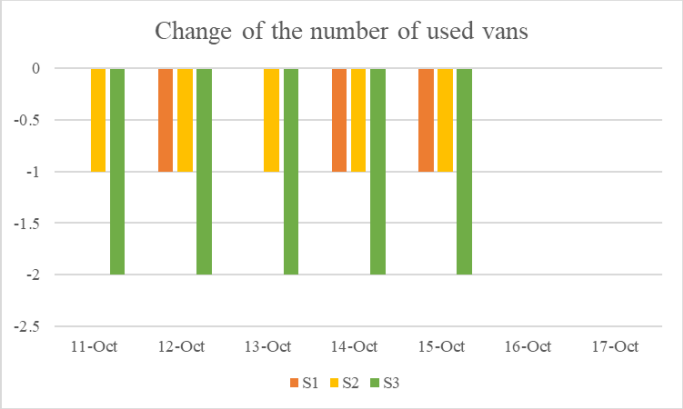

Figure 5: Change of the number of used vans under different scenarios

- Cost analysis

Four types of costs are related to the PT-based crowdshipping, i.e., driving costs of vans and trucks, external costs of traffic (e.g., marginal costs of air pollution, traffic congestion), drivers' salary, and compensation paid to crowdshippers. This section presents the potential befits of PT-based crowdshipping based on the transport economic unit prices (TEUP) of 2022 prepared by Transport DTU and COWI for the Ministry of Transport (Denmark) (https://www.man.dtu.dk/forskningsbaseret-raadgivning/teresa-og-transportoekonomiske-enhedspriser).

The driving costs of vans and trucks include costs for fuel, tires, repair and maintenance, and depreciation. These costs are split into fixed and variable costs per hour and per kilometer, respectively, in TEUP. The fixed costs for vans and trucks are 529 DKK/hour and 542 DKK/hour, respectively. The variable costs for vans and trucks are 1.82 DKK/km and 4.19 DKK/km, respectively.

The negative externalities of transport include air pollution, climate change, noise, accidents, congestion, and wear on the infrastructure. The marginal external costs are used to estimate the cost per kilometer for the external effects. The marginal external costs for vans and trucks are 1.46 DKK/km and 6.01 DKK/km, respectively.

The average salary for a postal delivery worker is 24274 DKK per month (https://www.paylab.com/dk/salaries-in-country?lang=en), and the compensation for crowdshipper is 10 DKK per parcel as Fessler et al. (2023) did in the field test.

Table 2 presents the four types of costs under different crowdshipping scenarios. The distribution of each type of cost under different scenarios is similar. The driving and external costs account for 25% and 1% of the total costs, respectively. Labor costs account for about 70% of the total costs, and the compensation for crowdshippers accounts for 0%-5% of the total costs. Compared with the base scenario, on average, the total costs of S1, S2, and S3 are reduced by 8%, 13%, 24% on weekdays and 1%, 3%, 4% on the weekend, respectively. Based on Table 2, we conclude that by providing small compensation, PT-based crowdshipping has great potential to reduce last-mile delivery's driving costs. Meanwhile, it could benefit logistics companies by reducing labor costs, but it might negatively impact laborers in terms of salary.

Table 2: Cost analysis of public transport-based crowdshipping under different scenarios

		11-Oct	**12-Oct**	**13-Oct**	**14-Oct**	**15-Oct**	**16-Oct**	**17-Oct**
Driving costs (DKK)	S0	16123	17275	17010	16239	15230	2717	7747
	S1	14117	15431	14882	14502	13558	2487	6965
	S2	12569	13648	13228	12887	12034	2256	6228
	S3	11239	12192	11806	11529	10780	2082	5618
External costs (DKK)	S0	288	314	292	282	279	58	140
	S1	281	289	283	255	252	57	138
	S2	253	286	255	253	251	56	137
	S3	225	259	228	225	223	56	137
Labor costs (DKK)	S0	42480	48548	42480	42480	42480	6069	18206
	S1	42480	42480	42480	36411	36411	6069	18206
	S2	36411	42480	36411	36411	36411	6069	18206
	S3	30343	36411	30343	30343	30343	6069	18206
Compensation (DKK)	S0	0	0	0	0	0	0	0
	S1	870	970	870	830	800	120	360
	S2	1730	1930	1740	1650	1600	240	720
	S3	2600	2900	2610	2480	2390	360	1080
Total costs (DKK)	S0	58890	66137	59782	59000	57989	8843	26092
	S1	57747	59169	58514	51998	51021	8732	25668
	S2	50962	58344	51634	51201	50297	8621	25291
	S3	44407	51761	44987	44576	43735	8566	25041
Percentage change of total costs	S1	-2%	-11%	-2%	-12%	-12%	-1%	-2%
	S2	-13%	-12%	-14%	-13%	-13%	-3%	-3%
	S3	-25%	-22%	-25%	-24%	-25%	-3%	-4%

4. CONCLUSIONS

This study investigated the impact of applying PT-based crowdshipping as a complementary solution to traditional last-mile delivery. We select the study area of the Nørrebro district in Copenhagen because of its high population density and good public transport coverage. PostNord provides the parcel data. Three crowdshipping scenarios with different percentages of crowdsourced parcels are created to compare with the base scenario and identify the effects of

PT-based crowdshipping under different development stages. We use three indicators, i.e., vehicle kilometers traveled, total working time of drivers, and the number of used vans, to evaluate the performance of different scenarios. All values of the indicators are reduced with the increasing percentage of crowdshipped parcels. In the most optimistic scenario where 30% of the parcels are delivered by crowdshippers, the reduction percentage of the first two indicators reaches 20% and 27% on average, and two vans (drivers) are released. The cost analysis shows that significant potential savings on driving and labor costs could be achieved by transferring some parcels to crowdshippers and providing them with small compensation.

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