Public transport services in support to the last mile freight deliveries

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1 INTRODUCTION

Last-mile urban deliveries for e-commerce are growing (Statista, 2020) and becoming less efficient due to the rise of short lead time requirements. Also, in congested cities is very hard to meet delivery deadlines. To overcome these challenges, some companies such as Amazon are using satellite facilities which are closer to final customers. However, adding these facilities may be frowned upon by neighbors (Citizen, 2021) and could increase delivery costs. In general, logistics facilities are sprawl outside metropolitan areas (Dablanc *et al.*, 2014). The logistics sprawl further increases costs if the level of service is time-sensitive due to the low number of customers that can be served per route.

One solution is to go for a collaborative approach with public transport services, using a two-tier delivery system where freight is first moved by segregated public transport services, and then by last-mile vehicles to customer locations. We envision that, in the first leg, public transport vehicles can carry packages on a hitched cart that its then dropped at one transit stop, from where the packages are transfer to a last-mile delivery vehicle. In this manner, packages do not interact with passengers and and the public transport vehicle is only marginally delayed when disconnecting the hitched cart.

The general objective of this paper is to analyze the value of using public transport services in the first leg in systems with time-tight delivery deadlines. As a benchmark, we use the case of delivering everything directly from a remote depot. We study two settings. The first case for a single line transit structure, and the second case for a fork transit services with known routes and schedules.

2 METHODOLOGY

We focus on finding the best transfer station locations to facilitate transfer between transit and last-mile vehicles. We assume one depot, and all customers spread uniformly in a delivery area to be served before a deadline T. The scheduled transit service operates with an average speed s_t, and with enough space in the cart to ship all goods. Each transit stop can potentially be used as a transfer station. Last-mile vehicles can depart from the transfer station and also directly from the depot with an average speed of s_l and a limited capacity. Our main goal is to minimize the expected travel distance of the last-mile vehicles across different customer instances.

First, we study a stylized system for a single depot, a transit line, and a single transfer station (Azcuy *et al.*, 2021). We look at several special cases using analytical expressions to get insights into the transfer location decisions when customers are continuously distributed on the transit line. Then, we analyzed customers located discretely over the region. This last case generalizes the multi-depot, multi-trip vehicle routing problem with variables starting times of the last mile vehicle routes. We use an Adaptive Large Neighborhood Search with local search to solve it.

Next, we study the case of delivery operations supported by scheduled fork-transit lines for a single depot and multiples transfer stations. We model this planning problem as a facility location problem considering aggregate and uncertain customer density over a delivery zone with tight delivery deadlines. In this case, we use the continuous approximation method to estimate the routing cost as was proposed by Beardwood *et al.* (1959).

3 RESULTS AND DISCUSSION

Below we present our base case results for the two settings considering a depot serving an area of 10 km by 10 km and where delivery locations are: (i) discretely and uniformly distributed over the region and there is one transit line to support deliveries (A single line setting); or (ii) continuously over the region and there is a scheduled fork transit line that branches $\frac{1}{3}$ into three transit lines running every 5 vehicles per hour at $s_t = 20$ each (A fork line setting).

For the line setting, the transit stops are located at one-third, two-third, and the end of the line from the depot. 50 customers are uniformly distributed across the delivery region. The last-mile vehicles can serve 40 customers per trip. In the base case experiment, we ignore travel times, because we consider that the deadlines is not a boundary. For every experiment, we generate 10 demand location realizations.

In the fork line setting, there are 87 potential transfer stations to be operated at a fixed cost of $ 22 per day. It takes 2 minutes to transfer orders from transit vehicle to last-mile vehicle. The last-mile vehicle can serve 493 customer locations per trip at a speed of $s_l = 15\ km/h$. We assume that it takes 5 minutes for each stop on the delivery route. The cost per unit distance is $0.6 per kilometer and per last mile vehicle required is $31 per day. In all our experiments, we generate 50 customer density realizations from a uniform distribution between 15 and 25 customers per km^2. We consider all customers to be served before 1, 2, 8 and 24 hours.

In both cases, the saving takes as benchmark the case without transfer stations.

Discussion Overall, both settings highlight that transit services can help reduce the total system-wide distance in urban delivery operations and reduce negative externalities. This integrated scheme has a high potential for distance savings, especially with short delivery deadlines in congested cities. Below we go into more detail on the results achieved in each setting.

3.1 A single line setting

Table 1 shows the main indicators of the base case. On average half of the customers are served

Table 1 – ***Baseline results of single line***

	% Customer via Transfer	% Savings	Transfer Location
min	22	1.2	
μ	54.2	4.9	$\frac{2}{3}L$
max	78.0	7.1	

via the transfer station. In terms of savings from using public transit, we see average distance savings of 4.9% and up to 7.1%. We note that the transfer location coincides with the analytical results in which we simplified the routing.

Next, we perform a sensitivity analysis of different parameters. We vary the capacity of the last-mile vehicles because it would be beneficial to use smaller, low- or zero-emission last-mile vehicles at the transfer station. The results suggest that using the transfer station may not be profitable, and the average savings drop from 4.9 to 2% as the capacity decreases.

We also vary depot location. As expected, when the depot is located farther away from the delivery zone, the savings are as high as 36.2%.

In addition, we study the impact of the number of customers in the service area. The results suggest that as the number of customers increases, savings decrease. One of the reasons is that as the number of customers increases, the more the last mile vehicle travels throughout the region, similar to the case of direct shipments. Next, we look for different customer cluster around the transit line. As expected, the savings are higher compared to the base case when customers are close to the transit line.

Finally, we checked the impact of tight delivery deadlines. We observe that as deadlines become tighter, savings increase when the last mile vehicle is slower than the transit vehicle ($s_l < s_t$) and decrease in the opposite case ($s_l > s_t$).

3.2 A fork line setting

Table 2 reports our key findings for the base case.

Table 2 – *Base case results over 50 instances. Mean values next the deviation in parenthesis.*

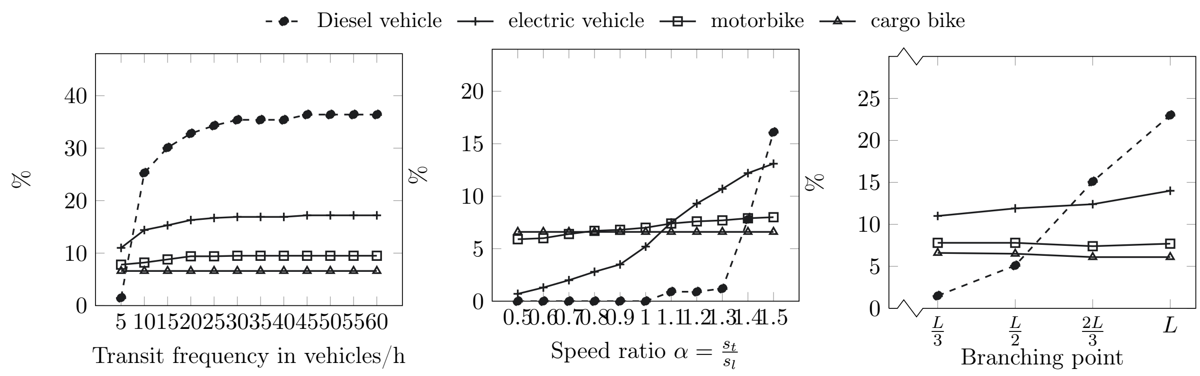
	1 h	2 h	8 h	24 h
Total Transfer stations	5	8	3	2
% Customer via Transfer	44.1 (9.5)	74.9 (4.5)	79.4 (1.4)	76 (0)
Cost per order	10.7 (0.1)	2.7 (0.1)	0.8 (0.1)	0.6 (0.1)
% Cost Savings	1.5 (0.4)	11 (1.3)	7.8 (2)	6.6 (0.1)

Overall, we see that as deadlines become small, a lower percentage of customers are served from a majority of transfer stations to the point that shipping via public transport is not as profitable, so both indicators decrease. As expected, tight deadlines increase the average cost per order, because fewer customers are consolidated per trip.In comparison to the case without transfer stations, we see that savings also increase until moving freight by public transport does not provide benefits and then decrease.

Next, we perform a sensitivity analysis of the base case. We evaluate more sustainable last-mile vehicles at transfer stations such as electric vehicles, cargo bikes, and cargo motorcycles. We assume the same congested network, but we set the cargo bikes to travel at 20 km/h, assuming they operate in bike lanes. It costs approximately 0.02 $/km for electric vehicles and cargo bikes and 0.0027 $/km for cargo motorbikes. The capacity per trip is 262, 91 and 8 customers for electric vehicles, cargo bike and cargo motorbike, respectively.

The results indicate that small vehicles in transfer stations reduce the number of transfer stations. This result is different from the single line setting. The reason is that in a fork line setting, the last-mile vehicles in the transfer station are more profitable than those in the depot. Furthermore, cost-effective vehicles allow traveling more distance from the transfer stations. As expected, the percentage of customers decreases as the deadline decreases. Interestingly, it increases sharply for cargo motorbikes when deadlines are very tight, because capacity no longer constrains more than deadlines. In terms of savings, we see that small and cost-effective vehicles available at the transfer station can provide further savings. The savings decrease with very tight deadlines. Still, using dedicated transit lanes followed by bike lanes can provide savings up to nearly 42 %.

We study how sensitive the cost savings is to transit frequency, transit speed and transit network branch point. Overall, we see that savings increase with better transit service performance, i.e. high operating frequency, higher transit speed or a branch point further away from the transit terminal. We summarize this results in Figure 1.



(a) ***Transit speed*** (b) ***Transit frequency*** (c) ***Transit branching point***

Figure 1 – *Impact on the cost savings, averaged over 50 random instances.*

In a practical context, potential customers could cluster around the transit line. Furthermore, the average customer density, the operating cost of each transfer station, and the cost of each required last-mile vehicle could change. To test the impact of these situations, we perform further sensitivity analyses. The key insights about using a transit line to support urban delivery operations are as follow.

- The savings increase with customers clustered close to the transit line, similar to the single line setting.
- The savings decrease as customer density increase with time flexibility, but increase in tight deadline situations until it is no longer possible to efficiently move many orders from the transfer stations and so the trend is downward.
- As the operating costs of transfer stations become expensive, fewer transfer stations are opened, lower percentage of customers are served via them and savings from using transfer stations decrease.
- The savings can be greater than the base case, if last mile vehicle costs are low, and even outweigh the higher costs as a result of very tight deadlines. Otherwise, the higher the vehicle cost, the lower the savings.

4 REFERENCES

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