DESIGN AND ANALYSIS OF CITY LOGISTICS SYSTEMS IN TORONTO FOR EXPRESS COURIER COMPANIES[i]

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1. Introduction

Cost effective and efficient goods delivery in urban areas is an essential business service that contributes directly to the competitiveness of Toronto-based firms. This efficiency is compromised in urban centres like Toronto because of urban congestion, a lack of commercial vehicle parking, inadequate loading facilities, and roadway geometric design. For example, courier vehicles, at least in part because of inadequate loading docks and on-street parking facilities in Toronto, are routinely issued parking tickets that impact the cost of doing business (Rosenfield, Lamers, Nourinejad, & Roorda, 2016; Wenneman, Habib, & Roorda, 2015). Urban congestion leads to significant delays and a lack of reliability in travel times, which makes optimization of the delivery route challenging. There is also concern with the impacts of delivery vehicles on emissions (Amirjamshidi, Mostafa, Misra, & Roorda, 2013), the contribution of stopped vehicles on congestion (International Parking Institute, 2015) and conflicts between parked delivery vehicles and bicycles that lead to safety concerns (Conway, Cheng, Peters, & Lownes, 2013). These challenges make the "last-mile" of deliveries in urban areas one of the most expensive parts of the logistics chain. Courier companies are particularly concerned with the "last-mile" of their deliveries due to their emphasis on punctuality, their high volume of pick-ups and deliveries in the downtown core, and their time constrained supply chain.

One of the common distribution systems courier companies operate with is the hub-and-spoke system. The hub-and-spoke distribution system mandates that most, if not all, of the delivered items be handled by at least three locations between the origin and the destination; the first location is a terminal where picked up items are sorted and consolidated, the second location is a hub where further sorting and consolidation occurs, and the third location is a terminal where the items are deconsolidated before they are delivered to their destination (Fig. 1).

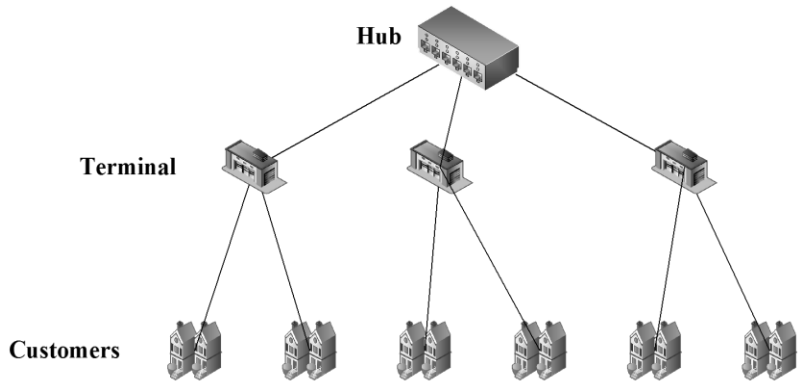
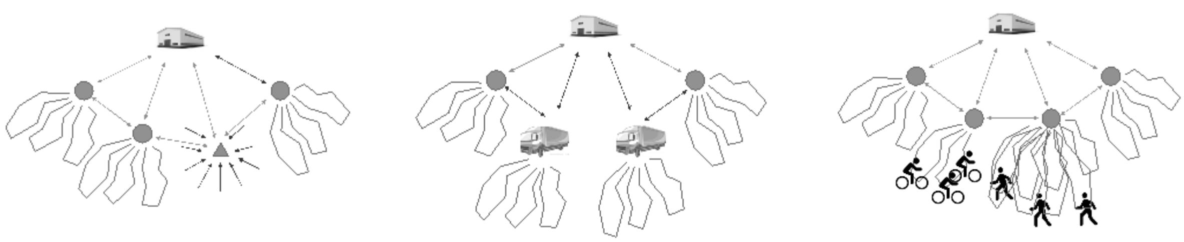


Figure 1: Hub-and-spoke

Opportunities exist to improve this distribution system. First, there is an opportunity to incorporate the use of pack stations, where customers have the choice to pick up packages from lockers rather than requiring delivery to the door. Second, mobile hubs, whereby full size trucks are used to deliver packages to a parking lot near the downtown area and transfer packages to smaller delivery vehicles, could be investigated. Lastly, it is possible to use active transportation delivery modes, such as cargo tricycles, for the "last-mile" component to improve the efficiency and reduce the impact of the distribution system. Stylized schematics of the three different operational scenarios are provided in Fig 2.



(a) Pack station (b) Mobile hubs (c) Active modes

Figure 2: Three operational scenarios

The objective of this project is to evaluate such alternative "city logistics" applications in downtown Toronto. The analysis is generalized to be applicable to the operations of any express courier companies serving metropolitan cities.

The report is organized as follows. Section 2 describes the scenario of using pack station, Section 3 describes the scenario of mobile hubs, and Section 4 describes the scenario of active transportation modes. Each section also presents the mathematical models used to evaluate each scenario. Conclusions and summaries are presented in the Section 5.

2. Pack Stations

When a pack station is installed, the customers within a certain radius of that station are able to self pick up their items. This reduces the tour length of the delivery vehicles as they can skip visiting customers that have agreed to pick up their items at the pack station. Fig. 3a presents a case without any pack-stations. In this scenario, a delivery truck traverses a line-haul travel distance of L before visiting all the customers located in the delivery zone. In Fig. 3b, however, the delivery truck makes the same line-haul travel, but it can skip the customers that are within a radius r of a given pack-station.

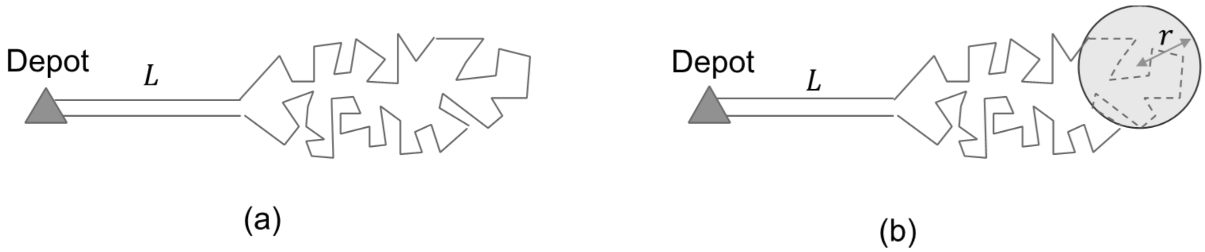


Figure 3: Truck tour with and without a pack station

Let A be the area of the entire delivery zone (without any pack-stations), let n be the number of pack-stations in the delivery zone which is a decision variable (to be found), let g be the amortized operating cost of a pack-station, and let D be the delivery density. The cost (travel time) of delivery in a region with n pack-stations is

$$T = 2L + ng + kA(1 - \frac{n\pi r^2}{A})\sqrt{D} \quad (1)$$

where the first term is the line-haul cost, the second term is the cost of operating n pack-stations, and the third term is the estimated cost of travel for making the deliveries where k is a constant parameter. We have assumed for simplicity that all customers within a radius r of a pack-station would self pick up their items. Here, we want to use Eq. (1) to find the optimal number of pack-stations n. Choosing a large n leads to a large cost ng for operating the pack-stations and choosing a small n does not exploit the benefit of installing a pack-station. Hence, there is an optimal value of n. We find the optimal n by taking the derivative of Eq. (1) as

$$\frac{dT}{dn} = g + k\pi r^2\sqrt{D} \quad (2)$$

which implies

$$\frac{dT}{dn} > 0 \; if \; g > k\pi r^2\sqrt{D} \quad (3a)$$
$$\frac{dT}{dn} < 0 \; if \; g < k\pi r^2\sqrt{D} \quad (3b)$$

This equation can be adapted into an algorithm for a case study for a company, if the delivery density, and the amortized cost of operating a pack stations are known. Eq. (3) indicates that it is ideal to build a pack station when the amortized cost g is smaller than the threshold $k\pi r^2\sqrt{D}$. This means that a pack-station is justified when

- The amortized cost of pack-station is low, and/or
- The delivery density within a radius r of a pack-station is large.

3. Mobile Hubs

Mobile hubs are beneficial in reducing the line-haul distance from the depot to the delivery zones. The conceptual framework of mobile hubs is illustrated in Fig. 4. In the absence of mobile hubs, Fig. 4a shows that all the vehicles have to leave the depot and head for their delivery zone. With mobile hubs, however,

Fig. 4b shows that several trailers leave the depot and head for large parking lots where packages are deconsolidated into pickup trucks. Graphically, the stem of each tree in Fig. 4b is the trailer path and the branches of each tree are the delivery truck line-haul paths.

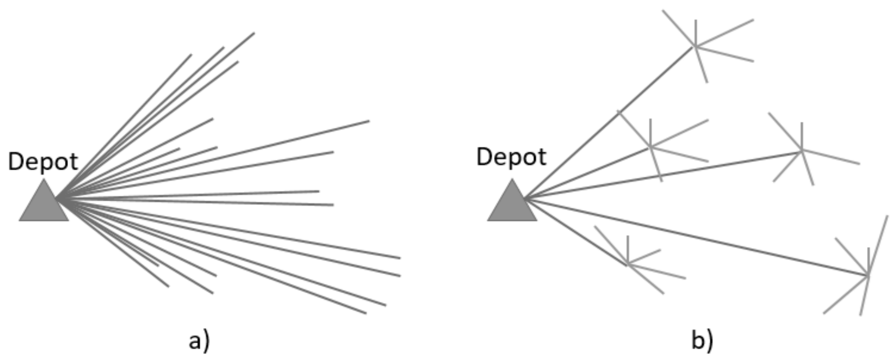
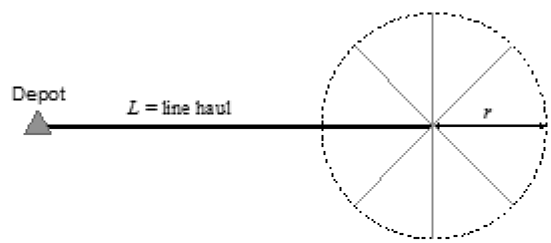
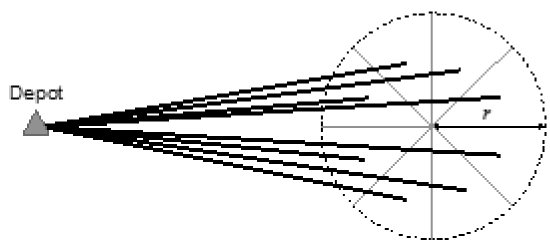


Figure 4: The conceptual framework of mobile hubs

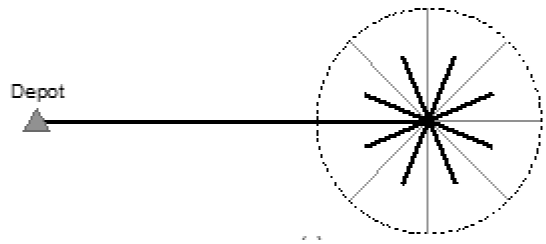
As proof of concept, we evaluate the benefits of implementing the mobile hub scenario in a stylized example presented in Fig. 5. The example includes a depot located L km away from the center of a delivery zone that is assumed to be circle with radius r as show in Fig. 5a. The delivery zone is divided into sectors that are each assigned to one vehicle. Fig. 5b illustrates the line-haul paths of trucks in the absence of mobile hubs. Fig. 5c, on the other hand, shows the mobile hub case where a trailer leaves the depot and heads for a parking lot located at centre of the circle. At the centre, packages are loaded onto pickup and delivery trucks and the trucks drive to serve their assigned sectors.



a) Line haul distance



b) Current operation



c) Mobile hub operation

Figure 5: Mobile hub scenario for a stylized example

The following notation in used in the stylized example.

L	line haul distance
r	service area radius
n	number of routes
c	unit travel cost ratio of trailers to trucks

Fig. 6 presents the cost of having and not having the mobile hub scenario at different ratios of L/r (ratio of the line haul distance to the radius of the service area). As illustrated, there are larger savings in the mobile hub scenario as the ratio L/r increases. This indicates that when the line-haul distance L is long, it is more beneficial to consolidate a number of pickup and delivery trucks into trailers.

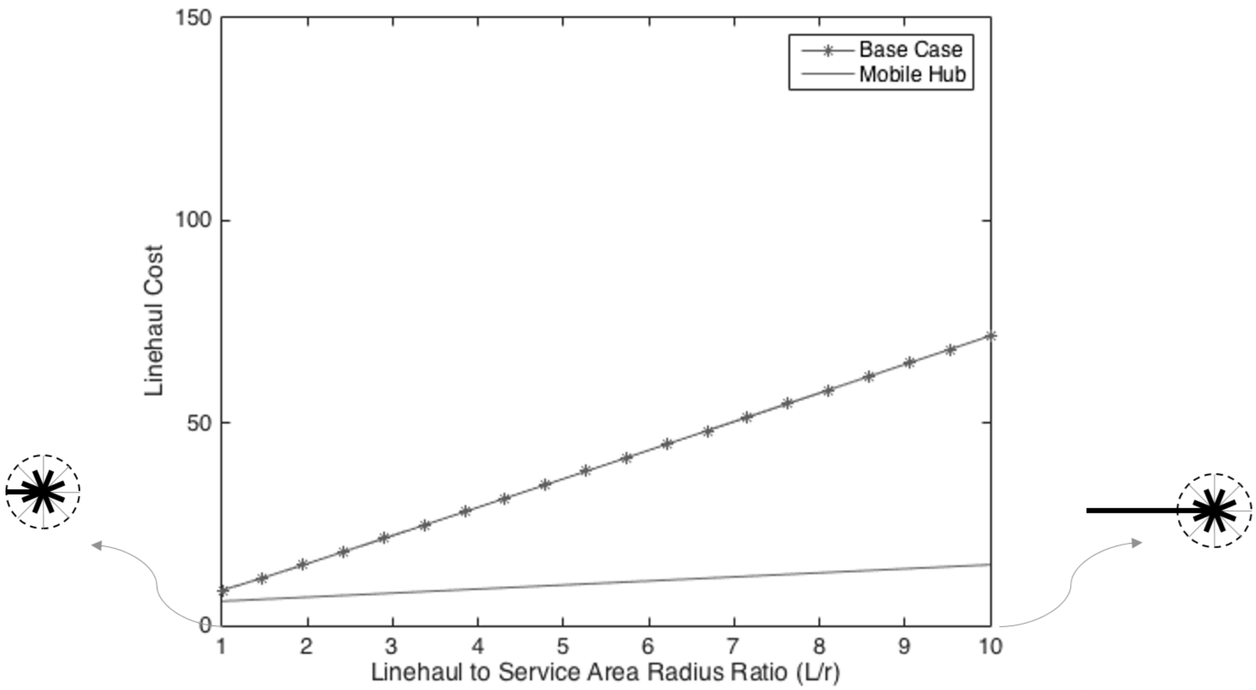


Figure 6: Total cost of mobile hub scenario at different ratios of L/r

In the following two figures (Fig. 7 & 8) the dotted line represents the base scenario and the flat line represents mobile hub scenario. The y-axis is the linehaul cost and the x-axis is the linehaul to service area radius ratio (L/r). Fig. 7 illustrates the cost as the number of delivery zones n increases. We show that mobile hubs are more beneficial at larger n because more pickup and delivery trucks bypass making the line-haul travel time. Fig. 8 illustrates the cost as the travel ratio c of trailers to trucks increase. We show that at large c, mobile hubs are beneficial only when the line-haul distance is larger than some threshold. Otherwise, when the line-haul distance is short, it is best not to use any mobile hubs.

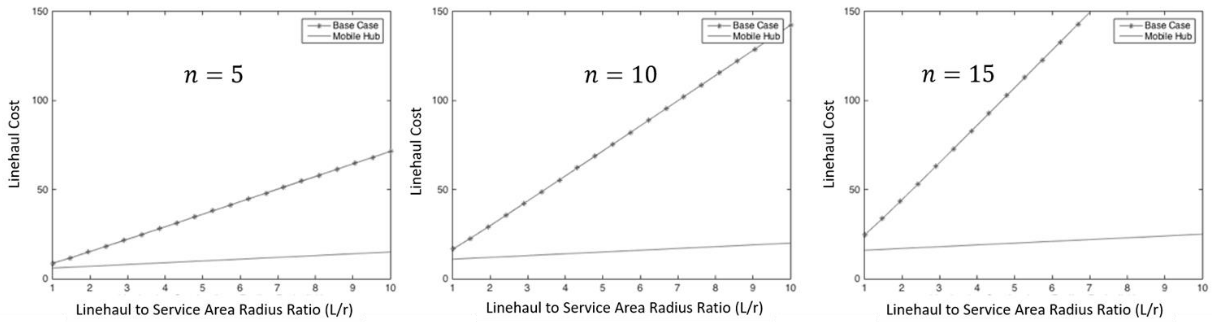


Figure 7: Total cost at different numbers of delivery zones

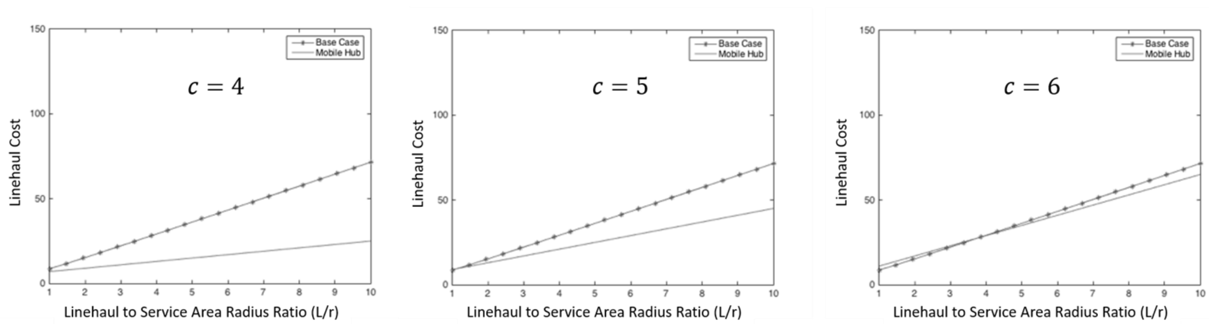


Figure 8: Total cost at different values of c (travel ratio of trailers to trucks per km)

4. Active Delivery Methods

The final city logistics solution is using active modes of transportation to deliver and pickup packages. Case studies of different active modes such as cargo bikes in London and New York have shown promising results. Irrespective of the specific mode used by the express courier company, the delivery operation will require a consolidation depot to support the staff and store the freight packages. In order to quantify the cost of shifting from a vehicle based operation to an active mode based operation, a simplified mathematical model was formulated.

$$C_{vehicle} = \underbrace{k_1 A\sqrt{D}}_{Vehicle\ Routing\ Cost} + \underbrace{DA\alpha}_{Stoppage\ (parking)\ Cost}$$

$$C_{active} = \underbrace{k_1(A - \pi r^2)\sqrt{D}}_{Vehicle\ Routing\ Cost} + \underbrace{D(A - \pi r^2)\alpha}_{Stoppage\ Cost} + \underbrace{k_2 \pi r^2 \sqrt{D}}_{Active\ Delivery\ Cost} - \underbrace{g}_{Amortized\ Facility\ Cost}$$

$$C_{active} < C_{vehicle}\ if\ k_2 < k_1 + \alpha\sqrt{D} - \frac{g}{\pi r^2 \sqrt{D}}$$

For a given potential depot location, if the density of the existing deliveries and pickups are known within a given radius, a quantitative analysis of the depot's feasibility can be performed using this model. The relationships between different amortized facility cost for a given operation radius and density is illustrated in Fig. 9.

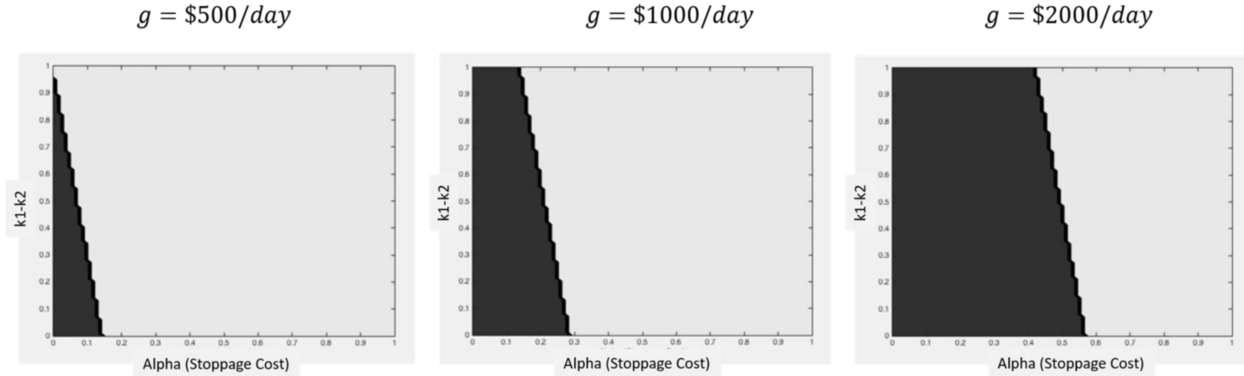


Figure 9: Quantitative analysis of the cost for a facility depot

The y-axis of the graph represents the averaged travel cost difference between vehicle and active mode, and the x-axis represents the stoppage costs. The values of both axes are normalized to 1. The figure shows that when the stoppage (parking) costs are high and the amortized facility costs are low, there is a higher incentive to build the facility depot. In addition, when the averaged travel cost difference is high, or in other words when the operation is high on the y-axis ($k1 - k2 \sim 1$), there is a greater incentive to build the facility depot. Concretely, it makes economic sense to open the new facility depot when the associated costs of the operation are in the light regions of the graph.

5. Conclusion

The report presents three different city logistics systems and defines each with mathematical models. The models of each system can be tailored to any express courier company with their specific requirements and show the economic trade-offs of adopting each system.

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[i] Type of Paper: Regular