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Moving towards “mobile warehouse”: Last-mile logistics during COVID-19 and beyond

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ABSTRACT

Supply chains in general and last-mile logistics in particular, have been disrupted due to COVID-19. Though several innovative last-mile logistics solutions have been proposed in the past, they possess certain limitations, especially during COVID-19 motivating the need for an alternative last-mile logistics solution. We present a review of literature related to last-mile logistics and supply chain disruptions to identify the limitations of existing last-mile delivery practices during COVID-19. Using a stylized analytical model, we then propose that “mobile warehouse” can be an effective solution to last-mile logistics issues faced during COVID-19 and beyond under certain conditions. A mobile warehouse is a truck dedicated to a particular geographical location and carries the inventory of various products based on the estimated demand requirements for these products in that geographical location. We provide the condition under which the B2C e-commerce providers find it profitable to adopt a truck as a mobile warehouse to sell high demand items quickly.

Introduction

Supply chains that play an essential role in the distribution of goods are prone to disruptions (Peck, 2005). In particular, supply chains focusing on product variety and outsourcing are more vulnerable to disruptions (Tang, 2006). Management of such supply chain risks is critical since it affects the operating performance (Hendricks and Singhal, 2003, 2005). Past studies have focused on managing and recovering supply chains from risks and disruptions (Lavastre et al., 2012; Chen et al., 2013; Ivanov et al., 2017). It is observed that supply chains recover the most when the supply chain members adopt a radical and expensive strategy (Chen et al., 2015). COVID-19 has affected the logistics and supply chains of various companies across the globe (Choi, 2020; Ivanov, 2020; Loske, 2020; Paul and Chowdhury, 2020b; Queiroz et al., 2020; Xu et al., 2020; Ishida, 2020). As a result, there have been disruptions on: (1) the supply side, (2) the demand side, and (3) the transportation and distribution of goods (Ivanov, 2020; Linton and Vakil, 2020; Paul and Chowdhury, 2020b). While the demand for sanitizers, food items and medicines has increased during COVID-19, the demand for garments and sports items has decreased (Paul and Chowdhury, 2020b). In fact, strategies have been proposed to improve the service level for high demand products like toilet paper during COVID-19 (Paul and Chowdhury, 2020a). It is well-known that transportation is an essential factor affecting supply chain resilience during an epidemic outbreak (Queiroz et al., 2020).

With respect to B2C e-commerce, there has been a significant increase in the total online sales during COVID-19 as consumers feel safe shopping from home; for example, the total online sales in the United States reached $73.2 billion in June year over year, up from $41.5 billion last year. This surge in e-commerce has resulted in increased pressure on last-mile logistics (Banker, 2020; Budd and Ison, 2020; Kim, 2020). In this context, we first review the last-mile logistics strategies adopted by the B2C e-commerce providers in the past (i.e., in the absence of COVID-19) and propose that “mobile warehouse” can be an effective solution to the last-mile logistics problems during COVID-19 using a stylized analytical model. In the past, various innovative solutions to solve the last-mile delivery problem of B2C e-commerce providers have been discussed, ranging from reception boxes to robots (Mangiaracina et al., 2019). In this context, we suggest that mobile warehouses can act as an effective last-mile delivery option, even post COVID-19.

Mobile warehouses, which are essentially dedicated trucks carrying various products near the consumer location, aid the B2C e-commerce providers in delivering the products to the consumers quickly and effectively. While the high real estate cost of maintaining warehouses near the consumer location is avoided for the B2C e-commerce

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provider, the consumer benefits by getting the product delivered to home quickly without having to travel to a particular outside location to obtain the product. Further, since the delivery time is expected to be short (usually in hours), consumers can conveniently collect the order on demand, and costs associated with the absence of consumers are avoided. In this paper, we present a framework on the logistics and distribution operations of a B2C e-commerce provider in the presence of a mobile warehouse. Using a stylized analytical model, we provide the condition under which the B2C e-commerce provider finds the mobile warehouse as a last-mile logistics option profitable. We also highlight the operational benefits of deploying this novel last-mile delivery option over alternative last-mile delivery options.

A review of the last-mile logistics strategies before COVID-19

Researchers in the past have looked at the design of distribution networks, which play an essential role in delivering products to the consumer (Mangiaracina et al., 2015; He, 2020). Last-mile represents the final leg of product distribution where the product is delivered to the end consumer and is considered the most crucial step in the distribution process (Lim et al., 2018; Mangiaracina et al., 2019; Perboli and Rosano, 2019). The traditional method of last-mile delivery involves using plenty of human operated delivery vehicles due to the ever-increasing dispersed demand, small order dimensions and delivery time expectations of the consumers; the result is that last-mile delivery is the most expensive part of the delivery process (Chou and Lu, 2009; Macioszek, 2017; Schwerdfeger and Boysen, 2020). To overcome this last-mile challenge, several innovative solutions have been analyzed by researchers (Mangiaracina et al., 2019).

Self-collection of the ordered items by consumers at pre-destined pick-up points within their vicinity has been in practice for some time (Wang et al., 2014). The ordered items can be self-picked by consumers from stationary or mobile locations (Weltevreden, 2008; Wang et al., 2018; Yuen et al., 2018). Parcel lockers are pick-up points located in public places where the consumer orders are stored in distinct lockers. The consumers can receive the ordered product after their identity is verified. Parcel lockers are of two types – stationary (Deutsch and Golany, 2018; Yuen et al., 2019) and mobile (Schwerdfeger and Boysen, 2020). While the consumers need to travel to a pick-up point in case of stationary parcel lockers, the ordered products are brought within walkable distance for the consumer to pick up in case of mobile parcel lockers. Mobile parcel lockers are flexible because the consumers don't need to pick up an order at a predestined location (for example, home and office); they can pick it up whenever the mobile parcel lockers are within walking range. Moreover, mobile parcel lockers also help e-commerce providers avoid high real estate costs associated with stationary parcel lockers (Joerss et al., 2016). Delivering to the trunk of the car by tracking the consumer's location is another last-mile delivery option (Reyes et al., 2017). Overall, self-collection reduces logistics costs associated with missed deliveries due to the consumer's absence at the delivery location and allows the consumer to pick up orders conveniently.

Another mode of delivery is via the reception box, which is kept in the consumer's home (for example, garage). Orders are delivered in this box. The advantage of this mode of delivery is that consumers are not required to stay at home when the order is delivered (Punakivi et al., 2001; McKinnon and Tallam, 2003; Wang et al., 2014).

Crowdsourcing the delivery of ordered products has marked a significant turnaround in last-mile logistics (Carbone et al., 2017; Akeb et al., 2018; Castillo et al., 2018; Seghezzi et al., 2020). Crowdsourcing logistics uses crowd workers to deliver the ordered item to the consumer as the cost of e-commerce providers themselves, providing last-mile delivery is exceptionally high (Wang et al., 2016). Usually, crowd workers are a group of local and non-professional drivers who are willing to temporarily work for delivery companies and provide their assets (for example, the vehicle) to perform the parcel delivery (Arslan et al., 2019). Crowdsourcing as a last-mile delivery concept is borrowed from sharing economy models like ride-hailing taxis (Uber and Lyft). Moving further, the notion of social commerce has been introduced wherein the e-commerce provider leverages on the friends and relatives of the consumer to deliver the ordered items (Devari et al., 2017). Through crowdsourced shared mobility, researchers are also looking at the coming together of ride-hailing services (for example, Uber and Lyft) and e-commerce (for example, Amazon). While crowdsourcing shared mobility is not as efficient as a traditional truck system when scaled up, it can reduce truck fleet size and provide other economic benefits (Qi et al., 2018).

Advanced technologies such as drones (Murray and Chu, 2015) and autonomous robots (Boysen et al., 2018) to execute last-mile delivery have also been explored in the literature. Drones or autonomous robots are launched to deliver the ordered items from the truck, which carries freight associated with a set of consumers.

Collaborative business models based on multimodal (De Sousa and Mendes-Moreira, 2015) and intermodal (Crainic et al., 2018) transportation modes have received significant attention in recent times. Specifically, business models have focused on integrated last-mile logistics solutions involving all stakeholders (Cagliano et al., 2015; De Marco et al., 2017; Brotcorne et al., 2019). Arriving at an appropriate traditional and low emission vehicle fleet mix has become essential to achieve cost-effective and environment-friendly last-mile logistics solutions (Cagliano et al., 2015; Brotcorne et al., 2019). Relying on the existing infrastructure in cities, last-mile delivery involving the usage of freight tricycles from urban micro-consolidation centers is another novel last-mile delivery solution (Conway et al., 2012).

While all these innovative modes of last-mile delivery are aimed at minimizing logistics costs and reducing delivery times, attaining both the objectives is found to be difficult in practice. It is particularly important to note that consumers expect the delivery times to be extremely low in practice; for example, while Amazon Prime members expect next day delivery for many products, Amazon Prime Now members expect grocery items to be delivered within two hours. The result is that Amazon relies on large regional distribution units and multiple small warehouses in urban areas for fast delivery. These small warehouses play a critical role as the consumer orders are sorted and loaded onto trucks to meet the delivery time expectations. Since delivery times decrease with increase in the number of large regional distribution units and small warehouses in urban areas, we can attain lower delivery times only at the expense of high rental costs for warehouses (Banker, 2020). We are interested in establishing a novel last-mile delivery solution that can deliver products quickly and safely at minimum logistics costs during COVID-19. Further, given that the different types of existing innovative last-mile logistics practices do not guarantee reduced delivery times at minimum logistics costs in general, understanding the sustainability of this novel last-mile delivery option in the long run in the absence of COVID-19 is essential. In this regard, we suggest that a mobile warehouse is an effective last-mile delivery solution during COVID-19 and beyond under certain conditions.

Is "mobile warehouse" a viable last-mile logistics option during COVID-19?

As discussed earlier, the arrival of COVID-19 has disrupted several supply chains across the globe. Therefore, innovative last-mile logistics strategies discussed in the literature have also become difficult to implement during COVID-19. Since people are psychologically worried about getting infected, especially when traveling outside (Choi, 2020; Hensher, 2020; Gkiotsalitis and Cats, 2020), last-mile delivery options such as self-collection via parcel lockers and crowd logistics are challenging to implement. Traditional delivery to consumers' homes is thus the norm in this scenario; in particular, reception boxes can be useful as the consumers do not come in contact with the delivery person when the order is fulfilled.

Crisis arising due to a pandemic such as COVID-19, can lead to innovation and change at different levels (Barragán-Quintero et al., 2020). Motivated by the need to identify an innovative last-mile delivery method that is cost-effective and meets consumers' delivery time requirements during COVID-19 and beyond, we come up with the idea of a "mobile warehouse". The mobile warehouse is inspired by the age-old vending cart (Lucan et al., 2013; Sharma, 2015), which are brought by vegetable and fruit sellers to different streets in a geographical location for sales. During COVID-19, we find evidence of even mobile music classes where classes are being organized in a moving vehicle near the participant's home (Choi, 2020).

It is well-known that warehouses form the backbone of product distribution in B2C e-commerce (Hu and Chang, 2010). We define the mobile warehouse as a warehouse (possibly a large truck) dedicated to a particular geographical location and carries the inventory of a variety of products based on the estimated demand requirements for these products in that geographical location. In particular, the mobile warehouse picks up inventory for the day from a traditional stationary warehouse located outside the city. The mobile warehouse then moves in the city throughout the day and enables delivering ordered items within an hour of the order being placed. Fig. 1 depicts the operations of a B2C e-commerce provider in the presence of a mobile warehouse. Once the consumer orders a product online, the mobile warehouse responds to the order quickly if it is available; otherwise, the mobile warehouse connects with neighboring mobile warehouses or the distribution unit to get the product and deliver it to the consumer. We suggest that the mobile warehouse can deliver the product to the consumer within a few hours, even if the product is not available at its location in the first place.

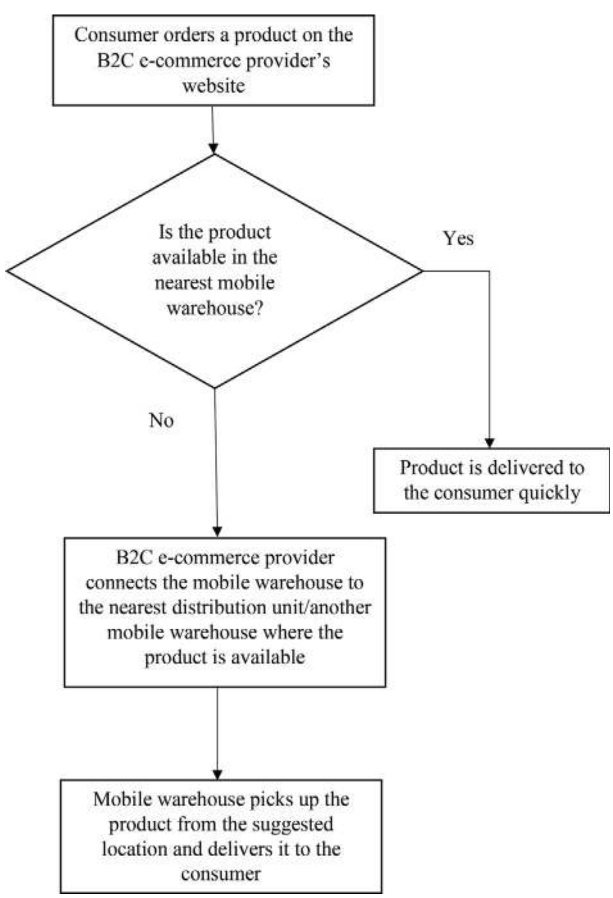

Fig. 1. B2C e-commerce provider's operations in the presence of a mobile warehouse.

We develop a stylized analytical model based on the framework of Choi (2020) to provide the condition under which the mobile warehouse is a feasible alternative to the existing last-mile logistics practices. We use the subscript e to denote the existing last-mile logistics practice and the subscript m to denote the proposed mobile warehouse. Let p_e be the delivery price, s_e be the service speed, h_e be the hygiene level and E be the fixed cost of operations in the existing last-mile logistics option. The consumer's valuation for the service is x and follows a density function $f(x)$. In line with the existing literature, we assume that the market is normalized to 1 and $f(x)$ follows uniform distribution between 0 and 1. The demand level of the B2C e-commerce provider using the existing last-mile logistics option is given by:

$$\int_{p_e-s_e-h_e}^{1} f(x)dx = 1 - p_e + s_e + h_e$$

The profit function in the existing last-mile logistics option is given by:

$$\pi_e = p_e(1 - p_e + s_e + h_e) - E$$

The consumer surplus in the existing last-mile logistics option is given by:

$$CS_e = \int_{p_e-s_e-h_e}^{1} (x - (p_e - s_e - h_e))f(x)dx = \frac{1}{2}(1 - p_e + s_e + h_e)^2$$

We find that the profit function is concave with respect to p_e since $\frac{d^2\pi_e}{dp_e^2} = -2 < 0$. We then find the optimal delivery price by equating $\frac{d\pi_e}{dp_e} = 0$ and solving for p_e.

$$p_e^* = \frac{1}{2}(1 + s_e + h_e)$$

Substituting p_e^* in π_e and CS_e, we then obtain:

$$\pi_e^* = \frac{1}{4}(1 + s_e + h_e)^2 - E$$

$$CS_e^* = \frac{1}{8}(1 + s_e + h_e)^2$$

Let p_m be the delivery price, s_m be the service speed, h_m be the hygiene level and M be the fixed cost of establishing the infrastructure in the mobile warehouse option. The demand level of the B2C e-commerce provider using the mobile warehouse is given by:

$$\int_{p_m-s_m-h_m}^{1} f(x)dx = 1 - p_m + s_m + h_m$$

The profit function in the mobile warehouse case is given by:

$$\pi_m = p_m(1 - p_m + s_m + h_m) - M$$

The consumer surplus in the mobile warehouse case is given by:

$$CS_m = \int_{p_m-s_m-h_m}^{1} (x - (p_m - s_m - h_m))f(x)dx = \frac{1}{2}(1 - p_m + s_m + h_m)^2$$

We find that the profit function is concave with respect to p_m since $\frac{d^2\pi_m}{dp_m^2} = -2 < 0$. We then find the optimal delivery price by equating $\frac{d\pi_m}{dp_m} = 0$ and solving for p_m.

Substituting p_m^* in π_m and CS_m, we then obtain:

$$\pi_m^* = \frac{1}{4}(1 + s_m + h_m)^2 - M$$

$$CS_m^* = \frac{1}{8}(1 + s_m + h_m)^2$$

We then provide the condition under which the B2C e-commerce provider benefits by investing in the infrastructure for a mobile warehouse. In Remark 1, we show that the B2C e-commerce provider finds it profitable to shift to the mobile warehouse as the last-mile logistics option if the fixed cost is less than a certain threshold.

Remark 1. The B2C e-commerce provider benefits by adopting the last-mile logistics option if $M < \frac{1}{4}(1 + s_m + h_m)^2 - \frac{1}{4}(1 + s_e + h_e)^2 + E$.

We observe that the consumer surplus is a function of the service speed and the hygiene level. Practically, it is apparent that the service speed using a mobile warehouse is greater than other existing last-mile delivery options since the primary objective of a mobile warehouse is to reduce delivery times. The products are also delivered to the consumers' homes directly in the mobile warehouse option, implying that the hygiene level using a mobile warehouse is at least as good as other last-mile delivery options. Overall, the consumer surplus with a mobile warehouse is greater than other alternatives. However, there is a fixed cost associated with establishing the mobile warehouse. Therefore, based on Remark 1, the B2C e-commerce provider finds the mobile warehouse option attractive if the fixed cost is below the given threshold.

The mobile warehouse offers several benefits to the consumers and the e-commerce provider during COVID-19. While orders are responded to quickly, it also does not require the consumer to travel to a pick-up point to get the product. Thus, it is safe for consumers. By storing a variety of products in a localized mobile warehouse to cater to the demand in that location, the immediate negative effect of disruptions at the upper echelon of the supply chain is also reduced. Before the effect of disruption at the upper echelon reaches the mobile warehouse, e-commerce provider can replenish the inventory by sourcing products from alternate providers. Also, high real estate costs associated with maintaining small warehouses in the locality are also avoided (Joerss et al., 2016; Banker, 2020).

Discussion – mobile warehouse beyond COVID-19

We argue that a mobile warehouse can be an effective last-mile logistics strategy, even post COVID-19. In general, a mobile warehouse is a truck that carries a variety of products depending on the estimated demand profile for different items in that particular geographical location. As mentioned earlier, products that are not available in the mobile warehouse can be replenished from the nearest distribution unit/mobile warehouse, which takes a slightly higher time. To overcome this challenge, we suggest that the e-commerce providers can focus on segmenting consumers based on their willingness to pay for quick delivery. Empirical studies have suggested that consumers who prefer free, next day delivery are willing to wait longer for the products to arrive under this delivery option (Rai et al., 2019). Thus, the e-commerce providers can leverage dynamic strategies and set appropriate delivery time expectations for the consumer (Asdemir et al., 2009). For example, there are Regular, Prime, and Prime Now consumers in Amazon who have different delivery time expectations (Banker, 2020). Accordingly, mobile warehouses can first stock items of consumers who expect quick delivery based on their demand for different items in the available space. The remaining space in the mobile warehouse can be allotted to high demand items of other consumers.

As the success of the mobile warehouse depends on the ability to fulfill orders based on inventory available in the truck, a strong analytics engine that can precisely predict the demand in a geographic location becomes necessary. Unlike mobile parcel lockers which receive the parcels from other delivery vehicles or distribution units based on consumer orders (Schwerdfeger and Boysen, 2020), mobile warehouses by themselves stock a variety of products based on the estimated demand profile in that area and respond to consumer orders in real time. Thus, accurate demand forecasting is critical for the success of mobile warehouses. Recently, Amazon patented a method referred to as anticipatory shipping which ships the items to a geographical location before an order is placed and completely specifies the delivery address for the order during transit (Spiegel et al., 2011; Kopalle, 2014). Mobile warehouses require such anticipatory shipping technologies for estimating the demand in a particular geographical location.

Mobile warehouses can be considered a mobile version of small warehouses used by Amazon in urban areas for quick delivery to Amazon Prime Now members within the two-hour window (Banker, 2020). However, an important distinction concerning delivery time window is that mobile warehouses can deliver all types of products even faster (possibly within an hour); it is pertinent to note that our focus is not necessarily restricted to grocery items and includes all types of products. Further, there is no cost associated with renting a warehouse as mobile warehouses can continue to move throughout the day or be parked in the distribution unit where they are replenished. This allows the e-commerce service providers to save on the high costs associated with operating small warehouses in urban areas.

Technological improvements can significantly improve the performance of logistics operations (Taniguchi et al., 2020). Similar to the expected transformation of mobile parcel lockers to autonomous mobile parcel lockers in the near future (Schwerdfeger and Boysen, 2020), autonomous versions of mobile warehouses without human drivers can be introduced. The application of advanced technologies to mobile warehouses can further aid the e-commerce providers in improving their last-mile logistics performance.

E-commerce consumers face the split delivery problem wherein multiple items in an order are delivered to them multiple times (Zhang et al., 2019). Mobile warehouses can help overcome this problem as they carry an inventory of items based on the estimated demand profile in that area. If there are multiple items in an order, mobile warehouses can cooperate with other mobile warehouses/distribution units to deliver ordered items quickly. While the absence of consumers during the delivery process results in significant logistics costs (Pan et al., 2017; Mangiaracina et al., 2019), quick delivery of products by mobile warehouses also ensures that these costs are avoided.

Implementing mobile warehouses for last-mile delivery comes with certain challenges. Firstly, accurate demand forecasting is essential since online consumers expect the ordered items quickly with an expected timeframe (Mangiaracina et al., 2019). Secondly, there is a need to focus on route and location optimization similar to mobile parcel lockers for efficient last-mile distribution (Schwerdfeger and Boysen, 2020). The dynamic route and parking location optimization of the mobile warehouse ensure that the truck stays closer to the potential consumers for quick delivery.

CRediT authorship contribution statement

S. Srivatsa Srinivas: Conceptualization, Methodology, Formal analysis, Writing - original draft, Visualization. **Rahul R. Marathe:** Conceptualization, Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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