Accessibility and Equity Analysis of Common Carrier Parcel Lockers at Transit Facilities in Portland, Oregon

Katherine Keeling  
*Portland State University*

Jaclyn S. Schaefer  
*Portland State University*, jsschae@pdx.edu

Miguel Figliozzi  
*Portland State University*, figliozzi@pdx.edu

Follow this and additional works at: [https://pdxscholar.library.pdx.edu/cengin_fac](https://pdxscholar.library.pdx.edu/cengin_fac)

Part of the Transportation Engineering Commons

Let us know how access to this document benefits you.

**Citation Details**
Keeling, Katherine; Schaefer, Jaclyn S.; and Figliozzi, Miguel, "Accessibility and Equity Analysis of Common Carrier Parcel Lockers at Transit Facilities in Portland, Oregon" (2020). *Civil and Environmental Engineering Faculty Publications and Presentations*. 574.  
[https://pdxscholar.library.pdx.edu/cengin_fac/574](https://pdxscholar.library.pdx.edu/cengin_fac/574)

This Pre-Print is brought to you for free and open access. It has been accepted for inclusion in Civil and Environmental Engineering Faculty Publications and Presentations by an authorized administrator of PDXScholar. Please contact us if we can make this document more accessible: pdxscholar@pdx.edu.
Accessibility and Equity Analysis of Common Carrier Parcel Lockers at Transit Facilities in Portland, Oregon

Katherine L. Keeling
Department of Civil and Environmental Engineering
Portland State University, Portland, Oregon, 97201
Email:kkeeling@pdx.edu

Jacelyn S. Schaefer
Department of Civil and Environmental Engineering
Portland State University, Portland, Oregon, 97201
Email:jsschae@pdx.edu

Miguel A. Figliozzi
Department of Civil and Environmental Engineering
Portland State University, Portland, Oregon, 97201
Email:figliozzi@pdx.edu

Word Count: 6939 words + 2 tables (250 words per table) = 7439 words

Manuscript Number: TRBAM-21-03977

Original Submission: 31 July 2020
Revision Submission: 29 November 2020

Paper accepted for presentation at the 2021 TRB Annual Meeting (January 2021, Washington DC) and potential publication in Transportation Research Record.
ABSTRACT
Transit goals have typically focused on commuter trips but facilitating urban last-mile freight logistics is a potential strategy to increase transit ridership and mitigate the demands of parcel distribution on the transportation network. Presently, most parcel lockers operate out of private businesses, but consumer surveys have found that transit users may be interested in locker facilities at transit connections. The implementation of an unmanned, secure, common carrier parcel locker system could have benefits for non-transit users as well. Consolidation of deliveries is expected to benefit courier companies by allowing operations at increasingly competitive rates, and retailers and consumers benefit from convenience and low shipping rates. This evaluation includes a case study of the light rail stations, transit centers, and transit malls in the greater Portland, OR area. The potential of hosting transit sites is reviewed based on ridership (the number of ons/offs at transit facilities), the number of residents in influence areas (whether transit users or not), and a framework for prioritizing locations based on best-practice equity metrics. Mode-specific accessibility of park-and-ride facilities outside the urban core, as well as the potential of consolidated distribution points in city resiliency plan are discussed.

Keywords: E-commerce, Parcel lockers, accessibility, equity, last mile, urban logistics, transit-oriented development
INTRODUCTION

E-commerce activity continues to grow worldwide, and business-to-consumer (B2C) sales in the US are predicted to reach over $500B by 2024, up from $365 billion in 2019 (1). Market competition pressures businesses to meet these growing volumes with increasingly short delivery lead times, low shipping costs, and high reliability. Operations have become streamlined in early supply chain phases, but the final segment of delivery—“the last mile”—is often the most expensive and least efficient segment (2,3). The operational costs of the last mile swell due to order fragmentation, which precludes economies of scale; many delivery tour stops deliver only one parcel per stop (4,5). Recent research examining the granular nuances of “the last 800 feet” finds it rife with distinct challenges to tour efficiency, such as locating parking and the operations performed outside the freight vehicle (6).

In commercial/mixed-use zones, rising volumes of B2C deliveries have exacerbated a shortage of loading zones; illegal parking has increased (7) as trucks and vans simply cannot find enough suitable places for unloading parcels (8). Freight trip generation at residential destinations is now on par with that of business destinations (9); however, residential areas are not designed for efficient parcel delivery. Neighborhoods may have insufficient road signage, and multi-unit complexes can be difficult to navigate (4). Moreover, where signed receipt of delivery is required, resident absence—coined the “not-at-home” problem—further multiplies last mile costs. Unfortunately, porch piracy has sustained consumer demand for signed parcel reception. If multiple delivery attempts fail to garner a signature, parcels are diverted to a retail center, post office, or freight locker for customer reception (4,10,11).

These challenges have driven innovative mitigation strategies, each of which have benefits and limitations. Porch piracy and the not-at-home problem can be alleviated by permanent reception boxes at homes or carrier- or retailer-owned secure delivery but these solutions fail to address the larger issue of fragmentation, and are not appropriate for all delivery destinations.

Fragmentation can be reduced by developing collection points, which reduce delivery vehicle dwell time, decrease first-delivery failures, prevent theft of parcels, and provide consumers with flexibility in electing a suitable retrieval time. Many collection points operate inside private businesses such as convenience or box stores, with staff available for customer service. This arrangement limits pick-up availability to the operating hours of the hosting business (5,12,13).

European parcel lockers date back to 2002, but US parcel lockers were not implemented until Amazon began offering Amazon Hub Locker service in 2011. Soon after, the United States Postal Service (USPS) launched a gopost® locker pilot in select cities, and UPS developed their Access Point Locker™ network. FedEx has a limited network of Ship&Get® lockers in Texas, but primarily promotes in-store shipping centers and on-street drop boxes. UPS and FedEx lockers only accept in-network parcels, so consumers must travel to multiple collection points when receiving from different carriers. USPS and Amazon lockers can receive and hold freight from UPS and FedEx, which offers some flexibility to their users.

The appeal of a common carrier parcel locker system is its extension of consolidation benefits to consumers; instead of multiple trips to courier-owned lockers, common carrier systems offer consumers a one-stop pickup location for packages from different couriers. This reduces the travel burden to consumers. Publicly accessible, unmanned parcel lockers are secured via electronic locks with variable codes to offer consumers the convenience of 24/7 access (4). Though USPS’s gopost and Amazon Hub Lockers will receive UPS- and FedEx-shipped parcels, a common carrier locker program ideally is independent from any singular courier in the highly competitive market of delivery logistics. The proprietary nature of logistics data and courier operations undermines the development of a common parcel locker systems, particularly in the US.

The development of a publicly accessible, self-serve, 24/7 parcel locker system can uncouple the operation of locker reception from the constraints of in-store retailers. During the Covid-19 pandemic, many businesses reduced their occupancy limits and/or hours of business, affecting the accessibility of parcel lockers hosted within. Self-service lockers are compatible with social distancing measures and an efficient, contactless method of delivery. Still there are other disasters—earthquakes, hurricanes, wildfires, landslides—than can preclude the normal operations of residential delivery; a system of freight
lockers could be incorporated into civic and state emergency response plans, as disasters often require the expeditious distribution of resources at consolidated points (14,15).

At the time of authorship, Covid-19 has altered many aspects of travel and day-to-day activities, including transit volume and e-commerce volume. At this point it is uncertain how transit ridership, the economy, and workplace will evolve. However, a transit-oriented locker system offers an additional layer of infrastructure, and can be developed within existing, underutilized assets. Evidence is growing that transit is highly utilized by essential workers and those who cannot work from home (16), justifying a prioritization of systems that serve such workers.

LITERATURE REVIEW

Last mile logistics are highly context specific as infrastructure, travel demand, and land use patterns vary greatly. Yet an overarching goal crosses borders: namely, finding the optimal balance between efficient logistic operations and the most competitive service to consumers. This review presents an international collection of research findings aimed at fully sustainable locker solutions: the potential environmental impacts, its economic viability, and its ability to serve people’s needs.

Environmental Externalities

One of the highest priorities of environmental stewardship is to reduce carbon emissions; transportation practitioners can most urgently reduce emissions by minimizing vehicle miles traveled (VMT). Researchers exploring VMT-reduction strategies have modeled the benefits of stricter limits on home-delivery attempts. Edwards et al. compared the carbon impacts of the three-attempt allowance for home delivery, to that of more limited delivery allowances (17). The baseline scenario assumed a tour of 120 home deliveries within 50 km (31 mi), and 100% success rate of first-attempt deliveries. Alternative scenarios included (i) three failed delivery attempts and a 15 km (9 mi) car trip by the consumer to a local depot for retrieval, and (ii) one failed delivery attempt, after which the parcel is taken to a collection point at a railway station and retrieved via a 3.2 km (2 mi) car trip by the consumer. Alternatives (i) and (ii) were applied to 10% and 50% of deliveries. The model predicted that alternative (ii) would only generate 26% of the emissions of alternative (i). The model’s alternatives assume that private vehicles are used for recovering failed deliveries, but the authors note that trips to collection points made via active travel and transit modes have the potential to further reduce emissions (18,19).

Giuffria et al. modeled direct delivery to parcel lockers, instead of any home delivery convention. In an urban context, direct locker delivery reduced carbon emissions by almost two-thirds (20). For suburban contexts, lockers have an even greater potential to reduce emissions, because residence-based delivery trips in low-density areas are very resource-intensive. So long as a suburban consumer’s locker-bound trip is either shorter than 6 kms (3.7 mi) or deviates from a regular driving trip less than that distance, their trip to a locker is expected to produce less emissions than conventional home delivery. In Belgium—where the collection point network is quite dense—consumer pick-up trips are easily completed as part of everyday errands, and trip-chaining has been demonstrated to produce less carbon emissions than home delivery, regardless of mode choice (19).

Logistics Efficiencies and Market Demand

The potential benefits of the aforementioned collection point/locker models were qualified based on the amount of driving a consumer incurred to in the pick-up process, but environmental impacts are also mitigated from the increased efficiency of freight tours. In general, consolidation and higher delivery density increases the efficiency of urban logistics (21). Delivery consolidation allows couriers to deliver more of their freight volume on shorter routes. Iwan et al. provides figures from the Polish courier InPost (5), contrasting typical courier operations of 60 parcel deliveries per 150 km (93 mi) tour, to the delivery of 600 parcels to parcel lockers in just 70 km (43 mi). In Belgium’s urban areas, conventional courier stops average a delivery of 1.2 parcels, but stops at parcel lockers average 25 parcel deliveries (19).

Though parcel locker service can reduce emissions and repeat-failed deliveries, most e-commerce consumers prefer home delivery. Belgian surveys find that 75% of respondents prefer home delivery (22)
and Chinese surveys find that only 22% of consumers prefer collection points and parcel lockers (23). Even in countries with established locker programs, actual usage rates of collection points or parcel lockers to range from about 10% to 20% (19, 24). Low adoption rates may be partly due to a lack of familiarity of parcel lockers as a delivery option (25), or because the option is not yet offered by many online stores (26). The initial audit of the USPS gopost pilot identified their foremost need of increasing locker utilization (27). Ultimately, Iwan et al. found the biggest barrier to adopting locker use is that consumers are required to make the final leg of the journey themselves (5).

Despite low adoption rates, consumer interest in parcel lockers or collection points may be growing. Consumers are highly motivated by free delivery options; 52% of US online shoppers would consider delivery alternatives if it meant avoiding delivery charges (28). Additionally, as consumers become more reliant on e-commerce for sensitive or costly goods, the value of secure delivery increases. In 2016, a US home security company commissioned a nationwide study by Research Now, which found that 45% of the 2,000 survey respondents have had a parcel stolen or known someone who has (10). These negative experiences may also increase interest in freight lockers.

Multimodal travelers may be distinctly amenable to locker use. Among light rail passengers who shop online, 14% of survey respondents claimed a parcel locker or collection point was one of their top preferred locations to pick up parcels, and 40% to 67% respondents stated a willingness to use a common carrier locker system at a light rail station (11). Similarly, nearly a quarter of survey respondents in Brussels prefer parcel pick-up at transit-oriented locations (25).

Among Polish consumers already using collection points, the majority (up to 79%) of users prefer lockers located close to home or to their employment (5, 26). Almost 15% of the users surveyed indicated they would use the parcel lockers more often if they were “better located”, particularly in proximity to public transport, shops, or supermarkets. New Zealand consumers echoed a desire for lockers at supermarkets, likely because they are a frequent destination, and amenable to trip-chaining (18).

**Locker Accessibility: Mode Choice and Convenience of Access**

Replacing automobile trips in favor of active travel (walking, biking, transit) increases the environmental benefits. Kedia et al. asked consumers about their willingness to use active transport modes to access collection points (18). Over half the respondents (54%) were willing to walk or cycle to the collection point. The mean maximum tolerable distances to walk and cycle were 1.7 km (1 mi) and 2.33 km (1.4 mi), respectively. Light rail riders surveyed by the University of Washington Urban Freight Lab gave a three to six block range as the most common answer to the question of how far they were willing to walk with a parcel (11). Researchers also noted that a relatively high proportion (24% to 42%) of riders said they were willing to walk seven or more blocks with a parcel. Survey results of parcel locker users in Brussels found that 12% to 15% of users accessed the parcel lockers via public transport, as many as one-third of users traveled on foot, and 18% to 23% of users traveled by bicycle (19). Moroz and Polkowski found that 44% of Polish millennials using parcel machines collect their parcels on foot (10).

Based on survey responses in the cited literature, the accessibility to a parcel locker is likely to influence the utilization of such a delivery service. For urban areas in the Eastern part of the Paris region, the population is, on average, only 1.6 km (1 mi) in Euclidean distance from the nearest pickup point. Additionally, half of the pickup points in this region are located within 300 m (less than 1,000 ft) of a commuter railway station (12). InPost prefers to locate their parcel lockers in areas of high population density, high traffic pedestrian areas, and near local commuting hubs (5). Lee et al. agrees that accessibility to the parcel lockers is an important factor to consider when selecting an optimal location (29). Placing them along the daily life path of consumers or near public transportation is believed to enhance their utilization. When discussing evaluation criteria for light rail-locker sites, residential density and walkability were paramount to the majority of the stakeholders involved in the project (11). High foot traffic also promotes an “eyes on the street” effect, giving pedestrians a greater perception of security (30). Perceived and actual security supports the use of lockers for receiving items of value, as opposed to
Keeling, Schaefer, & Figliozzi

a conventional front door drop-off. Additionally, since parcel lockers have not yet saturated the US market, high visibility may be advantageous to promote utilization of this delivery alternative.

Most of the research on transit-based locker systems focus on light rail stations as the facility of choice. In Portland, several transit centers also have substantial foot traffic, even if they do not include light rail access. The presence of park-and-rides at transit centers and rail stations is noted because most research on the customer experience assumes that the catchment area for transit riders is constrained by the distance they are willing to walk with a parcel, and do not consider the riders that access transit via car or bicycle. Previous research in Portland has already shown that package delivery can provide access to goods and services for many groups that are mobility impaired or face other accessibility barriers (31). Hence, this research presents an equity analysis, to demonstrate that the selection of locker sites can help a city reach its equity goals, particularly in light of racial and income disparities.

METHODOLOGY

This evaluation synthesizes Portland, Oregon’s transportation policy goals, transit data and demographic data from the 2018 American Community Survey 5-yr estimates (32). Transit facilities included in this analysis include light rail stations (MAX), transit centers (TCs), park-and-ride facilities (PaR), and the downtown transit mall.

Ridership Analysis

Based on the examples in the literature review, locker service adoption is related to high volumes of foot traffic. TriMet’s validated ons/offis data was used as a measure of expected foot traffic at transit stops. The data used was from the fall quarter of 2019 (33), before normal traffic patterns were altered by the Covid-19 pandemic. It is worth noting that at the time of authorship, the pandemic response is not yet resolved, and ridership patterns may not return to the same pre-pandemic pattern. Future review should evaluate this approach after transportation patterns have re-stabilized.

Estimating the foot traffic at transit centers, park-and-rides, and rail stations is relatively straightforward; the amount of boarding and alighting passengers (“ons/offis”) most directly reflects foot traffic. From stop-level data, bus/light rail stops occurring at the same transit facility are aggregated as to reflect the potential catchment of a locker site.

The transit mall differs from other transit facilities. It runs the length of two one-way streets, SW 5th and SW 6th avenues, through downtown Portland. Rail stations are located about a quarter mile apart, with multiple bus stops located between rail stops. Unlike the rest of the transit network, it is reasonable to bound catchment areas based on the qualitative aspects of the mall’s design and operational flow. To this end, catchment area bounds were formed by aggregating foot traffic at and between rail stops (Figure 1). This aggregation is different than typical association of same-route stops serving travel in opposite directions. The transit mall generally orients travel along the one-way streets with trip planning/navigation apps generally suggesting passengers to alight at the nearest stop upstream of their destination. In accordance with the findings in the literature review, it is assumed that transit users would be willing to walk up to 6 blocks to access a locker; Portland blocks are about 200 feet long.

Situating transit mall lockers between MAX stations is also amenable to courier needs. Staging will be easier when not at MAX stations, because the rail lines at MAX stations occupy the curbside lane at these stations. Bus stops between MAX stations have bays that can accommodate multiple 40-ft. buses. If an agreement was made such that locker-loading deliveries occur outside of peak transit service hours, freight vehicles could potentially use empty bus bays for speedy loading/unloading. For lockers located at bus stops between MAX stations, out-of-direction walking can be minimized if lockers are situated closer to the upstream MAX station. Figure 2 shows the layout of a bus station between rail stops on the transit mall. The bus bay is clearly visible, and the sightlines would allow multi-tasking transit riders to pick up their parcel while keeping an eye on the advancing buses and rail cars while retrieving their parcel. These stations already have trash cans, electrical wiring, and an established presence in the fabric of downtown.
Figure 1 Defining transit mall locker catchment areas

Figure 2 Mall qualities: Bus stop, bus bay, and sightlines of upstream light rail cars (Google Earth)
Locker Accessibility to Areas Surrounding Transit Facilities

Transit facilities are typically designed to be accessible 24-hours a day and to operate unmanned. These arrangements befit a common carrier locker program; unmanned lockers offer more flexibility in retrieval than lockers located inside private businesses with limited operating hours. Therefore a successful common carrier locker program may even attract customers who do not use transit facilities, especially those who work, commute, and run errands during non-traditional work hours, and live in suburban areas, where there tend to be fewer 24-hour or late night businesses. A special focus was placed on suburban park and ride (PaR) and transit center (TC) facilities, as studies discussed in the literature review found consolidated package options in the suburbs to have extra efficiency and environmental benefits.

TriMet has an extensive network of PaRs in the suburbs. To determine potential service populations for PaRs and TCs, a spatial analysis was performed to estimate the population within reach of a locker program based on mode choice. TriMet’s support of pedestrian- and bike-friendly development has been grounded in concerted efforts and reports such as 2011 Pedestrian Network Analysis Report (34), and the 2016 TriMet Bike Plan (35). All the TCs and TriMet-owned PaRs provide some form of bicycle parking accommodation, whether by covered racks, bike lockers, or a keycard secured bicycle storage facility.

For this spatial analysis, a half-mile walking distance was assumed as the threshold of a comfortable pedestrian trip to access transit facilities. This threshold is congruent with the default walk limits in the TriMet Trip Planner tool. For commutes chaining a bicycle trip to a transit trip, a 2005 survey found that Portland’s average bicycle trip to access light rail was 2.1 km (1.3 mi) long (36). Though the study’s sample size was small (n = 36), the trip lengths are based on actual commuter trips, and are similar to findings in other studies. This threshold is more conservative than the default bicycle limit in the TriMet Trip Planner tool, which is set at 3 miles. Lastly, a driving threshold was defined for users accessing PaR connections. A 2011 TriMet memo detailing the expected use as justification for new PaRs assumed a catchment area around PaRs based on a 10-minute drive. Since driving speeds vary greatly based on street type, an estimated average travel speed was based on the region’s average commute length of 7.1 miles, and taking 26 minutes (37). From these averages, a peak travel speed of 16.4 mph was derived. Thus, the catchment assumption of a 10-minute drive translates into a 2.73-mile range.

Though several studies use network distances through the ArcGIS Network Analyst Service Area problem solver (11,18,24). Euclidian distances were used for the purposes of this multimodal analysis. Correction factors were applied to these distances based on the mean circuitry of Portland’s driving and walking networks (38). Although cyclists can legally travel on any of the streets in Portland except the intracity freeways, Portland cyclists chose more comfortable routes averaging 0.24 miles longer than the shortest route possible (39). The Euclidian buffer for bicycle trips was adjusted for this average routing cost in addition to the network circuitry for the drivable/bikeable street network.

These buffer distances represent the areas of influence around TCs and PaRs. Demographic data was uniformly proportioned at the Zip Code Tabulation Area (ZCTA) level. Spatial analysis packages in R estimated the population with access to the transit facilities according to travel mode. Figure 1 and Figure 2 show maps of PaR and TC buffers by mode, respectively. For this review, only the PaRs owned by TriMet were considered; other lots are generously shared by local businesses and churches but are not reviewed for parcel locker suitability.

Finally, accessibility for delivery vehicles should also be considered. Presently, cargo bicycles operate in downtown Portland successfully and they can easily access the wide sidewalk areas (40) or gain other access that traditional freight trucks cannot. Cargo bicycles can contribute to important GHG reductions (41). In addition, small sidewalk autonomous delivery robots (42) could be utilized to increase the efficiency and resiliency of the locker system.
Figure 1 Service area and modal buffers around TriMet-owned park-and-ride (PaR) facilities (generated with MapView package in R)

Figure 2 Service area and modal buffers around transit center (TC) facilities (generated with MapView package in R)
RESULTS

TABLE 1 lists the top 20 transit facilities by ridership volumes, as ranked by total ons and offs in fall 2019. Figures about the connectedness of these locations and facility types are provided. Locations with four rail connections tended to have the highest ridership volumes. Lloyd Center MAX station is the only high-ranking transit facility that is neither a PaR or a TC. Lombard TC is the least connected location of the high-volume list, with only one rail connection and two bus route connections.

TABLE 1 Transit facilities with the 20 highest ridership volumes, fall 2019, weekday only

<table>
<thead>
<tr>
<th>Rank</th>
<th>Location</th>
<th>Connections</th>
<th>Facility type</th>
<th>PaR</th>
<th>Ons/off</th>
<th>Land Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pioneer Sq.—Madison on 6th</td>
<td>Rail 4 Bus 13 TC x Mall Stop</td>
<td>---</td>
<td>---</td>
<td>18,291</td>
<td>Downtown</td>
</tr>
<tr>
<td>2</td>
<td>Beaverton TC</td>
<td>Rail 3 Bus 11 TC x</td>
<td>---</td>
<td>---</td>
<td>18,253</td>
<td>Residential</td>
</tr>
<tr>
<td>3</td>
<td>Gateway/NE 99th</td>
<td>Rail 3 Bus 7 TC x</td>
<td>Mall 690 Stop 7:30a Stop</td>
<td>---</td>
<td>16,470</td>
<td>Residential</td>
</tr>
<tr>
<td>4</td>
<td>Pine—Pioneer Court on 6th</td>
<td>Rail 4 Bus 12 TC x</td>
<td>---</td>
<td>---</td>
<td>14,433</td>
<td>Downtown</td>
</tr>
<tr>
<td>5</td>
<td>Oak—Pioneer Place on 5th</td>
<td>Rail 4 Bus 17 TC x</td>
<td>---</td>
<td>---</td>
<td>14,378</td>
<td>Downtown</td>
</tr>
<tr>
<td>6</td>
<td>Rose Quarter</td>
<td>Rail 4 Bus 8 TC x</td>
<td>---</td>
<td>---</td>
<td>14,213</td>
<td>Arena</td>
</tr>
<tr>
<td>7</td>
<td>Pioneer Place—Jefferson on 5th</td>
<td>Rail 4 Bus 12 TC x</td>
<td>---</td>
<td>---</td>
<td>13,526</td>
<td>Downtown</td>
</tr>
<tr>
<td>8</td>
<td>Clackamas Town Center</td>
<td>Rail 1 Bus 12 TC x</td>
<td>Mall 750 Stop</td>
<td>---</td>
<td>9,937</td>
<td>Shopping</td>
</tr>
<tr>
<td>9</td>
<td>Madison—Montgomery on 6th</td>
<td>Rail 2 Bus 14 TC x</td>
<td>---</td>
<td>---</td>
<td>8,939</td>
<td>Downtown</td>
</tr>
<tr>
<td>10</td>
<td>City Hall—Mill on 5th</td>
<td>Rail 2 Bus 13 TC x</td>
<td>---</td>
<td>---</td>
<td>8,324</td>
<td>Downtown</td>
</tr>
<tr>
<td>11</td>
<td>Sunset TC</td>
<td>Rail 0 Bus 9 TC x</td>
<td>Mall 630 Stop 7:30a Stop</td>
<td>---</td>
<td>8,046</td>
<td>Residential</td>
</tr>
<tr>
<td>12</td>
<td>Mill—Jackson on 5th</td>
<td>Rail 2 Bus 12 TC x</td>
<td>---</td>
<td>---</td>
<td>7,972</td>
<td>University</td>
</tr>
<tr>
<td>13</td>
<td>Lloyd Center</td>
<td>Rail 3 Bus 2 TC x</td>
<td>---</td>
<td>---</td>
<td>7,903</td>
<td>Business</td>
</tr>
<tr>
<td>14</td>
<td>Davis—Pine on 6th</td>
<td>Rail 2 Bus 15 TC x</td>
<td>---</td>
<td>---</td>
<td>7,271</td>
<td>Downtown</td>
</tr>
<tr>
<td>15</td>
<td>Hollywood TC</td>
<td>Rail 3 Bus 4 TC x</td>
<td>---</td>
<td>---</td>
<td>6,536</td>
<td>Shop+Res.</td>
</tr>
<tr>
<td>16</td>
<td>Glisan—Couch on 5th</td>
<td>Rail 2 Bus 9 TC x</td>
<td>---</td>
<td>---</td>
<td>5,460</td>
<td>Downtown</td>
</tr>
<tr>
<td>17</td>
<td>Willow Creek</td>
<td>Rail 1 Bus 5 TC x</td>
<td>---</td>
<td>---</td>
<td>5,301</td>
<td>Downtown</td>
</tr>
<tr>
<td>18</td>
<td>Lombard TC</td>
<td>Rail 1 Bus 2 TC x</td>
<td>---</td>
<td>---</td>
<td>5,243</td>
<td>Residential</td>
</tr>
<tr>
<td>19</td>
<td>Couch—Oak on 5th</td>
<td>Rail 2 Bus 14 TC x</td>
<td>---</td>
<td>---</td>
<td>4,886</td>
<td>Downtown</td>
</tr>
<tr>
<td>20</td>
<td>Montgomery—College on 6th</td>
<td>Rail 2 Bus 12 TC x</td>
<td>---</td>
<td>---</td>
<td>4,406</td>
<td>University</td>
</tr>
</tbody>
</table>
Most of the high-ridership transit facilities are within the central city, including along the the transit mall, where PaR facilities are absent. However, the spatial analysis measured the total populations within convenient walking, biking, and driving distances. When ranked by population access, the top 15 locations are all located in the central city. But the next ten highest-reaching transit facilities all have a PaR amenity. Figure 4 displays these highly-accessible transit facilities outside the central city, with population reach shown by mode. Although these facilities are outside the central city where the population is less dense, a significant population would be able to reach a parcel at these locations with only a ten-minute drive. The walking reach is much less, but this suburban ring of potential locker sites can complement a centrally-located network of pedestrian-friendly locker sites downtown.

Furthermore, if suburban locker site locations are leveraged as part of a civic resiliency plan, the accessibility shown below further quantifies the civilian reach of a PaR as consolidated distribution centers. Locating distribution centers where there are lockers would streamline a civilian’s trip burden to retrieve privately-ordered parcels and publically distributed emergency supplies. Large parking lots in the Portland metro were utilized during the summer 2020 wildfires for distribution to wildfire evacuees as well as for drive-in Covid testing (43,44). However, for an emergency that damages the road network, such as an large earthquake, having more, smaller distribution centers within walking/cycling distance will be helpful.

![Figure 4 Reach by mode of park-and-ride facilities outside the central city](image)

**Equity Analysis**

Lastly, analyzing the socioeconomic makeup of the population and prioritizing equity goals is strongly promoted by the City of Portland and Portland Bureau of Transportation (PBOT). Household income levels and employment are not uniformly distributed across the city, so the selection of locker sites should consider how the services offered will benefit some groups more than others. PBOT has reviewed national best practices to present a simplified approach to calculating a race+income equity score, as these two factors include many intersectional determinants of opportunity (37). Race and income data are gathered for the contextual area of interest, and quintile breakpoints are established for assigning 1-5 scores for both race and income factors. The lowest possible equity score is 2, and the highest possible equity score is 10.

For this evaluation, the area of interest is all ZCTAs intersecting and included in the TriMet service boundary, and the previously established walking thresholds provide the basis for estimating the
demographic profile associated with transit facilities. Demographic data is provided by the ACS 2018 5-year estimates (32). To acknowledge the opportunity disadvantages for non-white racial groups, the percentage of white-only residents was used to figure the race subscore, with white-only prevalence being assigned a lower equity point value. Income levels were similarly weighted to assign lower subscores to higher median household incomes.

The transit facilities with the highest equity score should receive priority in locker site selection. See TABLE 2 for an abridged table of the equity analysis results.

**TABLE 2** Equity Evaluation for Residents Within a Half Mile Walk to Transit Facilities (abridged)

<table>
<thead>
<tr>
<th>Facility</th>
<th>% of white-only residents</th>
<th>% of median household income</th>
<th>Subscore, race</th>
<th>Subscore, income</th>
<th>PBOT equity matrix score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE Powell Blvd Park &amp; Ride</td>
<td>65%</td>
<td>69%</td>
<td>5</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>E 122nd/Menlo Park Park &amp; Ride</td>
<td>69%</td>
<td>67%</td>
<td>4</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Gateway/NE 99th Ave TC Park &amp; Ride</td>
<td>68%</td>
<td>74%</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Elmonica/SW 170th Ave Park &amp; Ride</td>
<td>67%</td>
<td>106%</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Hall/Nimbus Park &amp; Ride</td>
<td>83%</td>
<td>103%</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>SE Tacoma/Johnson Creek Park &amp; Ride</td>
<td>87%</td>
<td>95%</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Tigard TC Park &amp; Ride</td>
<td>85%</td>
<td>113%</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Barbur Blvd Park &amp; Ride</td>
<td>86%</td>
<td>139%</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Based on the data collected, a parcel locker system leveraging the transit mall’s ridership is strategic based on ridership volumes; it offers consolidated parcel collection points at the densest area of the city’s employment and transit networks. Not only does the transit mall define the nexus of transit use, but the mall’s well-designed pedestrian facilities may even attract non-transit riders; workers may elect to take a mid-shift short walk to send or pick up parcels at transit mall facilities. As mentioned in the methodology, the transit mall has environmental characteristics that are suitable for a locker site, such as the sightlines necessary for riders to remain watchful for their desired transit vehicle, and also a high amount of foot traffic to promote a sense of safety in numbers. Further research could model the ramifications of allowing freight vehicles to temporarily unload in bus bays; as assistive devices and automation in logistics handling increases, the dwell time of locker operations may become increasingly succinct.

Regarding GHG reductions, the literature review indicates that utilization of lockers generate GHG emissions reductions of up to two thirds. However, if packages are picked up as part of a transit trip there is potentially larger reduction in GHG emissions given the increased efficiency of delivery vehicles and the reduction in delivery vehicle-miles. When customers drive to the transit station to access a locker, other variables must be included in the analysis like type of vehicle driven. For example, the GHG reduction potential can still be significant if the user drives an electric car but less significant (or even negative) if a vehicle with below average fuel efficiency is utilized (45). The estimation of GHG reductions is beyond the scope of the paper and should be explored in future research endeavors.
Three-quarters of the high foot traffic locations are in the central city, and the street network in Portland is already a host of many different uses. Although Rose Quarter TC has high ridership and connectivity, the rail that dominates its landscape is inflexible, should a cargo vehicle happen on a conflict. Rose Quarter TC generally has good sightlines and often has transit security attendants. However, Rose Quarter TC has extreme variations in traffic activity—it is the arena home of the Portland Trailblazers and the city’s largest music venue. The reliability needed by couriers and the unpredictability of large crowds should be preemptively addressed. Again, cargo bicycles or sidewalk autonomous delivery vehicles or robots may be needed for their advantages in maneuverability.

Compared to the granular detail of establishing a locker system into the inner city’s maturing streets, the peripheral park-and-rides generally have more space (Figure 5). Ultimately, careful consideration should be given to the staging needs of the delivery driver. TriMet’s transit centers are designed for heavy vehicles (i.e. buses) so turning radii and sight lines would be conducive to commercial vehicles. However, careful design development is needed to orient the locker facility such that the number of bus/truck and truck/pedestrian/bicyclist conflicts is minimized. Lastly, further analysis can recommend a routing framework such that different courier companies have staggered appointments for loading lockers, hopefully in line with their freight products and not conflicting with peak ridership times. Transit hourly data shows that many stops experience their PM peaks of on's/offs as early as the 3-4pm hour, which presents challenges for afternoon delivery tours that want to avoid the PM rush.

Figure 5 Street view of the Clackamas TC covered parking facility (Google Earth)

It should be pointed out that although calculations were made for up to a half-mile walking distance, a more realistic approach would be to model the parcel locker usage as a function of distance, with the rate decreasing past a set distance band, e.g., a half of a mile. Future research could consider this approach once more insight into consumer travel pattern preferences is collected. Further application of network analysis could create more precise figures of accessibility. Similarly, detailed questions about behavior (e.g. choosing different pickup options) are outside the scope of this paper and better addressed by future studies that analyze tradeoffs utilizing revealed preference data or stated choice surveys.
Lastly, if a transit-based common courier locker pilot is successful for consumers and couriers, there is potential to establish them at any transit facility with suitable space and qualifying demand. A reasonable pilot will start with a smaller number of locations, so the role of the equity analysis is not to restrict lockers from prosperous areas, but to make sure that the incremental growth of a locker program includes the locations prioritized in the equity matrix. Like public transportation service overall, access to parcel locker amenities should be extended in an efficient and equitable manner.

**CONCLUSIONS**

The first key takeaway from this review is that parcel lockers have potential in different transportation facilities types, including transit malls, transit centers, rail stations, and park-and-rides. Secondly, transit practitioners should consider the socioeconomic ramifications of locker investments as part of overarching equity goals in addition to the typical focus on consumer attitudes and level of interest.

These two takeaways can prepare transit agencies to be proactive in developing public-private partnerships with interested couriers. Portland’s transit network has high ridership volumes and overall foot traffic along Portland’s transit mall. Other central locations such as the Rose Quarter TC demonstrate the relationship between a high number of rail lines and high ridership volumes, but they also carry constraints such as the spatial bounds of existing infrastructure.

In contrast, suburban park-and-rides generally have more space to install automated parcel locker facilities, but to compensate for lower transit foot traffic, the flexibility and security of 24-hour operations should be highlighted to attract consumers who do not otherwise utilize transit. Including suburban locations in a network-approach to parcel lockers can also add a layer of distribution infrastructure that makes the suburbs more resilient to emergencies. The Covid-19 pandemic is still highlighting the different impacts of disaster between low-density and high-density areas. The development of a locker program is amenable to incremental expansion that involves iterative review of the changes in consumer needs, travel pattern changes, and consumption.

Ultimately, these factors are congruent with the interest in transit-oriented development (TOD), which has typically centered on developing housing near transit facilities. A transit-oriented common carrier parcel locker system is a suitable complement to existing TOD plans, as it offers a relevant service and potentially a win-win-win solution: couriers can operate more efficiently, consumers can retrieve parcels securely and conveniently, and the environment can benefit from reduced congestion and air pollution from fewer courier and consumer miles traveled. Since locker adoption in the US is still in nascent phases, transportation practitioners can widen the evaluation of existing transit infrastructure to better negotiate public-private partnerships towards the sustainability goals of economic prosperity, environmental benefit, and equitable service to people.

**CONTRIBUTION OF AUTHORS**

The authors confirm contribution to the paper as follows: study conception and design: JS, MF; analysis and interpretation of results: KK, JS, MF; manuscript preparation: KK, JS, MF.

**ACKNOWLEDGEMENTS**

This research was funded by the Freight Mobility Research Institute (FMRI), a U.S. DOT University Transportation Center.
REFERENCES


19. Verlinde S, De Maere B, Rai B, Macharis C. What is the most environmentally sustainable solution: home deliveries or locker deliveries? International Conference on City Logistics; 2019 Jun 14; Dubrovnik.


