

Compact Logistics: Equitable Spatial Planning For Urban Freight

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Abstract

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Despite ample research related to the implications of e-commerce for last-mile logistics and environmental sustainability, there is limited research evaluating residential delivery using an equity lens. This dissertation investigates how e-commerce, logistics sprawl, and zoning policies shape racial disparities in urban residential delivery and how spatial planning can reconfigure these systems toward more equitable, compact logistics (CL).

Chapter 2 defines equity in freight, identifies freight’s “*distributive spheres*”—environment and health, accessibility, and labor—and illustrates how conflicts in one create injustices in another. *Chapter 3* maps e-commerce and logistics sprawl, identifying factors that influence the siting and expansion of last-mile delivery facilities. *Chapter 4* employs activity-based modeling and residential freight trip generation (RFTG) techniques and finds robust evidence of spatial racial disparities in 41 U.S. metropolitan statistical areas (MSAs): populations of color (POC) are exposed to roughly 35% more cargo van traffic than White populations on average, despite ordering less than half as many packages. *Chapter 5* extends this analysis by adding truck flows and external cost estimates. Using structural equation modeling (SEM), the analysis finds that racial disparities in externalities are partially attributable to a

spatial mismatch in delivery supply and demand and that long distances between them correlate to greater disparities. A one-mile reduction in mean last-mile delivery distance is indirectly associated with a 1.9% decrease in externality disparities. *Chapter 6* defines CL—operational and land use strategies seeking to match delivery supply and demand by densifying logistics networks in high-demand neighborhoods—and investigates 92 logistics-related zoning actions and their role as tools or barriers for equitably mitigating environmental impacts and enabling CL.

The dissertation concludes that spatial equity alone is insufficient without addressing deeper questions of social and economic justice. It proposes a research agenda for planners that follows the goods up (i.e., meet freight-burdened communities where they live, particularly near intensive warehousing), prioritizes local accessibility and community benefits, promotes a Just Transition, and partners with communities.

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Preface

Chapters in this dissertation are a synthesis of papers published in scientific journals, chapters in books, or are under review at the time of submission. Content in the dissertation is solely attributable to the author unless otherwise stated. Article co-authors have granted permission to the reproduction and reformatting of the papers. These include:

Chapter 2:

Fried, T., García, L., 2024. Planning for Equity and Justice in Freight, in: Tavassz, L., Browne, M., Piecyk, M. (Eds.), *Advances in Transport Planning and Practice*. Routledge, Oxford, UK.

Fried, T., Goodchild, A., Browne, M., Sanchez-Diaz, I., 2024. Seeking equity and justice in urban freight: where to look? *Transport Reviews* 44, 191–212.
<https://doi.org/10.1080/01441647.2023.2247165>

The author was responsible for the investigation and written production of the articles. García was responsible for *Figure 2.2*, and co-wrote a concluding subsection (*7.4 Partner with communities*) under the supervision of the author.

Chapter 3:

Fried, T., Verma, R., Goodchild, A., 2024. Ecommerce and environmental justice in metro Seattle. *Research in Transportation Economics* 103, 101382.
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Fried, T., Goodchild, A., 2023. E-commerce and logistics sprawl: A spatial exploration of last-mile logistics platforms. *Journal of Transport Geography* 112, 103692.
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Chapter 4:

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Chapter 5:

Manuscript is currently under review in the *Journal of Transportation Geography*.

Chapter 6:

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Chapter 1: Equity in Urban Freight, Where to Begin?

Cities depend on the reliable delivery of goods every day. Without deliveries, hospitals exhaust critical supplies in 24 hours and grocery stores run out of produce in three days (Fried et al., 2020). Since COVID-19 shutdowns, people get more goods delivered to their door than ever before (Beckers and Cant, 2024). But this trend is long-term. Global demand for goods is expected to double by 2050 (International Transport Forum, 2023), much of which is driven by urban growth: U.S. estimates suggest that 80% of freight volume starts or ends in one of the country's largest urban metros (Tomer and Kane, 2014).

Despite their necessity, urban freight systems impose substantial and uneven costs. Satellite-based estimates suggest low-income populations of color (POC) in major U.S. cities are exposed to 28% more diesel traffic-related Nitrogen Oxide (NO_x) emissions than high-income White populations (Demetillo et al., 2021). Despite a steady decrease in tailpipe emissions across cities, diesel exhaust from freight vehicles continues to harm respiratory and cardiovascular health. In Toronto, freight-related exhaust constitutes over half of all NO_x pollutants and equates to almost 10,000 years of life lost annually (Minet et al., 2020). Beyond air pollution, scholars measure racial disparities in freight-related road deaths (Yuan and Wang, 2021), exposure to hazardous material spills (Schweitzer, 2006), “bomb train” derailment risks (Schneller et al., 2022), and noise complaints (Yildirim and Arefi, 2021).

These disparities are not isolated in time. They are echoes of historically illiberal urban development practices that locked-in many of today's land use patterns. For instance, research partly connects “redlining,” a prominent example of racialized mortgage lending practices endemic throughout the early-to-mid 20th Century, to Black Americans' disproportionate exposure to air pollution today (Lane et al., 2022). In fact, despite major progress toward reducing aggregate transport pollution, racial disparities in exposure have remained largely unchanged for decades (Koolik et al., 2024).

But just as costs are unevenly distributed, so too are urban freight system benefits. Sanchez-Díaz et al. (2021) find in their analysis of Gothenburg, Sweden that populations who would benefit most from home-based medical delivery—namely, low-income and foreign-born seniors—are those with the lowest levels of access to these services. Analyses in Portland, Oregon find parcel lockers, an intervention intended to enhance delivery access and last-mile

efficiency, disproportionately benefit frequent online shoppers who are predominately high-income and White, rather than low-income and Hispanic populations who are most burdened by freight traffic (Figlioizzi and Unnikrishnan, 2021; Schaefer and Figlioizzi, 2021). These localized findings hint at broader patterns: high consumption rates among advantaged groups contribute to high costs borne by racially marginalized populations (Tessum et al., 2019).

The logistics sector may also be a driver of macro-economic development and job growth (Sheffi, 2012). In fact, municipalities and polluting industries frequently position jobs as a trade-off for community health impacts (Bullard, 2000). However, workers have increasingly questioned the quality of logistics work. Scholars observe how deregulation and cost-cutting trends in trucking, warehousing, and delivery destabilize labor in ways that reduce wages (Jaffee and Bensman, 2016; Viscelli, 2016), lower environmental compliance (Zabin and Appel, 2019), introduce safety risks (Vecchio et al., 2022), and disempower collective bargaining (Chua and Cox, 2023).

Should freight's disparate impacts surprise us? Few systems in the urban and market environment, including freight transport, are designed with fairness as the leading principle. Although racial and social biases persist in institutional structures (Banaji et al., 2021), inequities today often stem less from deliberate discrimination than from routine, technocratic planning processes (Pulido, 2017; Ranganathan, 2016; Sheller, 2018; Soja, 2010). In fact, mainstream urban freight literature—informed predominately by managerial and operations logics (Strale, 2019)—may frequently portray the movement of goods as an “apolitical science of circulation” (Chua et al., 2018). In doing so, research uncritically adopts a “utopian positivism” (to borrow from Lefebvre, 1996), which among other things, reduces freight distribution to optimizable routing problems, presumes efficiency gains are inherently sustainable (Lord et al., 2022), confines data-gathering and consensus-building to industry and state “decision-makers,” and treats cities not as places where people live but as nodes in global-regional trade networks and as bottlenecks to be overcome (Cowen, 2014; Hesse, 2020).

In fact, a significant portion of environmental justice (EJ) scholarship may neglect urban theories of place, power, and inequality (Banzhaf et al., 2019; Schweitzer and Stephenson, 2007). And when transport-related studies do conceptualize and operationalize equity, they often do so inconsistently (Bills and Walker, 2017; Karner et al., 2025a; Lewis et al., 2021). As a result, most

studies measure unequal distributions of transport burdens and/or benefits but rarely address deeper questions of *why* such inequalities are unjust in the first place.

1.1 Research Context and Objective

Despite the dismantling of environmental and anti-racist transport priorities at the U.S. national level (Karner et al., 2025), local and state agencies continue to advance equity goals. Recent adoption of Indirect Source Rules (ISR) and conditional use permitting (CUP) ordinances across jurisdictions in California, New York, New Jersey, and Illinois illustrate place-based attempts to mitigate the cumulative impacts of freight on marginalized communities.

The place-based nature of freight inequities are core to this dissertation's objectives. As alluded to above, fleet technologies and operational improvements can importantly mitigate freight's environmental impacts, but may be less effective in reducing racial inequity. Instead, disparities derive from the spatial configuration of freight supply generators (e.g., warehouses, intermodal yards, and ports, etc.), networks (e.g., highways), population proximity to these generators and networks, and a spatial mismatch between freight supply and demand. Freight literature commonly alludes to this spatial mismatch (albeit, indirectly) as "logistics sprawl," or the migration of distribution facilities away from urban market centers (Dablan and Browne, 2020). Logistics sprawl is a distinct expression of "urban sprawl," which research links to inequities in external costs, socio-economic disadvantage, and accessible opportunities (Wei and Ewing, 2018). This connection remains underexplored in urban freight research.

Simultaneously, an alternative vision of urban spatial planning for freight is gaining traction among researchers. "Proximity logistics" and "freight efficient land uses," for instance, offer frameworks for minimizing private and external costs by reducing spatial distances between freight supply and demand (Buldeo Rai, 2023; Buldeo Rai et al., 2022a; Holguín-Veras et al., 2021). Cases in Paris (France) and Rotterdam (The Netherlands) demonstrate how logistics facilities can integrate into neighborhoods, fulfill delivery needs of nearby businesses and residents, enable delivery by lower-impact vehicles, and host mixed-use opportunities such as restaurant suppliers and rooftop farms. Furthermore, this dissertation examines whether logistics sprawl—or its counterpoint, compact logistics (CL)—can help explain racially disparate externalities in urban residential deliveries. Specifically, this dissertation:

- Builds a normative and empirical framework for evaluating spatial equity in urban freight planning;
- Unpacks the relationship between logistics sprawl and spatial inequities in residential delivery; and
- Identifies how planners can enable more equitable CL.

1.2 Dissertation Structure

Mixed-methods are a cornerstone to this dissertation's research approach and structure. The dissertation follows an exploratory sequential design (Creswell and Clark, 2011), an inductive approach. I utilize systematic literature review (*Chapter 2*) and inferential spatial analysis (*Chapters 3*) to help develop and interpret a subsequent empirical analysis of e-commerce related spatio-racial disparities (*Chapter 4*), its linkage to logistics sprawl (*Chapter 5*), and local policies for enabling equitable and compact logistics (*Chapter 6*).

Chapter 2 defines freight equity and justice. It centers on the opening of an Amazon distribution center in Tijuana, Mexico to highlight urban freight's distributive, political, and multi-scalar conflicts. I conduct an extensive literature review to identify freight's *distributive spheres*—environment and health, accessibility, and labor—and illustrate how conflicts in one create injustices in another.

Chapter 3 maps the geographies of e-commerce and logistics sprawl. It identifies urban form factors that contribute to the siting (and sprawling) of last-mile facilities.

Chapter 4 presents a methodology for empirically evaluating spatial equity in residential delivery. The novel modeling approach draws on techniques from activity-based modeling, transport equity evaluation, and residential freight trip generation (RFTG). The analysis finds robust evidence for racial inequities in residential delivery in 41 U.S. metropolitan statistical areas (MSAs). By the most conservative measurement, POC are exposed to roughly 35% more cargo van traffic than White populations on average, despite ordering less than half as many packages.

Chapter 5 investigates this spatio-racial disparity further, supplementing the analysis with truck flow and external cost estimates. Using structural equation modeling, the analysis finds that external cost disparities are partially attributable to a spatial mismatch between delivery supply and demand and that smaller distances between them correlate to smaller disparities. The study

finds that a 1-mile reduction in mean last-mile delivery distance is associated with a 1.9% decrease in externality disparity. However, high racial segregation, supply chain spread, and social capital fully mediate this effect.

Chapter 6 investigates 92 U.S. zoning actions related to W&D, examining their role as tools—or barriers—for mitigating environmental impacts in communities historically burdened by freight traffic and enabling CL.

Importantly, however, this dissertation emphasizes the limits of focusing solely on spatial equity. In the conclusion, I offer a research agenda for more equitable and just spatial planning in urban freight. This agenda includes:

- Follow the goods up. Meet freight-burdened communities where they live, especially near intensive warehousing.
- Put local accessibility first. Ask how logistics can benefit local communities, beyond job creation.
- Promote a Just Transition. Center the concerns of logistics workers who seek safe, stable employment and a living wage.
- Partner with communities. Build and sustain relationships with community and worker groups at the earliest stages of major projects and until project completion, using shared metrics of success.

Chapter 2: When Amazon Comes to Tijuana

In September 2021, Amazon opened its eleventh distribution facility in Mexico: a 32,000 square meter, state-of-the-art fulfillment center in Tijuana. According to Amazon's Mexico division, the facility would expand access to same- and next-day home delivery in dozens of cities across northwestern Mexico. Mexico is one of Amazon's fastest growing markets. One survey finds almost one-in-five Mexican respondents do most, if not all, of their shopping online (Hiraoka and Campo, 2023).

When interviewed by journalists, residents living across the containment wall next to the recently opened facility claimed to have never heard of the company (Mendoza, 2021). Pictures shared by local photographers on social media are provocative (see *Fig 2.1*). The facility's neat, bone-white facade contrasts a smoggy sky and an assemblage of wooden shacks with tarp roofs. The neighborhood, La Nueva Esperanza ("The New Hope"), stretches in a thin, two-kilometer crescent between the Alamar Expressway and a recently constructed, 27-acre logistics park that hosts Amazon and a dozen other distribution and packaging centers. It may once have been the city's largest informal settlement and home to over 600 families (Zeta Editorial, 2018).

In response to the modest outcry, Amazon and the then-mayor of Tijuana released a statement reaffirming the company's commitment to local communities. The facility would provide 150 direct jobs with competitive salaries and benefits and support local charities. Donations include 1 million pesos (US\$ 59,000) and over 2,000 meal kits to food banks (Rivera, 2023). In 2022, a year after the facility opened, it was unclear how many La Nueva Esperanza residents worked there (Ayala and Ormerod, 2022). Those that did reported working as subcontractors receiving low pay and no benefits.

Yet Amazon is not the whole picture (see *Fig. 2.2*). Zooming out, the Tijuana logistical facility is just one of hundreds that huddle around both sides of the Otay Mesa land port of entry (LPOE) between the U.S. and Mexico. Otay Mesa opened in 1983 to redirect commercial vehicle traffic away from the terminally congested San Ysidro LPOE, the main border crossing between Tijuana and San Diego. Today, Otay Mesa is one of the busiest land border crossings in the world. The region's rapid industrial and logistical development, fueled by the maquiladora economy and a migrant workforce, has been the subject of a small number of environmental justice studies along the U.S.-Mexico borderlands (Grineski and Collins, 2017; Kopinak and

Barajas, 2002). Exposure to deadly black carbon, a component of particulate matter found in diesel exhaust, is over two-times higher for residents in Tijuana than across the border in San Diego (Shores et al., 2013). The magnitude of chronic exposure largely correlates with proximity to the congested border crossings (Quintana et al., 2014). Workers who walk across the border to access U.S. distribution centers are among the most vulnerable to pollution-related health risks.



Fig 2.1 Amazon fulfillment center near New Hope, Tijuana (Source: Omar Martinez @omartinezTJ, 2021)

The prevailing environmental strategy has sought to reduce congestion-related truck idling at the border. Ongoing projects include expanding road capacity, modernizing entry facilities, and the \$1.2 billion East Otay LPOE (Otay II) set to open in 2026. Mexico's General Consul in Southern California extols the project's economic and environmental benefits: "Mexico and the United States need Otay II... to first strengthen our binational trading capacity,

to reduce the emission of toxic gases and, finally, to reduce crossing waiting times” (Mendoza, 2023). Unmentioned in the project’s description and environmental impact statement is how expanded trade capacity could propel more commercial vehicle traffic and, eventually, more congestion and idling. Future freight traffic volumes will likely be substantial. One Latin American commercial analytic firm speculates that industrial real estate in Tijuana and Ciudad Juárez—across the Rio Grande from El Paso, Texas—will grow by 1.8 million square meters to meet forecasted demand in the U.S. near-shoring market (SiiLA, 2023). That is an area over 15-times the size of the new logistics park currently housing Amazon’s Tijuana fulfillment center.

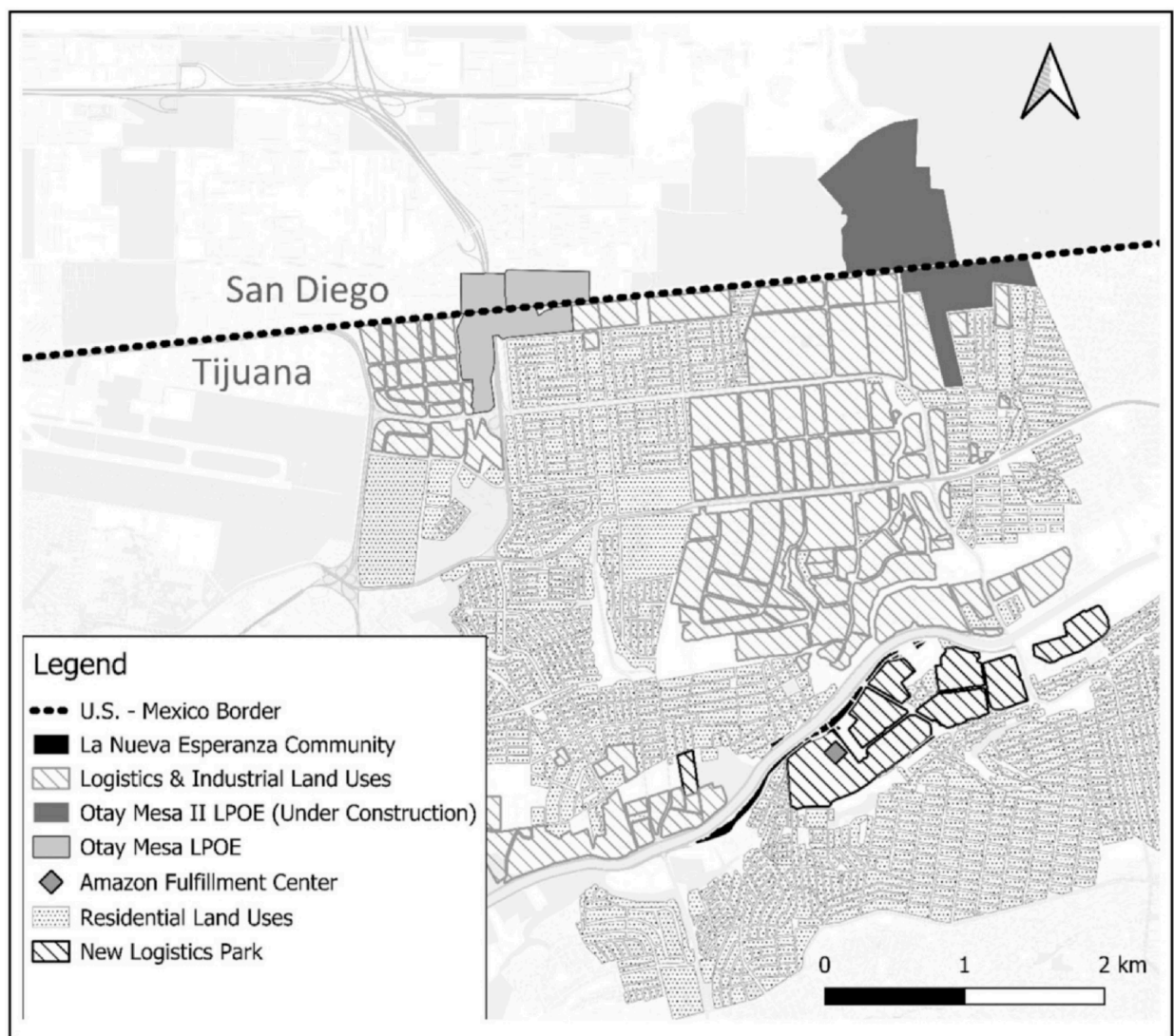


Fig. 2.2 Logistical development near Otay Mesa LPOE in Tijuana, Mexico (IMPLAN, 2014). Map by Lizandro Garcia. Data digitized from IMPLAN, 2014. Carta Urbana del Programa de

Desarrollo Urbano del Centro de Población de Tijuana 2010–2030.

<https://implan.tijuana.gob.mx/servicios/cartografia/carta-urbana-2010-2030.aspx> and Google Maps.

2.1 Introduction

I introduce the chapter with this case study to spotlight the layered conflicts of planning for equity in freight transport and land use systems. These conflicts encompass a:

- distributive conflict between freight’s social costs and benefits, and whether the benefits communities receive match the subsidy they give in their physical health,
- scalar conflict between globalized demands for trade and localized concerns about impacts, and
- political conflict between public planners, industry and real estate interests, and frontline communities.

La Nueva Esperanza is not an isolated case. Communities in the Red Hook neighborhood of New York City, in Joliet, Illinois, and in the Inland Empire of Southern California measure heightened traffic and air pollution near the swelling logistics parks in their own neighborhoods (Lisle et al., 2021; Torres and Victoria, 2021; Waddell et al., 2023). Residents that are closest to these facilities are disproportionately low-income, Black, Hispanic, and other people of color. The resulting disparity in traffic exposure often follows the spatial pattern of segregation created, in part, by the de facto and de jure planning processes that constructed highways and designated industrial zones, among other key logistical infrastructures, near Black and migrant communities throughout the early-to-mid 20th century.

Logistics companies that operate in these neighborhoods today may offer jobs to nearby residents. The promise of economic development can drive suburban municipalities to “fiscalize” commercial greenfield development through zoning revisions, infrastructure projects, and property tax abatements (Chapple, 2018). One U.S. data tracker suggests Amazon received roughly \$9.7 billion in disclosed public subsidies for their distribution centers and related infrastructure (Tarczynska, 2025). This estimate does not include subsidies given to their Whole Foods supermarkets, fashion and movie production studios.

But city planners and developers have long promoted investments in logistics as a “spatial fix” for a region’s deindustrializing economy and shifting demographics (De Lara, 2018;

Hesse, 2020). Economists debate whether these distribution centers deliver on the number of jobs promised (Jones and Zipperer, 2018; Pathania and Netessine, 2022). Meanwhile, communities have increasingly questioned the quality of proffered jobs. Wages remain well below the national average and court filings describe “inhumane” working conditions (Sainato, 2024). Growing frustrations among workers may have contributed to the transportation and warehousing sector seeing one of the largest upticks in union membership across public and private labor sectors in 2022 (Shierholz et al., 2023).

Meanwhile, the costs of logistics land uses on public health are uncertain. These “mega freight-generators” often do not require the environmental impact reporting, special use permitting, or pollution-scrubbing technologies that apply to more visibly noxious factories or power plants (Yuan, 2018). As Rubiano (2022) writes, contemporary distribution centers fall under a half-century old definition of a warehouse, and “building them triggers the same environmental requirements—none.” Here again we see these distributive, scalar, and political conflicts at play. This chapter investigates these conflicts while introducing planners to emerging equity issues within freight planning practice and research. Namely, it serves two purposes:

1. Summarize the state of contemporary research related to three “spheres” of freight-related equity: environmental disparities and public health, accessibility, and labor quality;
2. Argue that since the mobility of goods navigates through many distributive spheres, geographic scales, and terrains of political power, so too must freight planners.

Section 2.2 overviews the prevailing discussion surrounding transportation equity, which has generated novel discussion around transportation planners’ role in ensuring sufficient accessibility to opportunities. We explain how this framing, though useful in many respects, is incomplete when applied to freight planning. *Section 2.3* borrows the Walzerian definition of “distributive spheres” to explore how freight-related disparities in environmental stressors, accessibility, and labor ultimately converge to create injustices. *Section 2.4* applies this perspective to pressing freight issues that encompass equity in distribution, access, Just Transitions, and community engagement. In *Section 2.5*, we offer considerations for future planning.

2.2 Transportation Justice, what does it mean for freight?

Transportation equity, sometimes called Transportation Justice,¹ embraces the liberal tradition that emphasizes complex equality, sufficiency, and capability approaches (Bills and Walker, 2017; Luz and Portugal, 2022; Martens, 2016; Pereira et al., 2017; Vecchio and Martens, 2021). These researchers principally define transportation’s primary social good—accessibility to opportunities—and identify principles by which to fairly distribute it.

While this chapter will allude to some of these principles, I refrain from going into theoretical detail (for that, I recommend Lewis et al., 2021). For now, I define accessibility to opportunities as a capability, a proxy for the freedom of choosing and achieving a range of possible activities that facilitate a healthy and joyful life. This research area contains sizable debate on accessibility in relation to environmental impacts and trade-offs (Stokes and Seto, 2018; Vecchio and Martens, 2021; Willberg et al., 2024), paternalism, commons, and democratic governance (Karner et al., 2020; Nikolaeva et al., 2019; Vanoutrive and Cooper, 2019), quantitative best practices (Karner et al., 2024), as well as qualitative interpretations of accessibility among marginalized groups (Cooper and Vanoutrive, 2022; Vecchio, 2020).

Omitted from this rich debate, however, are considerations for freight (Fried et al., 2024a). The need to understand and evaluate equity in freight systems is increasingly salient for planners at multiple scales of governance (Browne, 2024). The European Union’s \$19.5 billion “Just Transition Fund” seeks to mitigate the socio-economic impact of a low- and zero-carbon energy transition, including in the freight sector. The U.S. Department of Transportation’s (USDOT, 2023) Guidance on State Freight Plans (2023) strongly encourages state DOTs to identify strategies that address equity concerns. A recent analysis of 31 statewide freight plans finds two-thirds of plans explicitly identify equity as an important objective (Barnes and Lindsey, 2023). However, only a small fraction of those analyze freight’s distributive impacts or engage directly with communities historically burdened by freight traffic.

Excluding communities from freight planning decisions may result from an uncritical view of logistics as an apolitical science of optimization and efficient flows (Chua et al., 2018). Yet logistics is political, affecting the lives and bodies of delivery drivers, truckers, warehouse pickers and packers, and dockworkers. Commercial vehicle tailpipes can pollute the air breathed

¹ Transportation Justice, outlined in the titular book by Martens (2016), draws on a school of political philosophy that treats equity, “distributive justice”, and “fairness” as mostly synonymous concepts. Whereas more critical social theorists distinguish equity from justice due to the latter’s emphasis on political procedure, recognition, reparations, accountability, restoration, truth and reconciliation, and “multi-scalarity,” i.e., justice unified across multiple geographic scales (Fraser, 2008; Sabbagh and Schmitt, 2016).

by sensitive populations, while pipelines and tire chemicals can toxify water stewarded by indigenous and rural communities. Logistics is a double-edged lifeline for people uprooted by economic or environmental crises (Sheller, 2018), and working-class residents who once called urban warehouse districts, now redeveloped, their home (Grodach, 2022). As such, it is difficult to isolate logistics from global supply chain power (Cowen, 2014), and disentangle it from the “matrix of domination” that intersects with class, gender, and racial experiences (Lindemann and Boyer, 2019). This web compels freight planners to examine the ways conventional practice and policies fail to respond to the diversity of cities, reflect hegemonic values and biases (Williams et al., 2023), and the economic objectives of Global North countries and firms (Stenmanns, 2019).

Therefore, it is not enough to ask “how do we fairly distribute freight’s costs and benefits?” We must also navigate the scalar and political conflicts that ultimately inform our freight decisions. The following section examines freight’s distributive spheres to illustrate how the movement of goods reflects and reproduces injustices across multiple scales and political arenas.

2.3 Freight’s Spheres of Justice

Accessibility has a distinct social meaning that begs policy interventions outside the market to ensure more equitable distributions (Martens, 2016). Within accessibility’s “distributive sphere” we might tolerate some inequality if it aligns with a moral logic, but raise boundaries to prevent or mitigate the domineering of other spheres, like wealth. I argue that freight does not belong to a separate distributive sphere. Though freight transport is similar to personal mobility in some respects (both are a form of derived demand), freight is an outcome of economic decisions made by a multitude of market agents across an often-global supply chain (Le Pira, 2024). As such, freight radiates outward from the market sphere and into many spheres of social life (see *Fig. 2.3*). Globalized market forces and political marginalization may conflict with distributive approaches to freight planning, which are often localized in geographic scale and stakeholder outreach.

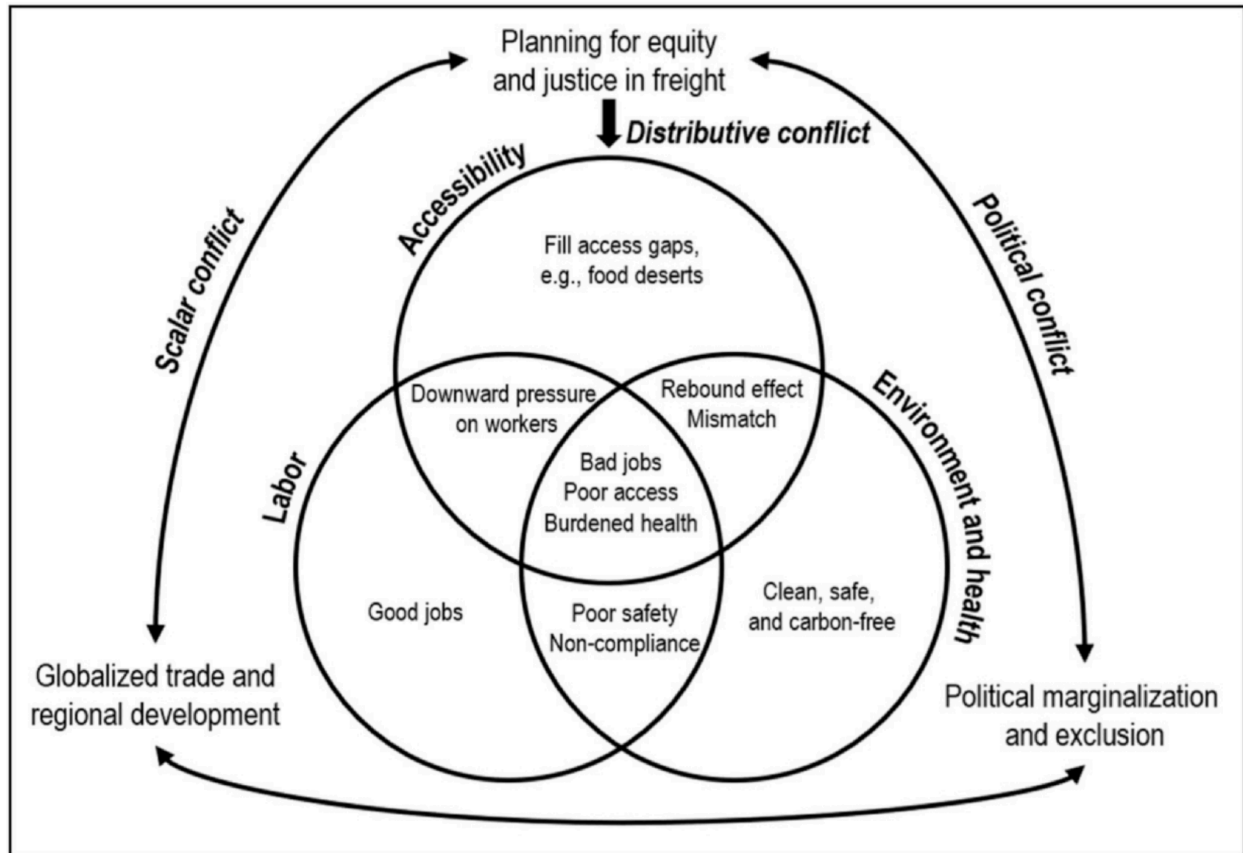


Fig. 2.3 Framework for freight planning conflicts and spheres of justice.

We explore freight’s intersections with accessibility and two other spheres of justice: a healthy environment and labor. The following section examines how these distributive spheres independently prescribe equity goals but overlap and conflict with each other to create injustices in freight. The articles of inclusion are based on the methodology conducted by Fried et al. (2024).

2.2.1 Environment and health

Freight vehicles represent a small fraction of the distance traveled on the road, less than 10% in most countries, but generate an outsized share of environmental costs. The largest body of freight-related equity work relates to disparities in chronic exposure to traffic-related air pollution—especially diesel exhaust-related particulate matter (DPM). In fact, DPM exposure is one of three transport-related U.S. Justice40 indicators that identify disadvantaged communities.

Despite falling tailpipe emissions across high-income countries, DPM from freight vehicles remains significantly linked to asthma onset and exacerbation, and respiratory- and circulatory-related mortality (Boogaard et al., 2022). Lathwal et al. (2022) find DPM exposure due to U.S. trucking constitutes nearly 40% of transport-related public health damages, which are disproportionately borne by Black and Hispanic populations.

The impact of chronic pollution exposure is complex and confounded by factors that include built environment, daily activity, meteorological conditions, medical susceptibility, and social vulnerability (Morello-Frosch et al., 2011). These factors have been observed, for instance, when analyzing the atmospheric dispersion of particles of day- and night-time freight traffic (Sathaye et al., 2009), port-based emission improvement programs across seasons (Lee et al., 2010), and workplace-versus-residential pollution exposure (De Souza et al., 2024). In fact, the last study finds that transportation and warehouse workers experience the highest exposure to PM_{2.5} across all workplace categories.

Direct observations of disparities in DPM exposure closely correlate to infrastructure proximity. In Toronto, Zalzal and Hatzopoulou (2022) find low-income immigrant families are disproportionately and increasingly exposed to heavy and light duty commercial vehicle NO_x emissions (a secondary source for PM_{2.5}), largely due to their proximity to major arterial roads. In U.S. neighborhoods adjacent to ports, cancer risks due to chronic air pollution exposure are over two times higher for low-income households and three times higher for Black populations (Rosenbaum et al., 2011). DeSouza et al. (2022) found similar health effects among disadvantaged communities living near warehouses. Brusselaers et al. (2023) estimate the health impacts of dynamic freight movement near schools and elderly care facilities in Brussels. They find these age-vulnerable populations share 60% of incurred health costs despite comprising only a quarter of the city's population. Fried et al. (2024b,c) estimate the distributional impacts of residential freight trip generation (RFTG) across demographics. They find that efficiency improvements in the “middle-mile” segment—i.e., freight activity near and between distribution centers—reduce more PM_{2.5} for low-income households and POC than those that improve the last-mile segment.

Commonly, policies promote vehicle and operational efficiency improvements to mitigate DPM exposure. However, the preeminence of proximity in determining exposure-related health costs suggest fleet-based environmental policies may do little to resolve disparities between

marginalized and non-marginalized groups. For instance, electrifying drayage trucks serving Southern California's San Pedro Bay Ports based on the Clean Air Action Plan's 2035 fleet electrification targets reduces the overall health effects of chronic air pollution exposure, but disadvantaged communities would still bear 68% of truck pollution-related mortality (Ramirez-Ibarra & Saphores, 2023). Meanwhile, Jaller et al. (2021) find in situ route efficiency improvements, such as off-peak delivery, does little to reduce exposure disparities. They recommend using geofences to route trucks around disadvantaged communities.

However, DPM exposure is only a portion of freight transport's cumulative health effects. Non-exhaust emissions (e.g., road silica, particles from tire and braking wear) already exceed exhaust emissions for many vehicle types (Harrison et al., 2021), which electrification may further exacerbate due to electric vehicles' higher gross weights (Liu et al., 2022).

Growing demand for goods also risks the safety of commercial drivers and road users, including pedestrians and bicyclists. Research in Minneapolis-St. Paul finds fatal collisions with urban freight vehicles disproportionately occur in low-income and majority POC neighborhoods (Yuan and Wang, 2021). These populations are also disproportionately exposed to freight-related noise and vibrations (Sahin et al., 2023). Hazardous material spills disproportionately affect Hispanic populations near trucking terminals in Southern California (Schweitzer, 2006). Petro-chemical pipeline leaks and risks of "bomb" train derailments can also violate the autonomy of tribal land and expose rural and indigenous communities to further environmental degradation (Schneller et al., 2022; Whyte, 2017).

Yet, transportation planners typically do not evaluate costs without margins. Instead, they weigh the negatives against positives. While costbenefit analyses have their own limitations (Van Wee and Roeser, 2013), identifying who wins is arguably as important as who loses (Levinson, 2002).

This begs the question: what are the social benefits of freight systems? One answer could be better accessibility to goods and economic opportunity.

2.2.1 Accessibility

Amazon leveraging its distribution network to deliver food to and for Tijuana food banks is not incidental. Technologists proclaim that the delivery service provided by companies like Amazon, DoorDash, and Instacart "kill food deserts" by rendering distance to grocery stores

irrelevant (Gilligan, 2022). While delivering groceries and meals to vulnerable populations is far from a new service, digital grocers present new economies of scale that weaken the constraints of mobility and time poverty often associated with food insecurity and unhealthy food choices (Dillahunty et al., 2019).²

In digitizing food accessibility, George and Tomer (2022) pinpoint several challenges. These include prohibitive delivery fees that go uncovered by food assistance programs, data privacy concerns, consolidation of smaller grocers (including those serving food deserts), poor rural coverage (Brandt et al., 2019; Newing et al., 2022; Trude et al., 2022), and the difficulty of navigating digital platforms for aging populations (Mishra et al., 2023; Rybaczewska and Sparks, 2022). In other words, population groups with the most to gain from home or near-home accessibility also face high barriers to adopting online delivery services. As such, contextual factors including socio-economic characteristics, social and medical vulnerability, delivery costs and speed, broadband access, mobility potential, and physical accessibility to delivery pick-up points at workplaces, transit stations, retail, community and senior centers, and parcel lockers are all relevant equity concerns for freight planners (Figliozi and Unnikrishnan, 2021; Geurden et al., 2022; Hood et al., 2020; Oliveira et al., 2020; Sanchez-Diaz et al., 2021; Schaefer and Figliozi, 2021; Sousa et al., 2023).

Nevertheless, researchers and planners present delivery services more as a cost-saving measure than a social benefit. Research most commonly treats delivering to food deserts as an optimizable vehicle routing problem (e.g., Choi et al., 2021; Haider et al., 2022). Meanwhile, researchers suggest crowdshipping platforms and automated vehicle technology will widen service access by driving down last-mile delivery costs (Buldeo Rai et al., 2017; Garus et al., 2022; Mishra et al., 2023).

However, framing food accessibility as an issue of goods distribution presents pitfalls. Food insecurity and nutritional inequality are as much a product of economic inequality as they are inaccessibility. Allcott et al. (2018) find that providing healthy foods to low-income households at the same prices available to high-income households only reduced nutritional inequality by nine percent. While public food assistance has become widely redeemable on major online grocery channels in the U.S. (George and Tomer, 2022), it is unclear how companies will use supply-side reductions in transport costs to defray delivery fees on the

² In the U.S., Meals on Wheels and other community non-profits have been successfully delivering food to home-bound populations since the 1950s (Gottlieb et al., 1996).

consumer side. Unless, of course, these fees are waived or publicly subsidized too. Increased home-based accessibility also has mixed environmental impacts.

These impacts hinge on how delivery providers and consumers consolidate orders, how distribution centers geographically organize in cities, and whether consumers are replacing a shopping trip they would otherwise be making in their car (Buldeo Rai et al., 2024; Jaller and Pahwa, 2020; Wygonik and Goodchild, 2018). Additionally, improving efficient access to goods can create a rebound effect that increases consumption and introduces environmentally unsustainable consumer practices (Lord et al., 2023).

A good example is returns. If the consumer dislikes the product, it gets damaged by handlers, or they “bracket” the product by purchasing multiple sizes and colors of the same item, they can re-order or send it back—often for free. According to one marketing firm, consumers return 30% of items purchased online, compared to just 9% of items purchased in-store (Saleh, 2016). So begins the long process of “reverse” or “return” logistics, which ends with many e-retailers simply throwing away the items due to the high costs and complexities of transporting, processing, and reselling them.

Many solutions that aim to improve last-mile delivery efficiency are also not benefiting marginalized communities. Schaefer and Figliozzi (2021) find low parcel locker accessibility for low-education, Hispanic population clusters in Portland, Oregon. These populations are also disproportionately exposed to DPM. Data provided by the U.S. Council on Environmental Quality (2024) suggests low-income Census tracts with DPM exposure at the 90th percentile, which fits the federal definition of a Justice40 community, have almost twice the share of Hispanic residents as non-Justice40 tracts in Portland. It is unclear how much DPM in these neighborhoods stem from home delivery traffic.

Nonetheless, the example reveals a mismatch between populations benefitted by access and efficiency improvements to freight systems and those who bear the system’s highest costs. Finally, boosters of last-mile innovation frequently overlook labor considerations. Cost-cutting technological trends in the trucking, warehousing, and gig delivery sector digitally Taylorize worker management (Altenried, 2019) and outsource labor in ways that can reduce wages, lower environmental compliance, introduce safety risks, and create barriers for collective bargaining. The following section examines why environmental, accessibility, and labor spheres cross boundaries for freight.

2.2.3 Labor

At the time of this chapter's writing, the transportation sector directly employs roughly 6.5 million people in the U.S. (U.S. BLS, 2024).³ The highest share of these workers find themselves in the logistics subsector, either in a warehouse or behind the wheel of a commercial vehicle. Although the precarity of gig delivery work has seen considerable attention as of late, trucking and warehousing are perhaps the most illustrative example of how today's markets influence labor conditions.

2.2.3.1 Trucking

The largest trade union in the trucking sector, the International Brotherhood of Teamsters, emerged as one of the most effective and highest membered trade unions in U.S. history throughout the 1950s and 1960s. Teamsters and regulators negotiated wage contracts with carriers, fixed freight rates, and implemented stringent conditions for new carriers entering the market. On the eve of the sector's deregulation in 1979, truckers earned 50% higher wages than educationally comparable jobs, such as manufacturing work (Viscelli, 2016, p. 16). Trucking became synonymous with upward social mobility and blue collar autonomy, with romanticized portrayals of the "outlaw trucker" becoming a cultural zeitgeist in county music and cinema (Balay, 2018).

Mounting pressure from both conservative and liberal political camps prompted a wave of deregulation in the trucking and rail sector throughout the 1980s. Some researchers see this as a natural consequence of the "logistics revolution," or the emergence of a whole systems approach to logistics management that enabled lean and offshore production, globalized supply chains, and cheaper consumer goods (Bonacich, 2008; De Lara, 2018). Lower barriers to market entrance spawned hyper-competition among small carriers to lower rates, placing downward pressure on drivers and creating an oversupply of trucking capacity. Less productive rail lines and trucking terminals were consolidated, causing small producers and shippers to increase their own trucking capacity or hire carriers that hauled goods over longer-distances (Fried et al., 2018).

³ The North American Industry Classification System (NAICS) defines the transportation and warehousing sector (NAICS 48 and 49) as a broad industry category that includes logistics workers, taxi drivers, flight attendants, related clerks and middle management, etc. It does not include temporary staff.

Carriers who brokered hauls at cheaper rates outcompeted union shops. In 1980, 57% of all truckers belonged to a union (Viscelli, 2016). By 2019, that number was around 18% (Burks and Monaco, 2019). Freight rates and consumer prices dropped, paving the way to just-in-time supply chain practices, hub-and-spoke integration (Hesse and Rodrigue, 2004), and the eventual Walmart-then-Amazon effect (Chua and Cox, 2023; Fried and Goodchild, 2023). Ultimately, driver compensation deteriorated. In 2021, the average pay for a truck driver was \$57,268 for men and \$44,607 for women, compared to roughly \$130,000 in 1980 (Jaillet, 2016, adjusted for 2021 inflation) (see Table 1). Back then, truckers earned over three-times the national average wage; today, men and women in the field earn 6% and 36% less than the average wage, respectively. The gender pay gap in trucking, 78 cents for every dollar, is wider than the national pay gap, 82 cents (Aragão, 2023).

But wages do not tell the full story. Hyper-competition and razor thin profit margins places carriers—often small businesses—in a position where they struggle to cut costs. One method is by hiring drivers as contractors, or “independent owner-operators,” rather than direct employees. Doing so allows carriers to transfer up to 30% of payroll and operating expenditures onto new drivers (NLEP, 2020). Unlike direct-hire drivers, independent owner-operators may pay for their own driver training, health and vehicle insurance, fuel, vehicle maintenance and repair, and go unpaid for down-time during deadheading (empty loads), loading/unloading at the depot, and while the vehicle is under repair. Carriers pay many independent owner-operators by the mile, while labor regulations exempt contractors from the regulated salary requirements that apply to other commercial sectors, such as minimum wage and overtime. Tax filing data from California suggests over one-in-five transportation workers are contractors, the highest share across any industry sector (Bernhardt et al., 2022).

However, contracting varies by the freight segment. Short-haul port truckers, or drayage drivers, disproportionately classify as contractors. One survey of 2183 drivers at seven U.S. ports found 82% of drayage drivers worked as contractors (Smith et al., 2010). Many are migrant workers. Among the most exploitative contracts are vehicle lease-to-purchasing agreements, which financially bind workers to the leasing firm and can result in subminimum wages after deducting payments and operational expenses (Jaffee and Bensman, 2016; Smith et al., 2010). Drayage drivers have reported falling into tens of thousands of dollars of debt to employers (Murphy, 2017). Others break federal safety laws that limit driving hours to complete hauls.

	Warehousing & storage		Trucking	
	Avg. wage	Emp. share	Avg. wage	Emp. share
Men	\$40,051*	66%	\$57,268*	87%
White	\$44,635	34.4%	\$59,799	57.5%
Black	\$33,663	14.9%	\$51,496	15.2%
Other POC	\$34,085	16.7%	\$51,027	14.3%
Women	\$30,848*	34%	\$44,607*	13%
White	\$33,721	16.3%	\$46,099	10.0%
Black	\$28,173	7.8%	\$41,184	1.4%
Other POC	\$31,441	9.9%	\$42,942	1.6%

Table 1: Average wage and employment share of warehouse and trucking sector workers, by gender and race (Source: U.S. Bureau of Labor Statistics, 2021)

Hour of service (HOS) regulations intend to reduce driver fatigue and improve road safety by capping the time drivers spend “over the road.” However, HOS regulations do not address the underlying economic conditions that compel drivers to overwork and endanger themselves and other road users (Soliani et al., 2024). Despite these measures, trucking-related fatalities per mile have increased by 22% in the past decade (NSC, 2021). Scott et al. (2019) attribute the rise to digital enforcement of HOS across smaller carriers, which may have the effect of encouraging truckers to speed and drive more dangerously to maximize payable miles. Researchers have also observed how performance-based pay for warehouse workers can lead to workplace injuries due to over-exertion (Delp et al., 2021).

2.2.3.2 Warehousing

In fact, the sector’s labor inequities do not start and end on the road. The freight sector’s drive toward low-cost, high-velocity follows conveyor belts and forklifts in mega-distribution centers and cross-docks that radiate along highway corridors in major metropolitan areas (Deblanc, 2024). Warehousing jobs grew exponentially in these suburban regions. Between 2008 and 2023 employment in the sector nearly tripled (see Fig. 2.3). The US BLS (2024) projects that

stockers and order fillers in warehouses will be the second-fastest growing occupation for workers without college degrees over the next decade, behind home and personal care assistants.

Warehouse workers do not share truckers' union history, their political and cultural visibility, and fare economically worse-off. Warehouse workers earn 33% less than truckers, and 39% less than the national average wage. Warehouses are also disproportionately and increasingly staffed by migrants and workers of color. Among the lowest paid workers are Black women who earn 63 cents and 84 cents for every dollar their White and Black male counterparts earn, respectively (see Table 1).

Importantly, these statistics do not include those employed as temporary staff. Distribution centers and warehouses rely on a stream of "flexible labor" provided by temporary staffing agencies for seasonal surges in demand and various piecework. This practice allows the employer to pay by output (rather than hourly wages) and avoid paying workplace injury compensation (Blix, 2017; Jaffee and Bensman, 2016).

One survey of 300 workers in 150 distribution centers around the Chicago metropolitan area finds 63% of respondents worked as temporary staff and earned \$3.48 per hour less than direct employees (Lisle et al., 2021). Like contractors, temporary staff are not protected by the same labor regulations as direct employees. Temporary staff also disproportionately live below the poverty line, work more than one job, and belong to a racial minority. In Illinois, Black and Hispanic workers account for 78% of the temporary assignments in factories and warehouses despite constituting 35% of the state's overall working population (DeSario and White, 2020). Temporary workers also disproportionately rely on public assistance, granting further subsidies to companies to cover what could otherwise be a payroll expense.

Industry sector employment (thou.)

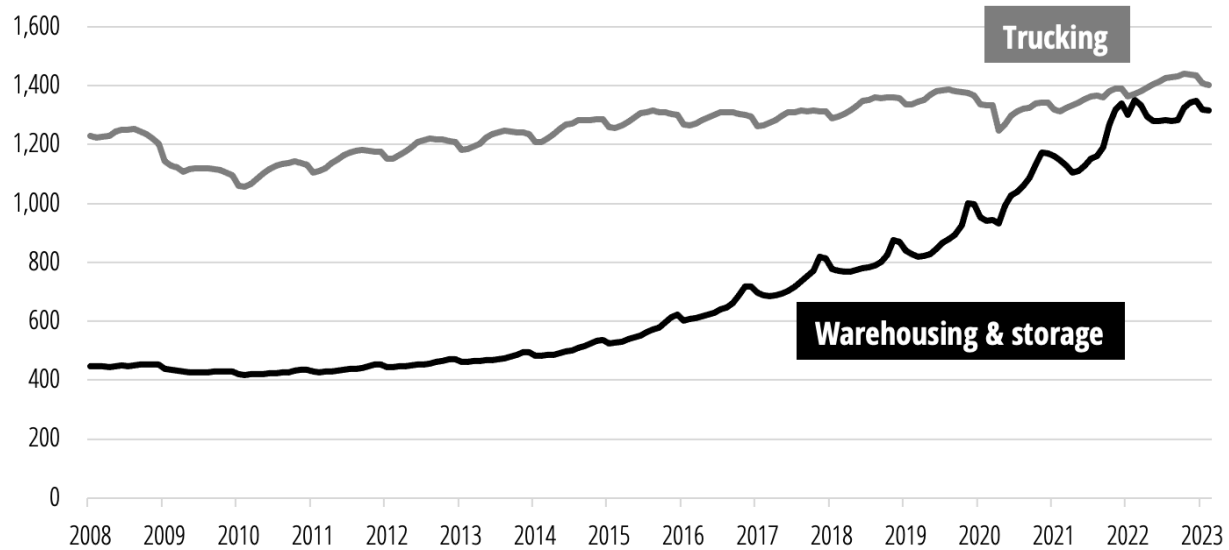


Fig. 2.3 Employment growth in the warehousing and storage and trucking sector between 2008 and 2022. Data from: US BLS, 2024, <https://www.bls.gov/iag/home.htm> (2024).

Highlighting historical and emerging inequities within the logistics labor sphere offers important context. Not only do they illuminate the human costs of “free shipping” and our improved accessibility to goods, but they also directly hinder programs that seek to improve the sector’s environmental accountability

2.2.3.3 Labor inequality and environmental non-compliance

Zabin and Appel (2019) analyze the effects of non-compliance to California’s Truck and Bus Rule, which aimed to accelerate turnover of older diesel trucks or retrofit them with DPM filters. The California Air Resource Board (CARB) described the policy as “one of the most... important tools to reduce smog forming and toxic emissions and protect public health in disadvantaged communities” (p.3).

CARB compliance data from 2018 revealed that statewide PM_{2.5} emissions were double the amount expected if every truck complied with the rule. The study found that nearly half of non-compliant trucks belonged to owner-operators and small fleets that operated “under the radar” as contractors. Much of the remainder belonged to large companies with a history of misclassifying drivers as contractors based on court rulings. As a point of comparison, FedEx Ground—with the most recent California case, *Alexander v. FedEx Ground*, finding the

company misclassified 2300 of its drivers in the state between 2000 and 2007—had 462 trucks out-of-compliance in 2018. UPS, a Teamster shop known for direct-hiring its drivers, had 9 out-of-compliance trucks.

Non-compliance is less a problem of truck drivers intentionally skirting environmental laws. Rather, it is “a failure of public policy to create labor market conditions that incentivize fair competition towards high-road, environmentally accountable economic development” (Zabin and Appel, 2019, p. 13). While large companies possess the economies of scale to ease a green fleet transition and the market power to absorb its costs, contracted drivers must front the capital needed to procure new or retrofitted vehicles and weather the uncertainties of new operating models with limited safety nets.

Without effective labor protections, environmental policies risk destabilizing the livelihoods of marginalized workers even further. It is here we see the spheres of environmental equity, accessibility to goods, and labor converge on freight.

2.4 Conclusion

While often treated as separate spheres, we illustrate how multi-scalar market forces and political marginalization result in distributive conflicts between accessibility, labor, and environmental quality. These conflicts render it difficult to address freight’s injustices in one sphere without addressing them in another.

Together, Fried et al. (2024) and Fried & García (2024) present a first effort to situate urban freight research in foundational transportation and mobility justice theories. These theories have been instrumental to helping advance justice in personal- and passenger-related mobility planning and social movements but have yet to reconcile urgent inequities and imbalanced power structures embodied in cities’ urban freight systems. The study achieves this theoretical grounding by interrogating urban freight literature’s engagements with equity and justice. Namely, this paper asks: what distributions are at stake and what are authors’ guiding principles? At what scales are injustices unresolved? And who is (un)involved in negotiating their resolution?

Consequently, the paper also presents the first comprehensive review of the state of equity and justice in urban freight literature. It illuminates several gaps and future directions for urban freight research:

- Identifying distributive spheres across urban freight that encompass labour quality, environmental justice, and accessibility to goods. In the case of the latter sphere, the paper explores home delivery as a public service that ensures sufficient access to goods for populations with low levels of accessibility. However, research is needed to understand the specific role urban freight systems play in expanding home or near-home based accessibility, as well as why and how they should be supported beyond the commercial sector.
- Highlighting multi-scalar inequities. The scalar scope for last mile delivery research is narrow, often occluding the impacts of middle mile urban freight movement, land use decisions in upstream distribution, and proximity to consolidation facilities. Studies occasionally take a regional perspective to community health impacts, but generally fall short in questioning more globalised, green growth assumptions. As a result, stakeholders often relegate external costs for labour and communities to mitigation tactics that are secondary compared to port, infrastructure, and warehousing expansion needs.
- Observing discrepancies in governance between those entitled to urban freight justice and those considered valid participants in urban freight decision-making. There is little consensus on how cities should democratically engage communities bisected by freight corridors and adjacent to freight-generating land uses. The exclusion of community members, advocates, and workers from the negotiating table necessitates deeper research on “from and for the bottom” freight management strategies and community-based participatory research applications in urban freight research.

Social and environmental inequities are not apolitical correlations to random external factors nor simply a byproduct of bad actors making purposely discriminatory decisions. Instead, inequities are locked-in through historical injustices and globally recirculated by today’s imperfect, often callous political and economic systems (Ranganathan, 2016). As such, the project of justice—even in as narrow a focus as urban freight—will almost certainly remain a contested ideal and unfinished business. However, serious action toward justice in urban freight requires political reckoning with the field’s assumptions of how benefits, burdens, and even death distribute down the urban distribution chain and who gets to have a say.

Chapter 3: Logistics Sprawl and E-commerce

ABSTRACT: The rise of e-commerce helped fuel consumer appetite for quick home deliveries. One consequence has been the placing of some logistics facilities in proximity to denser consumer markets. The trend departs from prevailing discussion on “logistics sprawl,” or the proliferation of warehousing into the urban periphery. This study spatially and statistically explores the facility- and region-level dimensions that characterize the centrality of e-commerce logistics platforms. Analyzing 910 operational Amazon logistics platforms in 89 U.S. metropolitan statistical areas (MSAs) between 2013 and 2021, this study estimates temporal changes in distances to relative, population centroids and population-weighted market densities. Results reveal that although some platforms serving last-mile deliveries locate closer to consumers than upstream distribution platforms to better fulfill time-demands, centrality varies due to facility operating characteristics, market size, and when the platform opened.

3.1 Introduction

E-commerce has transformed the “consumption geography” of cities (Buldeo Rai, 2021). These transformations have major implications for shopping behaviors and retail channels, last-mile operations and delivery mode choice, the management and pricing of competing uses for street and curb space, and the spatial ordering and functional role of logistics land uses (International Transport Forum, 2022). In the latter case, researchers have observed a diversification of logistics platforms to more efficiently serve home delivery demand. These platforms range from “dark stores” and “microfulfillment centers” that fulfill on-demand deliveries and omni-channel retail without a consumer facing storefront (Buldeo Rai et al., 2019; Shapiro, 2023), multi-use urban distribution centers that convert unproductive sites (e.g., abandoned rail depots) to more lucrative land uses (Raimbault et al., 2018), and “microhubs” that stage transloading between cargo vans and e-bicycles suited for dense urban neighborhoods (Katsela et al., 2022).

Logistics spaces play an important role in improving urban livability and environmental sustainability. Planning decisions scale geographically from the region-level to the curb. Facilities such as urban consolidation centers (Allen et al., 2012) and loading zones (Dalla Chiara et al., 2022) can mitigate common delivery inefficiencies, such as low delivery densities

and “cruising” for parking, respectively. These inefficiencies generate many negative externalities including climate emissions, air and noise pollution, congestion, and heightened collision risks, especially for vulnerable road users such as pedestrians and bicyclists (Browne et al., 2012). Limited commercial data has made it difficult, however, to observe spatial patterns with regards to e-commerce logistics platforms.

Using detailed proprietary data, this paper explores the evolving spatial organization of e-commerce logistics platforms. Given the company's preeminence as the leading online retailer in the U.S., the paper presents Amazon as a case study for understanding warehousing and distribution (W&D) activity in the larger e-commerce space. Utilizing proprietary data on Amazon logistics facilities between 2013 and 2021, this research explores the geographic shape and explanatory dimensions of e-commerce within major U.S. metropolitan areas. In the following section, this study defines the state of research related to broader W&D land use and its implications to e-commerce's distinct consumption geography. Afterwards, two methodologies for measuring logistics centrality are tested: a temporally relative barycenter-based metric, the prevailing method in literature, and another GIS-based, populationweighted service distance metric. The two measurements reveal nuances between facility- and region-level differences in the spatial organization of e-commerce platforms, which has yet to be fully researched. After presenting results from an exploratory regression analysis, this study discusses implications for future urban logistics land use and transport decisions.

3.2 Defining Logistics Sprawl

Woudsma et al. (2008) first spatially analyzed the centrifugal pattern of W&D localization in peri-urban regions, which Dablang and Rakotonarivo (2010) later described as logistics sprawl: “the tendency of warehousing development to move away from inner urban areas toward more suburban and exurban areas” (Dablang and Browne, 2020). However, patterns of industry and commercial sprawl are not unique to the logistics sector. Research has explored the outward suburban expansion of commercial office spaces (Lang, 2000) and big-box retail (Holmes, 2011; Karamychev and van Reeve, 2009). Meanwhile, the historical sprawl of population and employment, especially in North American cities, is well-evidenced as are the negative externalities (Ewing, 2008). In the past few years, however, sprawl within the logistics

sector has received heightened attention among urban transportation and economic geography scholars.

Aljohani and Thompson (2016) and Onstein et al. (2019) provide thorough literature reviews exploring factors that have influenced the geographic structure of regional logistics. These factors range from the globalization of trade and delocalization of production (Hesse and Rodrigue, 2004; Janelle and Beuthe, 1997), growing demand for “just-in-time” delivery, and rapid technological advancements in sorting automation and digital supply chain management. Spurred in part by ground-air freight integrators like FedEx and UPS (Bowen, 2012; Hall, 1989), contemporary “distribution centers” emerged as hubs conducting the directional flow of products along highways, airways, and even within their own walls, on forklifts, conveyor belts, and automated sortation machines (Cidell, 2011; McKinnon, 2009). As Cidell (2011) writes, “parts and products are not meant to sit on a shelf, but to be in constant motion along the supply chain until the final product reaches store shelves” (pp. 835).

Receiver demands for fast deliveries and high-volume throughputs shifted W&D's spatial footprint. W&D operators' appetite for space exploded to leverage economies of scale and reduce supply chain uncertainty (Andreoli et al., 2010). According to data from the U.S. Energy Information Administration (2018), the average square footage of W&D facilities grew from 118,000 square feet in 1946 to over 266,000 ft by 2018, a 125% increase over a 72-year period. Rather than the downtown-adjacent seaports and railyards, highways and airports radiated into the periphery of metropolitan regions and into the interstitial hinterlands between urban mega-regions (Bowen, 2008; Rodrigue, 2004). As such, co-locating around regional corridors and gateways in the metropolitan periphery provided better networked and cheaper siting opportunities than those in the urban core where space was politically contentious and priced at a premium.

Logistics sprawl does not always imply the diminishing density of logistic spaces in the urban core. Case studies in the Ohio River Valley and Greater Toronto Metropolitan Area found substantially higher rates of W&D facility openings in suburban or satellite municipalities than in the urban core, despite the urban core also exhibiting some degree of W&D growth (Cidell, 2011; Woudsma et al., 2016). Subsequent studies have measured logistics sprawl in the greater metropolitan regions of Paris (Dablanc and Rakotonarivo, 2010), Gothenburg (Heitz et al., 2020), Los Angeles (Dablanc et al., 2014; Kang, 2020a), Tokyo (Sakai et al., 2017), Wuhan

(Yuan and Zhu, 2019), Brussels (Strale, 2020), Cape Town (Trent and Joubert, 2022), and Sao Paulo (Guerin et al., 2021), among others.

Not all cities exhibited logistics sprawl equally, with some cities showing lower levels of decentralization or negative decentralization (i. e., centralization). Dablanc et al. (2014) analyzed W&D data from 1998 to 2009 for both the Los Angeles and Seattle metropolitan area and found that while the former city experienced substantial decentralization from its urban center, they found no evidence for sprawl in the latter. Also in comparison to Los Angeles, Giuliano and Kang (2018) found the cities of San Francisco, San Diego, and Sacramento to exhibit only marginal shifts in the geographic center of W&D facilities across

3.2.1 A new consumption geography for e-commerce?

A common feature that appears to underline newer e-commerce logistics platforms is their inward expansion into the urban core (Rodrigue, 2020). The economic implication suggests some private last-mile logistics platforms bear and adapt to the higher real estate costs and spatial constraints that dense urban environments entail in exchange for expedient access to home consumers (McKinnon, 2009). This trend departs from discussions surrounding logistics sprawl, which have typically considered the broader W&D sector without analyzing the logistical transformations arising from e-commerce's novel consumption geography.

Consumption geography—how W&Ds, stores, and consumers spatially organize (Buldeo Rai, 2021)—have important consequences for the livability and sustainability of urban environments. For instance, Wygonik and Goodchild (2018) find the spatial configuration and operational characteristics of urban delivery largely determines whether home delivery is more environmentally efficient than the in-person shopping trips that e-commerce is supposedly replacing (see also Jaller and Pahwa, 2020).

Therefore, this paper seeks to measure and explain Amazon centrality, a case study reflecting the e-commerce sector at-large, within U.S. metropolitan regions. Since logistics sprawl is a longitudinal phenomenon, and the proliferation of Amazon facilities is relatively recent, this paper does not attempt to determine if e-commerce logistics platforms are sprawling over time. Rather, this paper explores the facility and region-level dimensions that characterize platform centrality over the past decade.

3.3 Methodology

3.3.1 Data and region-level variables

MWPVL International, a logistics consulting firm, provided proprietary data on Amazon logistics platforms. MWPVL International collects monthly data on over 1,199 active Amazon facilities in the U.S. as of February 2022, since the construction of the first fulfillment center in 1997. This study selects facilities opened between 2013 and 2021 (explained in the following section) and filters Amazon platforms that are:

- Currently unoperational or closed;
- co-located logistics platforms that include adjacent, seasonal facilities that manage spill-over demand during holiday spikes (designated in the dataset);
- and distribution centers that serve Amazon-owned retail or grocery (e.g., Whole Foods);

Metropolitan Statistical Areas (MSAs) are urban amalgamations containing economically interrelated municipalities, often with a combined population over 50,000. MSAs are commonly used in urban spatial research over broad metropolitan regions and allows for integration with other public data sources. The consequent sample dataset includes 910 Amazon facilities in 89 MSAs.

To estimate (de)centralization (or centrality), this study utilized a gridded population raster as the weighting factor. WorldPop is an open data source maintained by the University of Southampton, which provides annual, UN-adjusted population data at a one kilometer (0.62 mi) spatial resolution from 2000 to 2020. Opposed to Census-provided population data, the most granular geographic unit being the block group, WorldPop provides higher resolution population information without irregular geographic enumerations. Population is used as the input into the centrality analysis. Since there is no 2021 population data, this study uses 2020 population to analyze the centrality of 2021 facility openings.

This study selects 89 MSAs based on the presence of at least one operational Amazon facility (see *Appendix* for table of included MSAs). According to Kang's (2020a) analysis, MSA population, facility size, and logistics sector strength largely determines the extent to which regions do or do not exhibit logistics sprawl. However, rather than using an employment density gradient and freight flow volume as a proxy for industry land value and strength (the latter data are unavailable for every MSA and for every year in the studied timeframe) (Giuliano et al., 2018), this study opts for a more straightforward geographic concentration metric. LQ captures

the employment strength of a region's particular industry cluster relative to other clusters and national employment (Ketels and Protsiv, 2021). The equation to calculate LQ for industry cluster i in region j follows:

$$LQ_{ij} = \frac{\frac{employment_j^i}{tot.employment_j}}{\frac{employment_{U.S.}^i}{tot.employment_{U.S.}}}$$

Therefore, LQ values greater than one indicates strong relative employment strength of an MSA's industry cluster. This study calculates LQ using North American Industry Classification System (NAICS) code 493 (*Warehousing & Storage*), which includes both W&D facilities and logistics providers (see Giuliano and Kang, 2018).

3.3.2 Amazon case study and facility-level variables

As an early entrant in the e-commerce space, Amazon's success parallels a growing digitalization of the retail and distribution spaces space (Hagberg et al., 2016; Sullivan, 2021). Rodrigue (2020) identifies four phases of expansion that define Amazon's physical logistics footprint (*See Fig. 3.1*). The phase encompasses the growth of online shopping and expectation for expedient deliveries, which prioritizes the coverage and speed of last-mile (node-to-consumer) delivery infrastructure. In May 2013, Amazon constructed its first "last-mile delivery station," marking a major step to a growing sophistication of the company's vertical distribution structure. Second, the devaluation of brick-and-mortar commercial real estate, a realignment of conventional retail to digital omni-channels, and a perpendicular growth in W&D facilities. Third, vertical supply chain integration that lent greater autonomy over Amazon's distribution infrastructure and fleets, culminating in 2016 when Amazon ended its contract with long-time logistics integrator, FedEx. Finally, the hyper-specialization of logistical platform functions, including *interstitial* (i.e., expanding digital and physical networking between facilities) and *intrastitial* sophistication (i.e., high-levels of internal platform automation and specificity of product handling across commodity types, sizes, and seasonality).

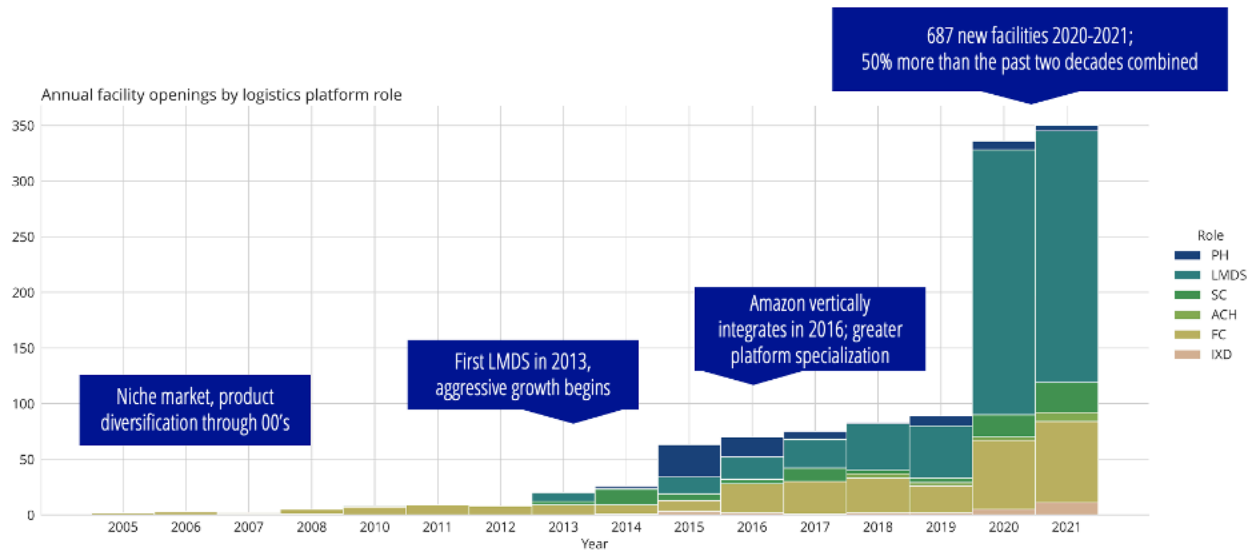


Figure 3.1: Annual facility openings by logistics platform role, 2005-2021

Amazon's distribution strategies in the past two decades have molded the modern shape of the company's supply chain: a multi-layered delivery network connecting global and domestic suppliers to consumer doorstops often in the span of 48 hours or less. Industry expert, MWPVL International, noted a three-tiered distribution chain that captures a broad range of logistics platform roles, which Fig. 3.2 also visualizes:

- **Level 1: Procurement and inventory fulfillment (i.e., gateway-to-node)**
 - *Inbound Cross Dock (IXD)*: Large-sized terminals responsible for receiving imported or domestic containerized products. Facilities are often co-located at shipping ports and intermodal terminals.
 - *Fulfillment center (FC)*: Among the largest-sized and most automated facilities, FCs represent the gateway node into Amazon's distribution channel. Since many products require custom handling equipment, transportation/storage needs, or spillover inventory space, Amazon specialized some facilities (a) by size (small boxed sortables < 10 kg, large boxed sortables <25 kg, and larger non-conveyable items), (b) by commodity types (e.g., jewelry and perishables), and/or (c) by time, which include newer sub-same day facilities often located inside FCs and seasonal facilities that service holiday spikes in demand.
- **Level 2: Sorting and distribution (i.e., node-to-node)**

- *Sortation center (SC)*: Large-sized, cross-docking facilities (i.e., serving in-bound trucks on one side, outbound on the other) that sort parcels bound for smaller geographic service areas.
- *Air cargo hub (ACH)*: Cross-docking facilities serving domestic cargo airports.
- **Level 3: Last-mile logistic centers (i.e., node-to-consumer)**
 - *Last-mile delivery station (LMDS)*: Medium-sized facilities that serve inbound trucks and outbound cargo vans adapted for dense urban street networks. These often include separate facilities for smaller parcels and heavier bulk items (e.g., furniture and large appliances).
 - *Prime hubs (PH)*: Small facilities designed to meet on-demand delivery needs for high-demand consumables.

Amazon has entered a new phase of horizontal growth. Since 2020, Amazon has accelerated platform openings in response to shifting consumer behaviors spurred by contagion concerns, new travel and remote work opportunities, entertainment and education patterns, and the long-term behavioral effects of in-store shopping restrictions (Gu et al., 2021; Kohli et al., 2020). In addition to building *more* logistics platforms, Amazon is building *out*: expanding its distribution footprint in most major cities and suburbs while also filling the service gaps in small urban and rural markets (e.g., the Upper Midwest and Great Plains), especially for FC and LMDS facilities (Schorung, 2021). Therefore, the remainder of this study focuses on the time period between 2013 and 2021 where Amazon exerted greater control on its own supply chain while reaching new heights in their economies of scale.

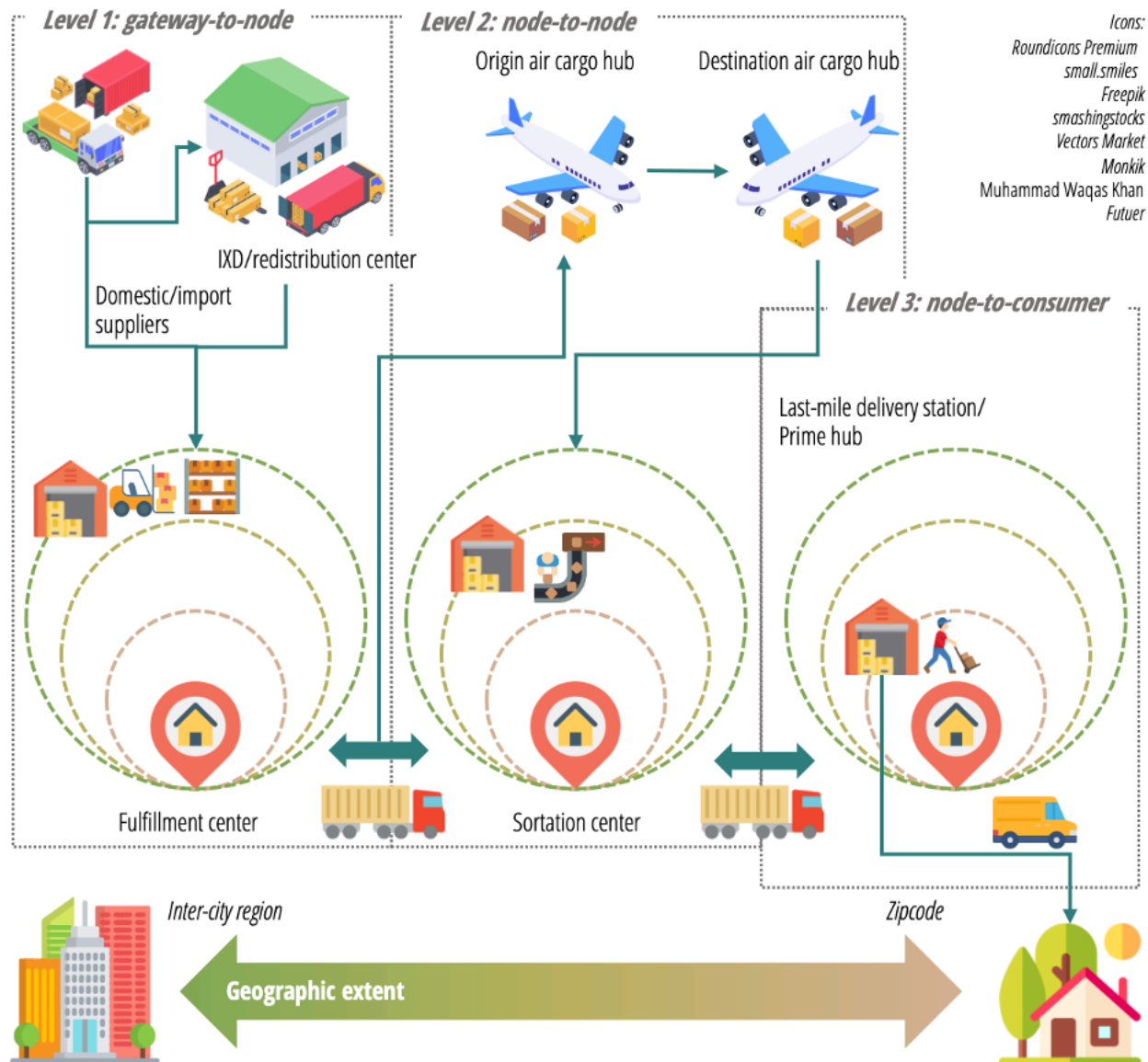


Fig. 3.2: Amazon's multi-layered physical distribution network across geographic extents
 (Adapted from MWPVL International, 2021)

3.3.3 Finding center

This research experiments with two methodologies to measure e-commerce centrality. The first method is rooted in centrophagic techniques, which measures the degree of dispersion around a weighted centroid using spatial statistics (Bachi, 1963). There is limited consensus on what metrics and reference inputs to utilize in centrophagic analyses, with studies often adopting one or multiple comparative metrics. Dablanc's work generally analyzed the relative barycenter (i.e. center of gravity) of W&D establishment distribution, which proved useful as a comparative

metric across international case studies (Dablanc et al., 2014; Dablanc and Rakotonarivo, 2010; Dablanc and Ross, 2012).

Kang (2020b) estimated the centrality of Los Angeles W&D facilities using a change in distance from the absolute barycenter, related transportation sector businesses, and population centroids. Kang found that W&D facilities sprawled in relation to each metric but to a lesser degree than the absolute barycenter, implying that logistics are paralleling a decentralization of other related industries, employment, and population. As in, it is not just warehouses that are sprawling but also demand for freight (see also Sakai et al., 2017).

Research generally estimates intra-metropolitan freight activity as a function of population, employment, and transportation supply (Giuliano et al., 2018). Since home consumers are the primary market for e-commerce, population can appropriately proxy market demand. In-line with prevailing centrographic techniques in logistics research, this study measures the Euclidean distance from Amazon platforms to an MSA's population-weighted centroid (i.e., market center) relative to the year the platform opened. However, despite centroid distances being an important aspect to measuring centrographic dispersion, they assume monocentric urban form with uniform distance decay. Therefore, this study selects a population-weighted distance metric based on a Thiessen-defined service area allocation (Church and Murray, 2009).

With delivery drivers assuming the role of traveling shoppers, the study assumes Amazon will deliver to consumers closest to the origin platform. Therefore, the equation to measure an Amazon platform's (j) temporally relative, mean population-weighted distance (d) away from all gridded population points (p_i) within a service area follows:

$$Pop. weighted distance = \frac{\sum_i T_i * p_i * d_{ij}}{\sum_i p_i * T_i} \text{ while } \sum_i p_i < k = \frac{Tot. MSA population}{Tot. MSA logistics platforms}$$

Where $T_i=1$ if p_i is in a non-co-located, Thiessen-defined service area and $T_i=0$ if p_i falls outside the boundaries. To ensure Thiessen polygons do not fracture service areas for co-located platforms, platforms sharing the same zipcode would also share the same Thiessen polygon. Moreover, the equation adds a population-based threshold break-point (k) to prevent distance inflation of more centrally located platforms.

Since both metrics use population proxies for home consumer access, this study labels the centroid-based metric as “distance to market centroid” and the population-weighted distance as “distance to market densities.” When compared, both metrics reveal nuances to how Amazon platforms have spatially organized across facilities and within MSAs over time.

3.3.4 Exploratory regression approach

Table 3.1 summarizes several variables present in the MWPVL dataset, including:

- Floorspace square footage, including ground and mezzanine area;
- Leasing costs per square foot;
- Capital expenditures (CAPEX), such as fixed equipment costs;
- Annual operating expenditures (OPEX), not including leasing (e.g., labor and packaging costs);
- Number of full-time staff, not including temporary seasonal workers;
- Daily average packages shipped, not including holiday peaks;
- Advanced automation (i.e., the facility contained Kiva automated guided vehicles);
- and whether facility received some form of public incentive, mainly property tax abatement, hiring subsidies, road construction, and/or other tax-related subsidies.

The study selects these variables based on their completeness in the dataset and relative independence from one another using variance inflation factor testing. The exception is facility floorspace, which had a strong collinear effect on most continuous variables. Larger platforms have larger everything: staffing, package throughput, lease costs, and CAPEX/OPEX. Several variables showed NAs in the dataset. Particularly, floorspace was 9.2% incomplete. This study uses a Multivariate Imputation By Chained Equations (MICE) algorithm to simulate missing data. The algorithm only uses determining variables with correlations, $|R^2|$, greater than 0.25 to improve predictive accuracy. The study then inputs the facility-level variables into an exploratory Ordinary Least Squares (OLS) regression analysis.

<i>Co</i> <i>unt</i>	<i>Avg.</i> <i>floorsp</i> <i>ace</i> <i>(mil.</i> <i>sq. ft.)</i>	<i>Avg.</i> <i>CAP</i> <i>EX</i> <i>(\$</i> <i>mil.)</i>	<i>Avg.</i> <i>OPEX</i> <i>(\$</i> <i>mil.)</i>	<i>Avg.</i> <i>Staf</i> <i>f</i>	<i>Kiva</i> <i>automatio</i> <i>n (count)</i>	<i>Public</i> <i>incentives</i> <i>(count)</i>	<i>Avg. lease</i> <i>cost</i> <i>(\$ per sq</i> <i>ft)</i>	<i>Avg.</i> <i>daily</i> <i>packages</i> <i>shipped</i> <i>(thousan</i> <i>d)</i>
-------------------------	--	--	--	--	---	--	---	--

IXD	23	0.65	8.3	50.6	1,163	0	5	7.5	NA
FC	223	1.2	134.9	102.5	1,482	96	57	6.1	151.7
SC	78	0.36	52.7	41.8	787	6	9	6.0	195.6
AC	12	0.48	185.5	35.5	784	1	1	5.1	NA
H									
LM	513	0.18	15.2	7.9	182	3	3	8.1	26.8
DS									
PH	61	0.05	5.9	3.9	95	0	1	10.3	7.1
TOT	910	0.47	49.6	34.4	570	106	76	7.5	75.2
.									

Table 3.1: Summary of variables for observed logistics platforms, 2013-2021 (MWPVL 2022)

To infer the most impactful variables, the analysis takes an exhaustive subset approach to OLS regression. The approach identifies variables for inclusion in best-fitting models by minimizing the Bayesian Information Criterion (BIC). The variable's inclusion, strength, and significance can then compare across models. Since platform role appears to largely influence centrality, the analysis conducts separate models for Level 3 platforms (n=574), Level 1&2 (n=336), and all three together (n=910) for both density and centroid metrics, totaling six models.

Level 3 platforms are included as a dummy indicator for the latter models (*L3*). Additionally, the analysis includes a dummy variable indicating whether the facility opened after 2020 (*post-2020*). *Section 4* describes the reasoning for the timeseries variable inclusion. The analysis also includes two region-level dummy indicators for high population MSAs (*metro*) and strong relative employment strength in the NAICS 493 sector (*LQ*). Moreover, to control for non-linear residuals and multicollinearity, the model log-transforms and normalizes continuous variables by square footage. In total, the exploratory regression includes 12 variables.

3.4 Results

3.4.1 Logistics centrality across platform roles and time: summary statistics

Centrality varied across platform roles. On average, Level 3 platforms (i.e., LMDS and PH) were closer both to market centroids and densities (see *Table 3.2*). PH facilities, which have the most

stringent delivery time windows, were substantially more centralized: the average PH was 7.9 mi and 3.5 mi from market centroids and densities, respectively. While LMDS were generally more decentral than PHs, their average distance from market centroids (12.8 mi) and densities (5.7 mi) still positioned them more centrally than Level 1 and 2 platforms. There was limited statistical difference in centrality across Level 1 and 2 platforms. Therefore, the subsequent OLS regression analysis groups Level 1 and Level 2 together, despite their distinct logistical functions. Market centroid and density distances between Level 1&2 and Level 3 platforms presented statistically significant differences in means according to an unequal variance t-test. In other words, platforms that serve a last-mile logistical function (i.e., node-to-consumer) are closer to consumers than platforms upstream in the distribution chain.

Note that platforms generally showed closer proximity to consumer market densities than they did market centroids. On average, platforms were roughly 12.9 mi from a market center (median = 11.1 mi). Whereas the mean distance from market densities was 6.2 mi (median = 5.3 mi). Centroid metrics also showed a higher degree of variance, with the minimum distance at roughly 0.4 mi and the maximum at 54.5 mi. Moreover, density and centroid distances have a moderate and statistically significant positive correlation ($R^2 = 0.31$; Pearson's p-value < 0.001). Results suggest that while the two metrics moderately interrelate, there is still some degree of unaccounted variance.

	<i>Market density distance (mi)</i>				Welch's t-test (H0:Level1&2 =Level3)	<i>Market centroid distance (mi)</i>				Welch's t-test (H0:Level1&2= Level3)
	me an	me d	ran ge	var		me an	me d	ran ge	var	
<i>IXD</i>	6.3 3	6.5 9	2.99 -9.2 0	2.4 8		16. 35	14. 72	3.27 -35. 56	67. 01	
<i>FC</i>	7.4 3	6.2 4	1.45 -27. 76	16. 30		13. 70	12. 39	1.28 -41. 26	50. 34	
<i>AC</i>	7.8	7.4	3.74	7.3		13.	13.	7.10	23.	
<i>H</i>	7	2	-12. 98	2		09	23	-22. 23	24	

SC	7.3	6.1	2.57	13.		14.	12.	2.27	48.	
	5	6	-20.	77		12	80	-38.	86	
			71					19		
LM	5.7	5.0	0.94	10.		12.	10.	0.38	71.	
DS	1	3	-23.	97		80	66	-54.	47	
			59					50		
PH	3.5	3.4	1.06	2.2		7.8	6.1	0.36	31.	
	4	9	-7.7	4		7	4	-25.	84	
			7					66		
Lev	7.3	6.2	1.45	14.	<0.001 ***	13.	12.	1.28	50.	<0.001 ***
el	5	5	-27.	45		95	61	-41.	23	
1&2			76					26		
Lev	5.4	4.8	0.94	10.		12.	10.	0.36	61.	
el 3	8	0	-23.	49		27	00	-54.	51	
			59					50		

Table 3.2: Summary statistics of market density and centroid distances across platform roles

Centrality also fluctuated over time (see Fig. 3.3). Level 3 platforms openings trended further away from market centers and densities during the observed timeframe. For instance, between 2014 and 2021, distance from market centroids and densities for PH platforms increased by 1.9 mi and 2.5 mi respectively, constituting a 29% and 136% increase in respective distances. For LMDS, the percent increase in distances from market centroids and densities between 2013 and 2021 increased by 46% (9.6 mi to 14.1 mi) and 114% (2.7 mi to 5.8 mi).

On the other hand, market centroid distances for Level 1 and 2 platforms exhibited only weak changes between start and end years. FCs opened *closer* to market centroids and densities, decreasing by 5% (14.7 mi to 14.0 mi) and 20% (9.5 mi to 7.6 mi), respectively. Meanwhile, SC increased their market density difference by 80% (4.7 mi to 8.5 mi). Except for FCs, however, most platforms opened after 2020 were further from their region's market centroid and density.

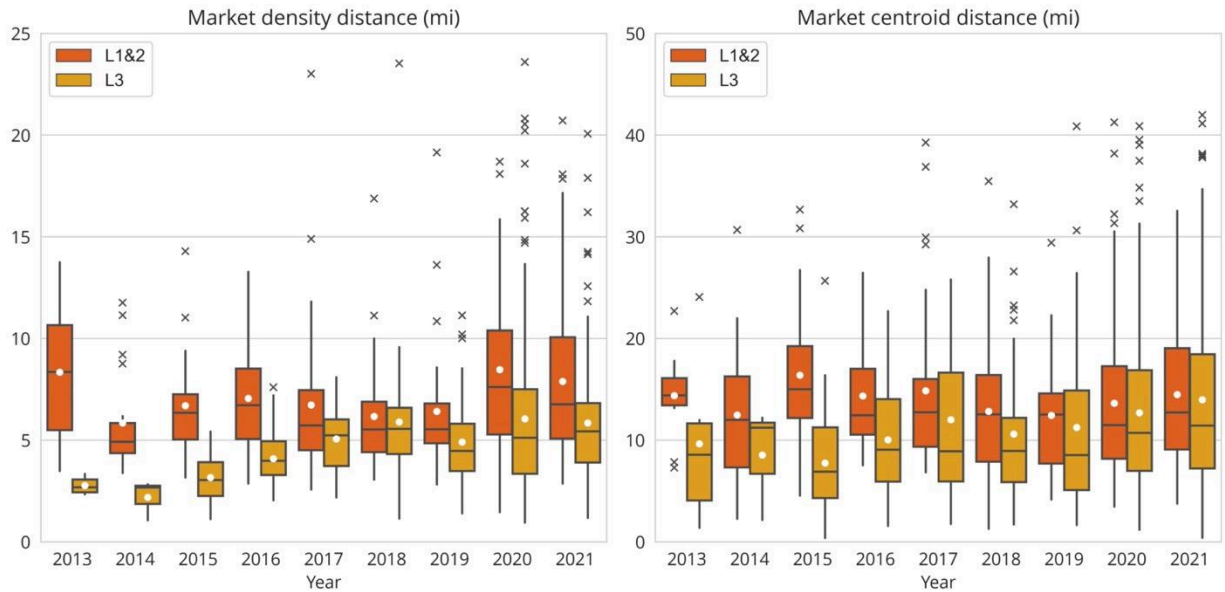


Fig. 3.3: Annual change in density and centroid distances by logistics platform role, 2013-2021 (NOTE: white dot represents mean)

This initial analysis indicates there are significant differences in centrality between a) platform roles, especially Level 3, and b) platforms opened after 2020, which also marked a substantial acceleration in new facility openings. *Fig. 3.4* shows the cumulative frequencies of both distance metrics by platform role (Level 1&2 versus Level 3) and timeframe (2013-2019 versus 2020-2021). While both metrics exhibit yearly fluctuations, they differ in relative magnitude. *Table 3.3* validates the differences in means between the two timeframes for both Level 1&2 and Level 3, as well as corresponding Welch's (unequal variance) t-tests.

The results confirm that Level 1&2 and Level 3 platforms opened after 2020 were significantly more decentralized. The exception is Level 1&2 platforms did not show significant differences in centroid distances. The results also validate a significant difference in mean relative distances between Level 1&2 and Level 3 platforms, especially relative to centroid distances. Level 3 platforms opened between 2020-2021 decentralized to a larger degree around market centroids ($\Delta \text{mean} = 3.1 \text{ mi}$), whereas centroid distance remained static across most new Level 1&2 openings. Meanwhile, both Level 1&2 and Level 3 platforms that opened after 2020 decentralized around market densities, although the difference between them is less substantial (albeit significant).

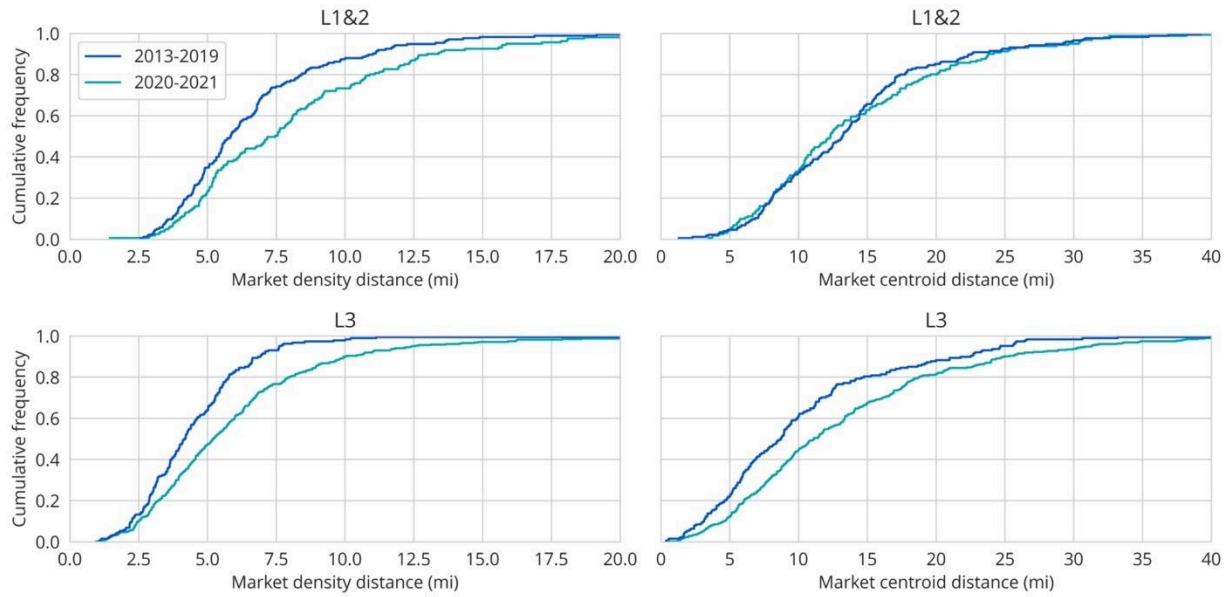


Figure 3.4: Cumulative distances from market densities (left) and centroid (right) for different logistics platform functions and timeframes

	Logistics function	N	Δ mean	Δ median	Welch's t-test (H0: $\Delta D = 0$)	Welch's t-test (H0: ΔD Level 1&2 = ΔD Level 3)
Centroid distance	Δ Level 1&2	336	0.23	-0.87	0.765	<0.001***
	Level 3	574	3.05	2.42	<0.001***	
Density distance	Δ Level 1&2	336	1.54	1.62	<0.001***	<0.001***
	Level 3	574	1.46	1.03	<0.001***	

Table 3.3: Mean differences in relative distance measurements (mi), 2013-2019 and 2020-2021

3.4.2 Facility- and region-level factors for centrality: OLS Regression

The degree and significance of platform decentralization varied across market density and centroid metrics. Table 3.4 presents the results of the best model subsets. The table also presents the R^2 , log-likelihood, and BIC of the null model (subscript 0), which includes all variables. All best subsets show small to moderate improvements in model fitness compared to the null. The paper summarizes the findings below.

	<i>Density mi[log]</i>		<i>Centroid mi[log]</i>		<i>Density mi[log]</i>		<i>Centroid mi[log]</i>		<i>Density mi[log]</i>		<i>Centroid mi[log]</i>	
	All levels		All levels		L1&2		L1&2		L3		L3	
	[model 1]		[model 2]		[model 3]		[model 4]		[model 5]		[model 6]	
	<i>Coef.</i>	<i>Std</i>	<i>Coef.</i>	<i>Std</i>	<i>Coef.</i>	<i>Std</i>	<i>Coef.</i>	<i>Std.</i>	<i>Coef.</i>	<i>Std</i>	<i>Coef.</i>	<i>Std</i>
		<i>.e</i>		<i>.e</i>		<i>.e</i>				<i>.e</i>		<i>.e</i>
<i>Intercept</i>	2.06*	0.2	0.92*	0.3	1.71*	0.2	1.10*	0.3	1.71*	0.2	3.39*	0.3
	**	4	**	3	**	5	**	9	**	8	**	4
<i>floorspace[log]</i>	0.06*	0.0	0.12*	0.0	-	-	0.09*	0.0	0.09*	0.0	-	-
	**	2	**	2			**	3	**	3		
<i>lease cost[log]</i>	-0.29	0.0	-0.17	0.0	-0.18	0.0	-	-	-0.36	0.0	-0.20	0.0
	***	4	***	6	**	7			***	5	**	7
<i>packages [log]</i>	-0.03	0.0	-	-	-0.05	0.0	-	-	-	-	0.11*	0.0
		2			**	2					**	4
<i>staff[log]</i>	0.06*	0.0	-	-	-	-	-	-	0.06*	0.0	-	-
	*	3								3		
<i>post-2020</i>	0.18*	0.0	0.17*	0.0	0.16*	0.0	-	-	0.18*	0.0	0.27*	0.0
	**	3	**	5	**	5			**	4	**	7
<i>metro>2.2mil⁺</i>	-0.31	0.0	0.43*	0.0	-0.32	0.0	0.32*	0.0	-0.32	0.0	0.47*	0.7
	***	3	**	5	***	5	**	6	***	5	**	
<i>LQ>1</i>	0.06*	0.0	-	-	0.08*	0.0	-	-	-	-	-	-
	*	3				5						
<i>L3</i>	-0.16	0.0	-0.13	0.0	-	-	-	-	-	-	-	-
	***	4	**	6								
<i>kiva auto.</i>	-	-	-0.21	0.0	-	-	-0.19	0.0	-	-	-	-
			***	8			***	6				
<i>public incentive opex[log]</i>	-	-	-0.09	0.0	-	-	-	-	-0.52	0.1	-	-
				8					***	7		
<i>capex[log]</i>	-	-	-	-	0.12*	0.0	-	-	-	-	-0.25	0.0
					*	4					***	6
<i>capex[log]</i>	-	-	-	-	-	-	-	-	-	-	-	-
<i>R² adj.</i>	0.28		0.16		0.20		0.10		0.23		0.15	
<i>LL</i>	-565.		-866.		-172.		-236.		-378.		-601.	
	03		50		85		60		30		30	

<i>BIC</i>	1198. 19	1794. 33	392.2 3	502.2 8	807.4 2	1247. 08
<i>R² adj.₀</i>	0.28	0.15	0.19	0.10	0.23	0.15
<i>LL₀</i>	-562. 00	-865. 05	-171. 63	-233. 03	-377. 20	-597. 05
<i>BIC₀</i>	1221. 39	1825. 49	418.8 9	541.6 8	836.9 8	1276. 68

Table 3.4: Best subset models for density and centroid distance measurements across logistics facility function (NOTE: continuous log-transformed variables normalized by floorspace sq. ft.;

*** $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; + 2.2 million people derives from a natural break in population, see Kang 2020a)**

3.4.2.1 Finding 1: Floorspace and leasing costs

Similar to other studies that examined at facility-level W&D characteristics (Kang, 2020a; Sivitanidou, 1996), platform size and leasing costs largely determined how far facilities located from the urban core. Model 1 and 2 (all levels) showed positive, non-linear relationships between centrality and floorspace and the inverse for leasing costs per square foot. Platforms opened further away from consumer market densities and centroids were generally able to leverage higher land availability and lower land values to build large facilities, enhancing their economies of scale (Andreoli et al. 2010).

However, the correlation strength and significance of these factors were not constant across all relationships. In L1&2 models, floorspace was insignificant for density distance (model 3); conversely, leasing costs were insignificant for centroid distance (model 4). In L3 models, high floorspace and low leasing costs strongly determined density decentralization (model 5); however, only leasing costs had a significant influence on centroid distance in the best subset (model 6). Although it is difficult to generalize a pattern from these observed discrepancies, results do suggest e-commerce platforms follow similar siting decisions as those made for general W&D facilities. Although the strength of these factors varied by metric used and what logistical role the platform played.

3.4.2.2 Finding 2: Post-2020 openings

The OLS regression validates the observation made in *Section 4.1*: platforms opened after 2020 located further away from both market densities and centroids, especially for L3 platforms. The dummy indicator, *post-2020*, showed positive significance for five out of six models. Generally, platforms opened between 2020 and 2021 located 17-20% further away from consumer markets than those built in years prior, depending on model subset and metric used. The exception is model 4, which showed no significance, and model 6, which showed a substantially stronger effect. In other words, post-2020 siting did not significantly influence observed centroid decentralization for L1&2. Whereas post-2020 siting for L3 platforms decentralized roughly 31% on average from market centroids, controlling for other facility attributes.

3.4.2.3 Finding 3: MSA population

Again in-line with Kang (2020a), the OLS regression modelling revealed MSA population substantially influenced platform centrality. Interestingly, however, the relationship sign differed across metrics. Platforms sited in large MSAs (population greater than 2.2 million people) located 38-60% further away from market centroids on average, depending on platform role. Conversely, platforms in small MSA were roughly 27% *closer* to market densities, regardless of platform role. At first glance, this observation appears obvious. Kang (2020a) observed W&D facilities sprawl from urban centroids in larger metropolitan regions; however, higher population densities in large MSA means logistics platforms are still likely to open near denser consumer markets than smaller MSAs.

3.4.2.4 Finding 4: Level 3 (L3) platforms

A platform's logistical role largely influenced its centrality. The *L3* dummy indicator Model 1 and 2 was negative and significant, providing further evidence for the assumption that last-mile e-commerce platforms (i.e., node-to-consumer facilities) localize closer to urban consumers than upstream distribution facilities. When controlling for variables in the best subset, L3 facilities were roughly 15% and 12% closer to market densities and centroids on average, respectively.

3.4.2.5 Finding 5: Other variables

Beyond the variables already discussed, several present different implications across models. For instance, number of staff per square foot of floorspace (*staff*) was positively significant in the base density distance model and for L3 platforms (model 1 and 5). L3 facilities closer to dense

urban markets were less staffed. Conversely, L3 facilities closer to market centroids had higher package volumes (*packages*) when normalized by facility size (model 6).

Administering public incentives (mainly, property tax abatement) helped bring L3 platforms over 40% closer to market densities than platforms that received zero subsidies (model 5). The finding provides some empirical credence—and intriguing insight—to the influence of public planning practices on W&D siting decisions. Yuan (2019) shows how favorable and often lax zoning, taxes, and environmental regulations helped drive W&D firms deeper into the economically opportunistic suburbs of Southern California’s Inland Empire. More direct public incentives likely have to counteract urban municipalities’ higher financial and political costs to nudge L3 platforms closer to dense consumer markets.

Meanwhile, L1 or L2 facilities that contained advanced, Kiva robotic automation showed negative and significant coefficients (model 2 and 4). Since most Kiva-outfitted facilities are FCs, the implication is that FCs located closer to market centers were more automated. Non-lease related OPEX showed positive significance for model 3, but negative significance in model 6. Density decentralized L1 and L2 platforms had higher annual operating costs, while centroid decentralized L3 platforms had lower costs. Finally, CAPEX did not show any significance across best subsets.

3.4.2.6 Finding 6: Market density metrics v. centroid metrics.

As the dependent variable, density distance created best-fitted models. For instance, model 1 presents the highest adjusted R^2 , accounting for 28% of the variance. In the absence of additional metrics, cost-optimal distance away from market densities, rather than market cores, may more closely reflect Amazon platform siting decisions.

3.5 Discussion and conclusion

This study spatially explored Amazon’s growing logistics footprint by using two distinct centrographic methods: distance from market (i.e., population) centroids and densities. While Amazon has pioneered innovative models for distribution and inventory management, Amazon’s platform siting has followed similar geographic pathways outlined in past studies on broader W&D activity (e.g., Bowen, 2008; Cidell, 2011; Giuliano and Kang, 2018; Kang, 2020b). Platforms with larger floorspace needs generally opened further from market centroids where

leasing costs were cheaper, especially in bigger metropolitan areas. These platforms did not necessarily open in less consumer-dense regions, however.

Moreover, facility attributes unique to e-commerce space also influenced platform centrality, which this study is the first to analyze in detail. Particularly, certain platforms strategically localized in closer proximity to urban consumer markets to expediently fulfill home delivery demand. Between 2013 and 2015, Amazon aggressively built out their logistics network to manage inventory and staging for last-mile delivery. Level 3 platforms (i.e., LMDS and PH) located moderately closer to market centers and densities than Amazon's Level 1 and 2 cross-docks, air hubs, fulfillment and sortation centers. In a short time period, however, Level 3 platforms showed signs of decentralization. On average, Level 3 platforms opened after 2020—a year that marked another major uptick in Amazon's horizontal expansion—dispersed 20% (11.1 to 13.4 mi) from market centroids and 23% (4.9 to 6.0 mi) from market densities.

The explanation is familiar: decentralizing last-mile platforms paralleled ballooning facility floorspaces and, to a lesser extent, falling land values. Between 2013 and 2020, for instance, the mean, annual rate of change for Level 3 floorspace and leasing costs was 21.8% and -6.8%, respectively (see *Fig. 3.5*). However, this study does not claim a trend toward logistics sprawl. In fact, the future of “e-commerce sprawl” seems uncertain as Level 3 platforms opened in 2021 showed signs of decreasing floorspaces and increasing rents.

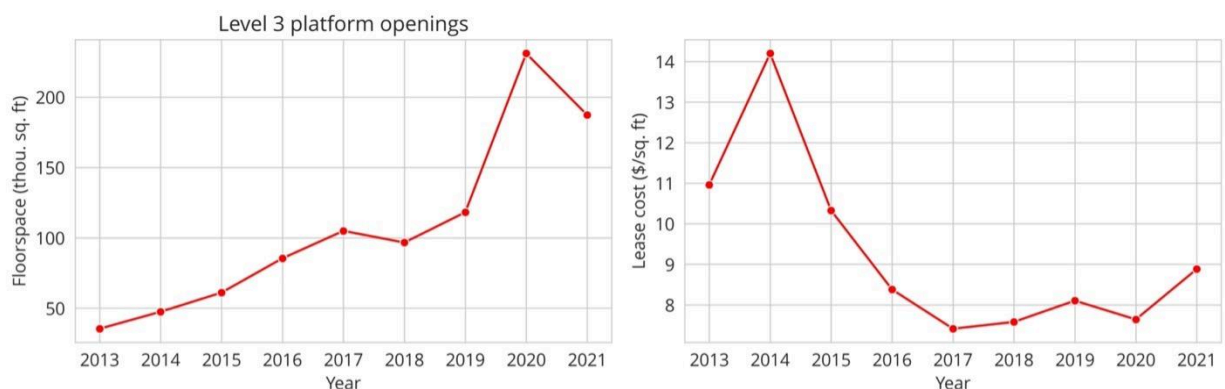


Fig 3.5: Annual change in mean floorspace and leasing costs for Level 3 platform openings

This study also found that state and municipal incentives play an important role in pulling Level 3 facilities closer to dense consumer markets, which departs from previous discussion of

public sector's more passive role in W&D development (Yuan, 2019). Moreover, since the spatial analysis finds the market density metric has stronger explanatory power for platform siting decisions than the market centroid metric, this study provides evidence for observations of Amazon's "fill the gap" strategy in recent years (Schorung, 2021). That is, the horizontal integration of logistics activities across less consumer-dense regions.

3.5.1 Implications for logistics transport and land use

The effects of logistics sprawl, both positive and negative, are not well-quantified. Compact distances between W&D and consumer markets brings network optimizations that could reduce freight vehicle-miles-traveled (VMT) and consequent emission intensities (Dablanc and Rakotonarivo, 2010; Rivera-Gonzalez et al., 2023). However, it is not always intuitive to isolate the phenomenon from decentralizing freight demand. As Sakai et al. (2017) demonstrates, logistics sprawl does not imply increasing distances between platforms and demand and, thus, nonoptimal freight efficiencies (see also Robichet and Nierat, 2021). Even with longer distances between origin and market destinations, possible efficiency trade-offs occur as larger, more automated platforms leverage higher average loads per truck than their smaller, urban counterparts. In a scenario of decentralizing freight demand, optimized inventory sorting and truck loading procedures, decentralized logistics platforms could hypothetically bring operational efficiencies that create freight network improvements.

Conversely, inward expansion of urban logistics platforms puts freight activity in closer proximity to high population densities and sensitive urban land uses, which would magnify the effect of negative, local externalities (Holguín-Veras et al., 2021). Considering diesel truck exhaust constitutes a major fraction of urban mobility-source air pollution (Kozawa et al., 2009; Minet et al., 2020), facility localization would have important implications for pollutant-related respiratory and heart disease morbidity and social costs (HEI, 2010; Vohra et al., 2021). Additional externalities include urban heat island (Voogt and Oke, 2003), noise pollution (Münzel et al., 2021), traffic congestion and collisions, and surface runoff pollution (Müller et al., 2020), creating undesirable and potentially dangerous neighborhood conditions.

Therefore, last-mile logistics platforms' inward move towards denser, urban neighborhoods raises proximity concerns. Emerging research on Freight Efficient Land Uses

(FELUs) presents public and private strategies for balancing competing land use, transport, and community priorities (Holguín-Veras et al., 2021). For instance, multi-use urban distribution centers maximize economically productive land uses while simultaneously mitigating external costs associated with “proximity logistics” (Buldeo Rai et al., 2022). Nature-based buffers or “complete streets” road design around logistics platforms can also enhance safe interactions between commercial vehicles and vulnerable road users, such as pedestrians or bicyclists (Conway et al., 2013; Pitera et al., 2017).

There is also an opportunity to adapt public health language, air quality/traffic monitoring, and Health Impact Assessments (HIA) into municipal permitting for freight-intensive land uses (Garcia et al., 2013; Nowlan, 2023; Schneller et al., 2022). Doing so can help planners and private operators better understand the community impacts of e-commerce logistics. In 2021, for example, the South Coast Air Quality Management District, Los Angeles metro’s air pollution regulatory board, adopted the Warehouse Indirect Source Rule (ISR). ISR requires W&D operators to report truck traffic impacts and incentivizes large platforms to offset freight emissions in vulnerable neighborhoods via a point-or-fee system (South Coast AQMD, 2021).

3.5.2 Conclusion

This study presents a first effort to reveal spatial nuance in e-commerce platform siting decisions around U.S. metropolitan areas. The study homes in on Amazon’s recent build out of last-mile delivery stations, which differ from conventional distribution centers in their ability to more expediently serve home delivery. Namely, these facilities have moved moderately closer to consumer households, forgoing the larger floorspace and lower rents that more suburban locations accommodate—sometimes. More recently, LMDS have shown signs of decentralization matching the spatial trends of more upstream logistics facilities and W&D spaces more generally, indicative of a new phase in Amazon’s horizontal integration to smaller markets. Robichet et al. (2022) also show in their analysis of microhub allocation in Paris that high real estate prices can eventually render urban siting unattractive as platforms near the city core become more saturated.

Amazon’s newness limits this study’s temporal scope, and this study does not attempt to make long-term projections regarding future e-commerce platform localization. Moreover, while

this study measures the extent of e-commerce logistics (de)centralization, it does not causally explain *why* Amazon is sprawling in some cities and centralizing in others. However, the results do present implications that extend beyond any one e-commerce platform. The observed spatial trends reflect the restructuring of retail and logistics spaces that have generated heightened commercial competition for real estate, curb and street access in the urban core, leading to a supposed “space race” for freight carriers (ITF, 2022). But this has not been at the expense of e-commerce’s sprawling logistical footprint in the exurbs. As the analysis itself reveal a heterogeneity of cases across facility types and cities, which future studies can and should explore.

Appendix

MSA name, state (largest city)	Pop., 2020 (mil.)	LQ NAICS4 93	# logistics platforms	MSA name, state (largest city)	Pop., 2020 (mil.)	LQ NAICS493	# logisti cs platfo rms
New York City, NY	19.22	0.59	65	Birmingham, AL	1.09	0.56	5
Los Angeles, CA	13.21	0.68	36	Grand Rapids, MI	1.08	0.47	5
Chicago, IL	9.46	1.23	49	Rochester, NY	1.07	0.18	3
Dallas, TX	7.57	1.60	40	Tucson, AZ	1.05	0.94	5
Houston, TX	7.07	0.99	26	Fresno, CA	1.00	1.18	2
Washington, DC	6.28	0.29	16	Tulsa, OK	1.00	0.87	3
Miami, FL	6.17	0.49	24	Omaha, NE	0.95	0.53	3
Philadelphia, PA	6.10	1.21	37	Worcester, MA	0.95	1.82	6
Atlanta, GA	6.02	1.61	27	Bridgeport, CT	0.94	0.15	3
Phoenix, AZ	4.95	1.14	27	Greenville, SC	0.92	1.19	1
Boston, MA	4.87	0.45	17	Albuquerque, NM	0.92	0.44	3

San Francisco, CA	4.73	0.43	19	Albany, NY	0.8	8	0.96	4
Riverside, CA	4.65	6.19	39	Knoxville, TN	0.8	7	0.47	1
Detroit, MA	4.32	0.81	17	McAllen, TX	0.8	7	0.73	1
Seattle, WA	3.98	0.82	28	New Haven, CT	0.8	5	1.11	4
Minneapolis, MN	3.64	0.55	13	Oxnard, CA	0.8	5	0.36	5
Denver, CO	2.97	0.84	15	El Paso, TX	0.8	4	0.66	1
St. Louis, MO	2.80	0.94	13	Columbia, SC	0.8	4	0.94	2
Baltimore, MD	2.80	0.99	22	North Port, FL	0.8	4	0.88	4
Charlotte, SC	2.64	1.68	13	Dayton, OH	0.8	1	NA	2
Orlando, FL	2.61	0.58	9	Greensboro, NC	0.7	7	1.25	4
San Antonio, TX	2.55	1.41	13	Cape Coral, FL	0.7	7	0.35	3
Portland, OR	2.49	0.75	12	Stockton, CA	0.7	6	7.44	12
Sacramento, CA	2.36	1.95	10	Boise City, ID	0.7	5	0.59	5
Pittsburgh, PA	2.32	0.65	7	Little Rock, AR	0.7	4	0.39	5
Las Vegas, NV	2.27	1.28	17	Lakeland, FL	0.7	2	5.68	7
Cincinnati, OH	2.22	1.77	15	Akron, OH	0.7	0	1.33	4
Kansas City, MO	2.16	1.54	13	Des Moines, IA	0.7	0	0.57	5
Columbus, OH	2.12	3.45	14	Ogden, UT	0.6	8	1.80	1
Indianapolis, IN	2.07	2.73	16	Poughkeepsie, NY	0.6	8	NA	2
Cleveland, OH	2.05	0.48	8	Deltona, FL	0.6	7	0.38	2

San Jose, CA	1.99	0.14	10	Madison, WI	0.6	6	0.58	2
Nashville, TN	1.93	1.81	12	Syracuse, NY	0.6	5	0.59	2
Virginia Beach, VA	1.77	1.13	6	Provo, UT	0.6	5	0.42	1
Providence, RI	1.62	0.99	5	Durham, NC	0.6	4	0.76	5
Milwaukee, WI	1.58	0.67	4	Toledo, OH	0.6	4	1.14	3
Jacksonville, FL	1.56	2.13	9	Wichita, KS	0.6	4	0.26	2
Oklahoma City, OK	1.41	0.37	7	Harrisburg, PA	0.5	8	2.24	4
Raleigh, NC	1.39	0.26	4	Spokane, WA	0.5	7	0.35	4
Memphis, TN	1.35	4.63	8	Chattanooga, TN	0.5	7	0.49	1
New Orleans, LA	1.27	0.76	3	Modesto, CA	0.5	5	1.42	1
Louisville, KY	1.27	0.98	5	Youngstown, OH	0.5	4	0.81	1
Salt Lake City, UT	1.23	1.30	10	Lexington, KY	0.5	2	2.34	2
Hartford, CT	1.20	1.18	6	Pensacola, FL	0.5	0	0.12	1
Buffalo, NY	1.13	0.71	2					

Appendix Table 1: Observed MSAs and region-level variables

Chapter 4: Estimating Spatial Equity in E-commerce

ABSTRACT: Despite large bodies of research related to the impacts of e-commerce on last-mile logistics and sustainability, there has been limited effort to evaluate urban freight using an equity lens. Therefore, this study proposes an activity-based modelling framework that enables researchers and planners to estimate the baseline equity performance of a major e-commerce platform and evaluate equity impacts of possible urban freight management strategies. The study also analyzes the sensitivity of various operational decisions to mitigate bias in the analysis. The model adapts empirical methodologies from activity-based modelling, transport equity evaluation, and residential freight trip generation (RFTG) to estimate person- and household-level delivery demand and cargo van traffic exposure in 41 U.S. Metropolitan Statistical Areas (MSAs). Evaluating 12 measurements across varying population segments and spatial units, the study finds robust evidence for racial and socio-economic inequities in last-mile delivery for low-income and, especially, populations of color (POC). By the most conservative measurement, POC are exposed to roughly 35% more cargo van traffic than white populations on average, despite ordering less than half as many packages. The study explores the model's utility by evaluating a simple scenario that finds marginal equity gains for urban freight management strategies that prioritize line-haul efficiency improvements over those improving intra-neighborhood circulation. This chapter presents a first effort in building a modelling framework for more equitable decision-making in last-mile delivery operations and broader city planning.

4.1 Introduction

Spatial inequities are prevalent in urban freight systems. Satellite-based estimates suggest low-income populations of color (POC) in major U.S. cities are exposed to 28% more diesel traffic-related Nitrogen Oxide (NOx) emissions than high-income white populations (Demetillo et al., 2021). Despite a steady decrease in tailpipe emissions across high-income countries, diesel exhaust from freight vehicles remains deleterious to respiratory and heart health in cities. In Toronto, freight-related exhaust constitutes over half of all NOx pollutants and equates to almost 10,000 years of life lost annually (Minet et al., 2020). Urban freight traffic is also an accelerating source of increasing road fatalities and injuries, especially among vulnerable road users such as

pedestrians and bicyclists (McDonald et al., 2019). Research in Minneapolis-St. Paul finds fatal and injurious collisions with freight vehicles disproportionately occur in low-income and majority POC neighborhoods (Yuan and Wang, 2021).

Though racial and social biases may still be commonplace, observed inequities rarely result from explicit discrimination in public and private decision-making. They emerge as side-effects of historical practices and perpetuate through conventional political and market processes (Ranganathan, 2016). In the U.S., for instance, the persistence of racial inequities in urban freight partly connect to the urban development practices of the early-to-mid 20th Century that locked-in freight-generating land uses and highway infrastructure near black and immigrant communities (Bullard et al., 2004; Yuan, 2018a, 2018b).

Fortunately, most government agencies seek to redress the historical injustices that still manifest in transport today (Martens and Golub, 2021). Even some companies acknowledge the private sector's role in ensuring equitable provision of service and mitigation of negative externalities (Burri et al., 2021). However, there exists no uniform approach to evaluating whether current and future environmental conditions are inequitable, and analytical decisions as seemingly straight-forward as defining spatial units or population segments are subject to bias (Noonan, 2008). In transportation equity research, guidelines on empirical standards and analytical methods are equally scant and practice is inconsistent across actors (Bills and Walker, 2017; Karner and Niemeier, 2013). These inconsistencies can influence the effectiveness in identifying programs that remedy environmental injustices or halting programs that perpetuate them. There has also been limited effort by broader transport research to evaluate urban freight using an equity lens (Fried et al., 2023). Therefore, this paper proposes a modelling framework that achieves two ends:

1. Establish a baseline estimate for racial and socio-economic disparities in last-mile delivery demand and traffic exposure; and
2. enable the evaluation of urban freight operational, transport and land use decisions and their distributional impact across socially disadvantaged communities.

The literature review draws methodological insights from three bodies of empirical work: activity-based demand modeling, transport equity evaluation, and residential freight trip

generation (RFTG) (*Section 4.2*). As far as the authors are aware, this study is the first to implement an activity-based approach to link online ordering behavior to environmental injustices faced by communities. *Section 4.3* describes a four-phased methodology that calibrates a model utilizing public household travel survey data and estimates racial and socio-economic distributions of last-mile home delivery activity in 41 U.S. Metropolitan Statistical Areas (MSAs). *Section 4.4* presents the results, weighs the sensitivity of different operational decisions to mitigate bias, and demonstrates the model's utility by conducting a simple scenario evaluation across the model's two delivery segments: cargo van line-haul and a travelling salesperson problem (TSP). *Section 4.5* discusses analytical limitations, practical applications for private and public actors, and concludes with how future research can expand inquiry.

4.2 Literature Review

Modelling freight demand and trip generation enables researchers to project the distributional impact of offered transport/land use strategies to better inform equitable urban freight decision-making. It is especially applicable to last-mile delivery given e-commerce's growing influence on urban livability, form, and sustainability. Research around on e-commerce's impact on shopping-related travel patterns; spatial reordering of logistics land use and retail; last-mile delivery fleets, operations, and consolidation; and curbside management in dense urban areas (see International Transport Forum, 2022 for an overview).

However, equity research on ecommerce is nascent. Socially disadvantaged groups, including low-income households and POC (Figliozi & Unnikrishnan, 2021), order less and have low home-based accessibility to goods (see also Newing et al., 2022; Sanchez-Diaz et al., 2021). Simultaneously, these groups experience disproportionate exposure to van and truck-related externalities due to their unequal proximity to logistics facilities and infrastructure (Fried et al., 2024).

The following review summarizes the current state of demand modeling techniques in transport and urban freight literature and distills relevant insights to designing a modelling framework for evaluating equity in residential, last-mile delivery.

4.2.1 Activity-based models in transport equity evaluation

The most well-known modeling practice in transportation planning are activity-based travel demand models (ABM). ABMs are a spatial microsimulation that use household travel surveys

to represent the effect of transport conditions on individual- or household-level travel choice and activity (Castiglione et al., 2014). ABMs have steadily superseded conventional *four-step travel models* as a principal tool regional planning agencies implement to forecast travel demand and evaluate impacts of future transport investments, due to ABM’s ability to capture individual travel capabilities that zonal, four-step models otherwise obscure (Martens and Hurvitz, 2011). For this reason, ABMs have been widely adapted to evaluate equity in proposed transport programs, with numerous authors identifying best practices for researchers and practitioners (e.g., Bills and Walker, 2017; Castiglione et al., 2006; Karner and Niemeier, 2013; Martens and Hurvitz, 2011; Williams and Golub, 2017). Distilling these practical guidelines, this study identifies the most relevant “operational decisions” when designing an equity evaluation:

- *output metrics* that define or proxy the distributed cost/benefit;
- *equity indicators* that identify inequitable outcomes, reflecting a reasoned moral standard;
- *spatial units* by which to aggregate output metrics; and
- *population segmentation* that defines socially marginalized “target” groups by which to compare to a control group.

In terms of *output metrics*, most equity-oriented ABMs assess socio-spatial distributions and shifts in accessibility (i.e., n opportunities accessed via t time budget and j modal choice) to proxy for activity participation and social inclusion (Allen and Farber, 2020). To a lesser extent, researchers use ABMs to evaluate transport’s distributive environmental and safety impacts (Guo et al., 2020). In urban freight research, delivery vehicle miles traveled (VMT) has served as a base proxy for deriving many freight traffic-related externalities such as emissions, road deaths/injuries, or generalized costs (Cárdenas et al., 2017).

Most *equity indicators* reflect normative preference for absolute or “simple” equality, frequently captured by statistical difference in means tests (e.g., t-tests) between population segments or Gini indices between spatial units. Simple equality is sometimes referred to as the “default criterion for fairness” (Folger, 1996), requiring authors to argue the case when their reasoning normatively or empirically departs. Recent transportation planning literature, however, has adopted more nuanced, liberal egalitarian arguments (Pereira et al., 2017). For instance, Bills (2022) calculate individual difference densities in logsum accessibility—a relative,

distribution-based indicator—to evaluate proportional and Rawlsian equity in proposed transportation improvements in the San Francisco Bay Area. Nahmia-Biras and Shiftan (2020) draw on a Capabilities Approach (CA) to transport, which centers freedom of choice and well-being over need-based access to resources, and derive a value of capabilities metric that monetizes accessibility gains, which can then input into conventional cost-benefit analyses.

Some transport equity evaluations highlight the impact of the modifiable areal unit problem (MAUP), which can generate statistical biases based on the *spatial unit* selected for GIS analysis. In the U.S., spatial discrepancies manifest in the selection of Census-defined enumeration units, which ranges from transportation analysis zones (TAZ), to smaller tracts, and then block groups. There is sizable debate within environmental justice research on the most representative spatial or distance-based unit for estimating harmful proximity to environmental hazards (Baden et al., 2007; Chakraborty et al., 2011), with transportation researchers observing statistical discrepancies in the strength, significance, and (occasionally) sign of correlations across scales. For example, the case of disparate socio-economic and racial exposure to near-roadway traffic (Rowangould, 2013).

Population segmentation represents another source of variability. Analysts typically define target populations using cross-classified “social vulnerability” indicators (e.g., non-white, populations of color [POC] and/or low-income) and thresholds (e.g., incomes at $x\%$ below the regional mean), against a control group. Rowangould et al. (2016) compared public transport accessibility metrics across relative, absolute thresholds, population-weighting, and community-defined population segments and concluded the latter two segments to be most useful in evaluating equity for current and future transport conditions.

However, in the absence of community knowledge, equity evaluations should at a minimum address geographic and social biases by employing multiple equity indicators, spatial units, and population segments. The process encourages analysts to be deliberate about operational decisions that could otherwise appear arbitrary, or worse, purposely selected to achieve desired results.

4.2.2 Residential freight trip generation (RFTG)

With methodologies stemming largely from passenger ABMs and four-step models, freight trip generation (FTG) models the complex logistical decisions made by commercial agents in response to economic activity (Holguín-Veras et al., 2012). While most FTG models concern business-to-business freight flows, residential FTG (RFTG) models have emerged more recently to understand e-commerce's influence on consumer shopping/travel habits and external net-impacts. Residential delivery constitutes a sizable fraction of total urban commercial freight traffic volume, although modeled estimates range from a quarter (Sakai et al., 2022), a third (Wang and Zhou, 2015), to half (Holguín-Veras et al., 2021) depending on geographic context and/or model sophistication.

Freight models abstract a large degree of heterogeneity in agent behavior (Sánchez-Díaz, 2017). Households are core agents in e-commerce supply chains, with consumer behaviors largely affected by socio-demographics, commodity type, local built environment, and accessibility to shopping opportunities (Beckers et al., 2022; Sakai et al., 2022; Wang and He, 2021). The proliferation of retail omni-channeling (Buldeo Rai et al., 2019) and automated collection and delivery points (CDPs) (e.g., electronic parcel lockers) also means many online orders are delivered outside the home, adding a spatial mismatch that is unaccounted for in many RFTGs. As such, freight trip models implemented without ground-truthed calibration and/or supplementary, qualitative knowledge can lead to ecological fallacies (McLeod et al., 2019).

Data availability has also presented challenges (Buldeo Rai and Dabanc, 2022). Many RFTG models rely on extensive field data collection efforts (e.g., Rodrigue, 2017) or proprietary sources, such as GPS traces or travel logs from logistics providers (e.g., Cárdenas et al., 2017). Although these data are important for fine-tuned understanding of local delivery activity, they are difficult to obtain and findings often do not transfer across cases.

Nevertheless, RFTG has contributed valuable insights for understanding consumer travel and ordering behavior. Jaller and Pawha (2020) use publicly-available American Time Use Survey data to evaluate emission trade-offs between in-person versus online shopping behaviors and conclude emission mitigation is more sensitive to delivery's operational characteristics rather than simple substitution of one shopping behavior over another. Beckers et al. (2022) use socio-economic data and delivery pick-up location preference to forecast delivery trip frequency in a mid-sized Belgian city using an ordered logit model and a spatial microsimulation heuristic. Escand et al. (2018) use U.S. Postal Service (USPS) survey data to evaluate spatio-temporal

mismatch in supply/demand of curbside parking in commercial districts and residential neighborhoods in New York City.

However, this study does not observe any freight modeling research that assesses social inequities. Most pertinent to this study is the work of Wang and Zhou (2015), who presented an early effort to model and spatially analyze RFTG using the publicly available National Household Travel Survey (NHTS). The following methodology details how this study supplements the authors' preliminary approach by connecting to ABM techniques and operational decisions embedded in transportation equity evaluation.

4.3 Methodology

This paper draws on ABM and RFTG techniques to estimate current and future social inequities in residential, last-mile delivery. As discussed in *Section 4.2.1*, operational decisions taken in the analysis can greatly influence observed inequities. Therefore, *Fig 4.1* overviews the four-phased methodology, which builds off preliminary research by Fried et al. (2024). This paper adds to the previous study by formulating a replicable approach using predominantly open data/tools and expanding the analysis across 41 U.S. metropolitan statistical areas (MSAs). The approach additionally focuses the operational decisions undertaken in the equity evaluation and explores their analytical impact.

4.3.1 Phase 1: Delivery demand model calibration

Phase 1 concerns the calibration of the behavioral model that estimates person- and household-level demand for home delivery. The underlying dataset is the NHTS, conducted by the Federal Highway Administration in 2017. The survey asks respondents for the number of home deliveries received in the past 30 days. Wang and Zhou (2015) employed a nested binary choice and negative binomial (negbin) regression model to estimate residential freight trips at the zipcode-level in the New York State Capital District using the same dataset from 2009. Following Wang and Zhou, this study censors ordering frequency greater than 10 packages per month.

When observing monthly delivery frequency in the 2017 NHTS data, the most recent release at the time of the study, the authors find evidence of overdispersion ($\mu = 2.27$; $\sigma^2 = 8.85$), confirming a negative binomial count distribution, and excessive zero frequencies (42.8%). As

described by Sanchez-Diaz (2020), excessive zeros stem from two behaviors: a) the respondent does not order any parcels or b) order frequencies are so low, the respondent cannot recall the last delivery. Zero-inflated negative binomial (ZINB) model is, therefore, appropriate. ZINB models differ from conventional count models in that high incidences of zero outcomes are a result of two different processes: the logit-probability of an outcome occurring and its expected count frequency should the non-zero outcome occur. The mathematical relation follows:

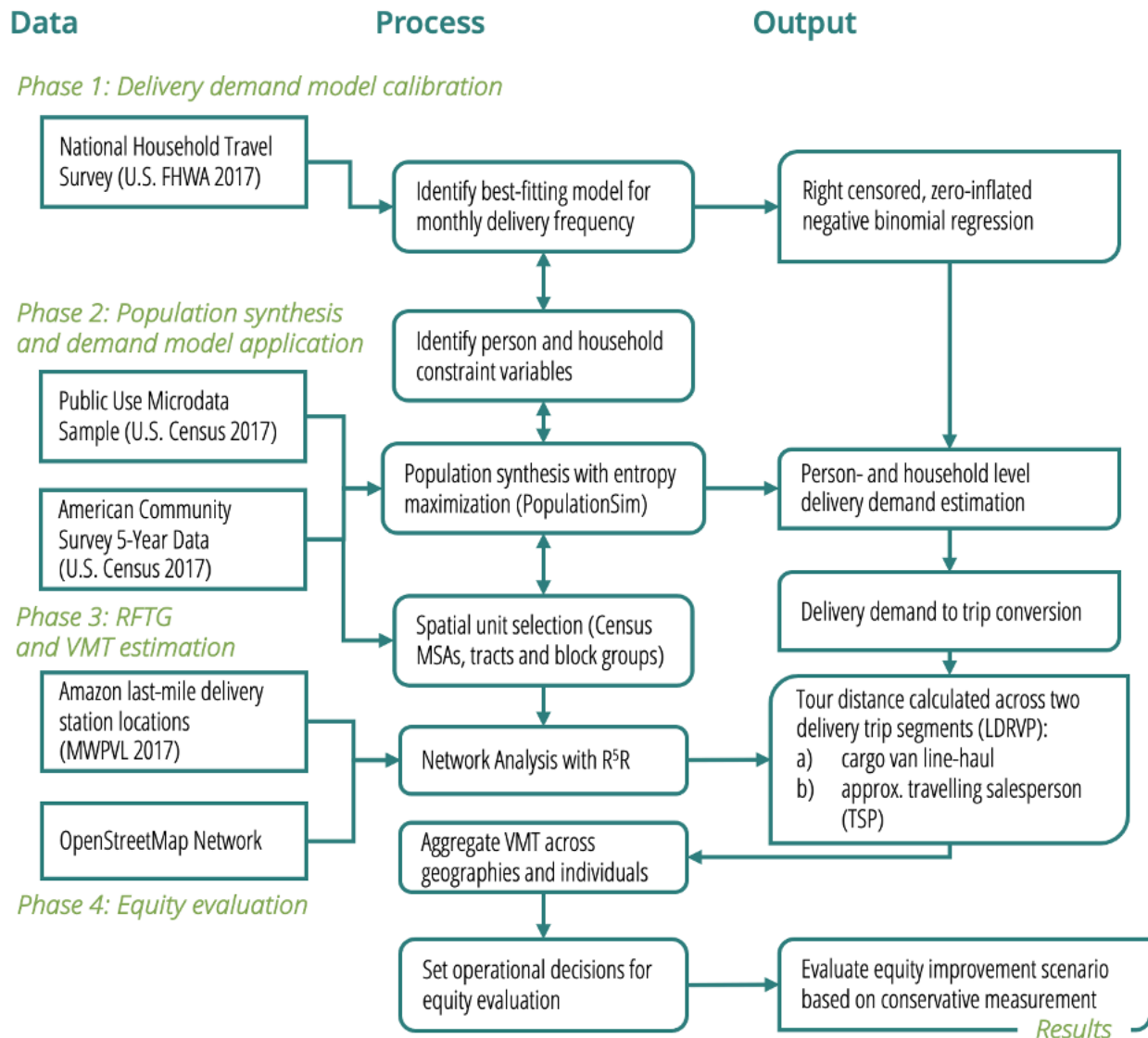


Fig. 4.1: Procedural overview of four-phased methodology

$$y_i = 0 \text{ with probability } p_i + (1 - p_i) \left[\frac{\frac{1}{\alpha}}{\frac{1}{\alpha} + \lambda_i} \right]^{1/\alpha}$$

$$y_i = y \text{ with probability } (1 - p_i) \left[\frac{\Gamma\left(\left(\frac{1}{\alpha}\right) + y\right) u_i^{1/\alpha} (1 - u_i)^y}{\Gamma\left(\frac{1}{\alpha}\right) y!} \right]^{1/\alpha}, y = 1, 2, 3 \dots 10$$

Equation 1 where:

y_i = parcels recieved in last 30 days

$u_i = (\frac{1}{\alpha}) / [(\frac{1}{\alpha}) + \lambda_i]$

$\lambda_i = e^{x_i \beta + \varepsilon_i}$ and β is a coefficient of independent variable x with standard error ε

α = dispersion parameter with Γ gamma function

Table 4.1 overviews the selected independent variables. The authors selected variables based on their prevalence as behavioral factors observed across e-commerce literature (Beckers et al., 2022, p. 301). The model inputs eight independent variables across three categories: household-level demographic constraints (income, size, and vehicle ownership), person-level demographic constraints (working age, sex, white/non-white race, and college-level education attainment), and a dummy indicator signifying high levels of urbanization. High urbanization signifies that a household occupies a tract with population density greater than 3,000 people per square mile, roughly one standard deviation (σ) above the mean (μ) population density in observed MSAs. NHTS also categorizes respondent incomes into 11 groupings at intervals ranging from “less than \$10,000” to “\$250,000 or more.” The model reclassifies income into *low* (<\$50,000), *middle* ($\geq$ \$50,000 and <\$150,000) and *high* ($\geq$ \$150,000), which most closely resembles one σ below and above the μ household income.

<i>Variable</i>	<i>% Relative frequency (% non-response)</i>	<i>Variable</i>	<i>% Relative frequency (% non-response)</i>
<i>Household constraints</i>		<i>Person constraints</i>	
<i>Income</i>	<i>(3.1)</i>	<i>Race</i>	<i>(0.5)</i>
high	13.1	white	82.1
middle	48.8	POC*	17.4
low	35.0	<i>Sex</i>	<i>(0.1)</i>
<i>Household size</i>	<i>(0.0)</i>	male	46.7
1	17.7	female	53.2
2	46.3	<i>Working age</i>	<i>(0.2)</i>

3	16.0	18-64 yro	66.5
≥ 4	20.0	no	33.3
<i>Vehicle ownership</i>	<i>(0.0)</i>	<i>College attainment</i>	<i>(0.1)</i>
yes	96.6	yes	44.3
no	3.4	no	55.6
<i>High urbanization indicator</i> (population density $\geq 3,000$ people per sq. mi.)			
yes	44.7		
no	55.3		

Table 4.1: Relative frequencies of unweighted, urban and demographic constraint variables, NHTS 2017 ($n = 235,771$). * POC includes respondents that respond with one or more Census-defined racial categories that do not include white, non-Hispanic.

Table 4.2 compares the coefficients (β) and standard error outputs from both the negbin and ZINB models. Using both maximum log-likelihood (LL) and Akaike Information Criterion (AIC) testing, the authors determine the ZINB model parameters possess a strongest fit than the negbin model. In the ZINB, all coefficient proved statistically significant at $\Pr(>|z|) < 0.01$, except the high urbanization indicator in the negbin portion that had weaker significance. The results confirm the inclusion of all person, household, and urbanization variables in both ZINB portions.

Income, race, working age, and college attainment proved particularly strong determinants in both expected frequency and zero probability of package ordering. For instance, the expected log change in ordering frequency would decrease 0.39 for low income households compared to high income income households, holding all other variables constant, while the log odds for an excessive zero would increase by 1.3. In other words, wealthier households, white, working age, and college educated individuals are more likely to order a package and at higher frequencies. The authors also tested interactions between these four variables, but found nominal LL improvements, low significance in the interaction terms, and no evidence for multicollinearity (using variance inflation factor testing). As such, the model does not include interaction terms.

<i>NEGBIN</i>	<i>ZINB</i>
---------------	-------------

	Negbin part				Logit part	
	β	<i>Std. e</i>	β	<i>Std. e</i>	β	<i>Std. e</i>
intercept	0.176***	0.023	1.117***	0.023	0.074	0.048
income[mid]	-0.252***	0.009	-0.192***	0.007	0.488***	0.027
income[low]	-0.738***	0.010	-0.386***	0.009	1.302***	0.028
household size	-0.024***	0.003	0.022***	0.003	0.146***	0.007
vehicle[yes]	0.270***	0.019	-0.096***	0.020	-0.719***	0.033
race[white]	0.287***	0.008	0.121***	0.008	-0.525***	0.017
sex[male]	-0.120***	0.006	-0.098***	0.005	0.406***	0.013
age[18-64 yro]	0.535***	0.007	0.240***	0.007	-0.908***	0.015
college[yes]	0.448***	0.006	0.160***	0.005	-1.051***	0.016
urban[yes]	0.031***		0.012*	0.005	-0.078***	0.014
log(θ)			0.636***	0.010		
α (1/ θ)	1.390				0.529	
L	-4.373e5				-4.267e5	
AIC	8.747e5				8.534e5	

Table 4.2: Results for both negbin and zero-inflated negbin models. Note: * = $Pr(>|z|) < 0.1$, * = $Pr(>|z|) < 0.01$**

4.3.2 Phase 2: Population synthesis and demand model application

Since the ZINB is calibrated using person- and household-level responses while demographic data is provided zonally. Therefore, this study synthesizes a population to derive residential freight trips from the underlying behavioral model. Population synthesis requires a microdata sample, assumed representative of the study area, and target constraints at the desired spatial level by which to control person and household variables (Lovelace & Dumont, 2018). The U.S. Census Bureau’s Public Use Microdata Sample (PUMS) provides a 5-year estimate of person and household data, providing weighted sampling of 10 percent of the population by Public Use Microdata Areas (PUMAs). The U.S. Census Bureau’s American Community Survey (ACS) provides constraint data (i.e., count totals) at smaller geographic areas (e.g., tracts and block groups).

While there are several heuristic algorithms that synthesize persons within households within zones, this study opts for an entropy maximization-based approach. PopulationSim is an

open-source package that synthesizes population weights while preserving the distribution of initial households weights, the base entropy, in the PUMS data. The tool then employs list balancing to match the geographic constraints. PopulationSim’s advantage is that it allows for relatively low deviations between the distribution of synthesized person/household variables, the seeded weights, and marginal controls. Moreover, PopulationSim has become a widely adopted tool by several transportation agencies in initializing regional ABMs and informing long-term mobility plans.

The population synthesis processes inputs from spatial units (PUMAs, tracts, and block groups) contained within the 41 sampled MSAs’ boundaries. The analysis selects MSAs based on the presence of at least one Amazon last-mile delivery station (LMDS) that was open in 2017 (the NHTS sample year).

After dropping NAs,⁴ the synthesized population contains 107.4 million persons in 52.7 million households. The authors then apply the ZINB to estimate delivery demand at the individual-level, which can be assigned and aggregated to various spatial units. On average, white individuals ordered 44% more packages per month than non-white individuals. Additionally, individuals belonging to high-income households ordered 45% and 174% more packages than their middle- and low-income counterparts, respectively.

4.3.3 Phase 3: RFTG and VMT estimation

This methodology expands on Wang and Zhou (2015) by assigning residential freight trips to the road network, which is critical in transport equity analysis given the high correlation between highway proximity and socially marginalized populations (Rowangould, 2013). This study uses the OpenStreetMap network.

Fig 4.2 overviews the 41 sampled MSAs, including select demographic characteristics and number of Amazon LMDS. LMDS facility location information was the only proprietary data source used, which the authors purchased from MVPWL International, a third-party logistics firm. LMDS are medium-sized facilities (or “depots”) that transload inbound trucks and outbound cargo vans that complete home deliveries. Trucks originate further up the urban distribution chain at regional sortation centers, air cargo hubs, or warehouses. Since there is greater uncertainty regarding warehouse origin, this study only analyzes the depot-to-consumer

⁴ The authors observed roughly 48.0 million, person-level NAs in the college attainment variable, approx. 24% of the sampled population. This observation is partly due to the coding of education-level for persons under 3 years-old as NA in the PUMS dataset.

portion of Amazon's distribution chain. Since the company is the preeminent online retailer in the U.S., Amazon's logistical decisions are assumed to be representative across the e-commerce space.

The analysis assumes home demand is fulfilled by the closest depot. As such, LMDS locations serve as the origins points for a local depot vehicle routing problem (LDVRP). Goodchild (2017) provides an approximated LDVRP formula (Equation 3), which is the sum of two segments:

- a) a two-way line-haul distance (d) between the depot and spatial unit (i) centroid and
- b) a traveling salesperson problem (TSP) distance for a given square-shaped, spatial unit area (A).

$$Total\ VMT_i = k\sqrt{A_i * D_i} + \frac{2D_i}{v}d_i$$

Equation 2 where:

k = constant approximating network geometry (0.92 for Manhattan distance)

D = number of customer households or residential freight trips

v = the mean cargo van capacity (i.e., load factor)

Applying the demand model generates an estimate for deliveries/packages (y), which does not necessarily equate to residential freight trips (D). Delivery drivers make several trips during a tour and may deliver several packages during a trip, e.g., for customers residing in an apartment complex. Therefore, this study uses the urbanization indicator to estimate housing unit size for higher and lower population dense areas, which is then used as a conversion factor between delivery demand and freight trips.

If population density for a spatial unit is less than 3,000 people per sq. mi, the authors assume a one-to-one equivalency between delivery and trip ($D=y*I$). That is, most non-urban customers live in single-family homes. Populations living in more urbanized areas are more likely to reside in apartment complexes. However, MSA populations ranged dramatically from New York City (19.9 million) to North Port/Sarasota, FL (732,300), leading to a large variance in average urbanized housing unit size. The study uses the *mode* urbanized housing complex in the synthesized population, two units. The conversion factor for urbanized spatial units equals the inverse ($D=y*0.5$). However, as Wang and Zhou (2015) note, the usage of conversion factors is likely to underestimate the number of freight trips, and more localized applications of RFTG should adapt the conversion factor to local housing density conditions.

Finally, the study calculates line-haul distances (d) using R5R, an open source, R-based network analysis package developed by Conveyal.

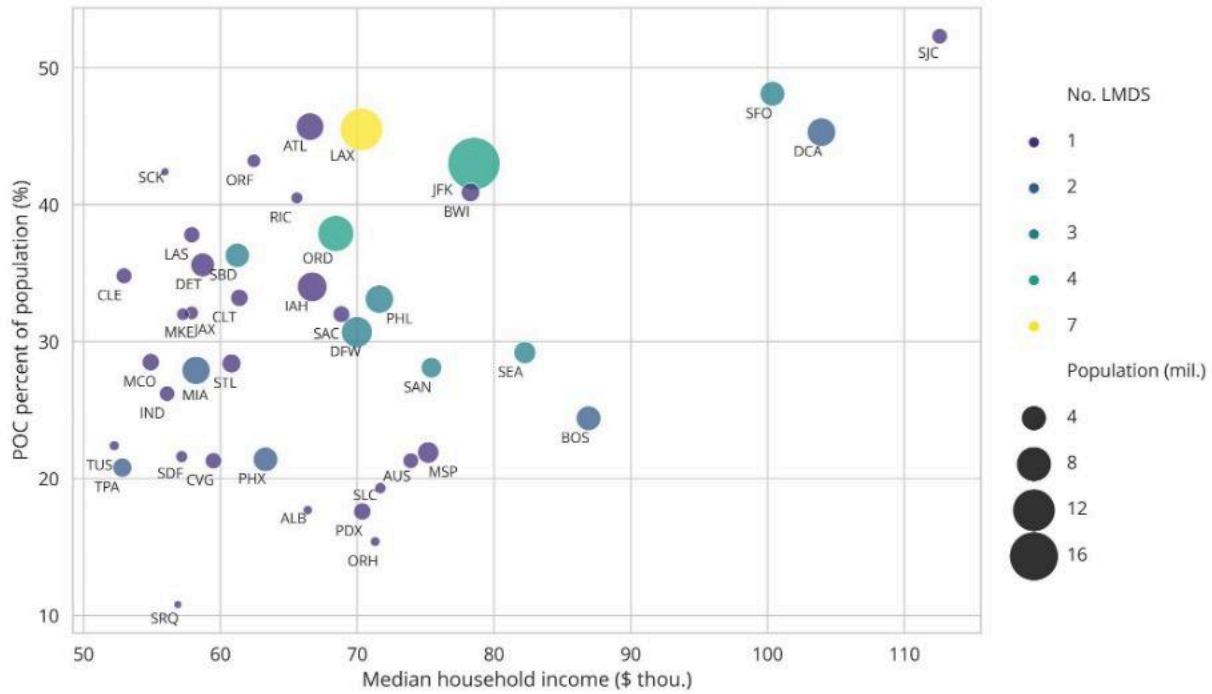


Figure 2: Sampled MSAs including select demographic information and number of Amazon last-mile delivery stations (LMDS). NOTE: MSA names shortened to the IATA code of largest city.

4.3.4 Phase 4: Equity evaluation

Phase 4 relates to the operational decisions this study undertakes to evaluate racial and socio-economic equity. The study generates measurements across geography and populations while controlling for geographic (i.e., MAUP) and social biases and weighs the sensitivities of the operational decisions against each other. The evaluation makes the following operational decisions:

- **Output metric** is delivery vehicle miles traveled (VMT). This study normalizes VMT by the area of the coinciding spatial unit (mi²).
- **Equity indicators** utilize statistical tests to define inequitable outcomes. This study adopts a default, simple egalitarian ethical standard, i.e., an outcome is inequitable if there exists *any* statistical difference across space and/or population groups.

- **Population segmentation** defines social marginalization as low-income (*low*) and non-white, POC based on three thresholds. However, rather than compare the target to a singular control group, which obscures ordinal differences between income, the evaluation compares population groups between each other. The thresholds include:
 - *Relative threshold*: one σ below the μ mean for income and more than $\mu\%$ non-white population, relative to the MSA. The relative threshold creates six groups (*LowPOC*, *LowW*, *MidPOC*, *MidW*, *HighPOC*, *HighW*).
 - *Absolute threshold*: less than 200% the federal poverty line for a two person household (\$32,480 in 2017) and with more than 40% POC population (roughly the national $\mu\%$ in 2017). The poverty threshold is often used to determine qualification for most public welfare programs. The absolute threshold creates four segments (*povertyPOC*, *povertyW*, *nonpovertyPOC*, *nonpovertyW*).
 - *Population-weighted*: uses the synthesized population and constraint thresholds defined during Phase 1 and 2. Rather than comparing populations between spatial units, such as for the threshold-based segments, population weighting compares delivery exposure between individuals. Population-weighting creates similar groupings to the relative threshold.
- **Spatial units** include both tracts and block groups. The evaluation tests two spatial proximity estimates:
 - *Unit hazard coincidence (UHC)*: is a spatial intersection between delivery routes and coinciding spatial units.
 - *Areal containment (AC)*: is a distance-based proximity estimate that joins spatial units if 50% of their area is contained within a buffer distance of a delivery route. Mohai and Saha (2015) present evidence for this approach's merits, including using a three km (1.86 mile) containment buffer that this study also adopts.

Since the methodology's utility derives from its applicability to evaluating equity in urban freight improvement scenarios, the secondary evaluation presents a cross-sectional analysis in which the study tests improvements in efficiencies for both the line-haul and TSP delivery segments. The study selects the most conservative measurement to utilize in the scenario evaluation.

4.4 Results

The operational decisions generate 12 measurements based on combinations of three population segments (relative threshold [RT], absolute threshold [AT], and population weighting [PW]) and four spatial units (tracts and block groups [bg] via unit hazard coincidence [uhc] and areal containment [ac] spatial joins). The following section compares the analytical sensitivities of spatial unit and population segment selection.

The LDVRP's treatment of line-haul and TSP delivery segments allows for useful applications to estimating the equity impact of urban freight management strategies for both public and private actors. As such, this section also presents a scenario evaluation that compares efficiency improvements to both segments.

4.4.1 Sensitivity of spatial unit selection

Spatial unit selection affects the observed distribution of cargo van VMT density across delivery segments. *Fig. 4.3* presents the histogram of the natural log-scaled output metric across tracts and block groups. AC and UHC spatial join types impact observed exposure to delivery's line-haul segment, whereas spatial geometries do not influence TSP distances. The line-haul's dependence on depot and road network geometries creates a large skew in the observed distribution. Spatial units near depot locations and/or major roads show substantially higher near-route exposure to line-haul VMT, while non-proximal units exhibit zero or near-zero exposure. Line-haul values of zero signify that all delivery trips contained within the spatial unit complete a delivery in said unit.

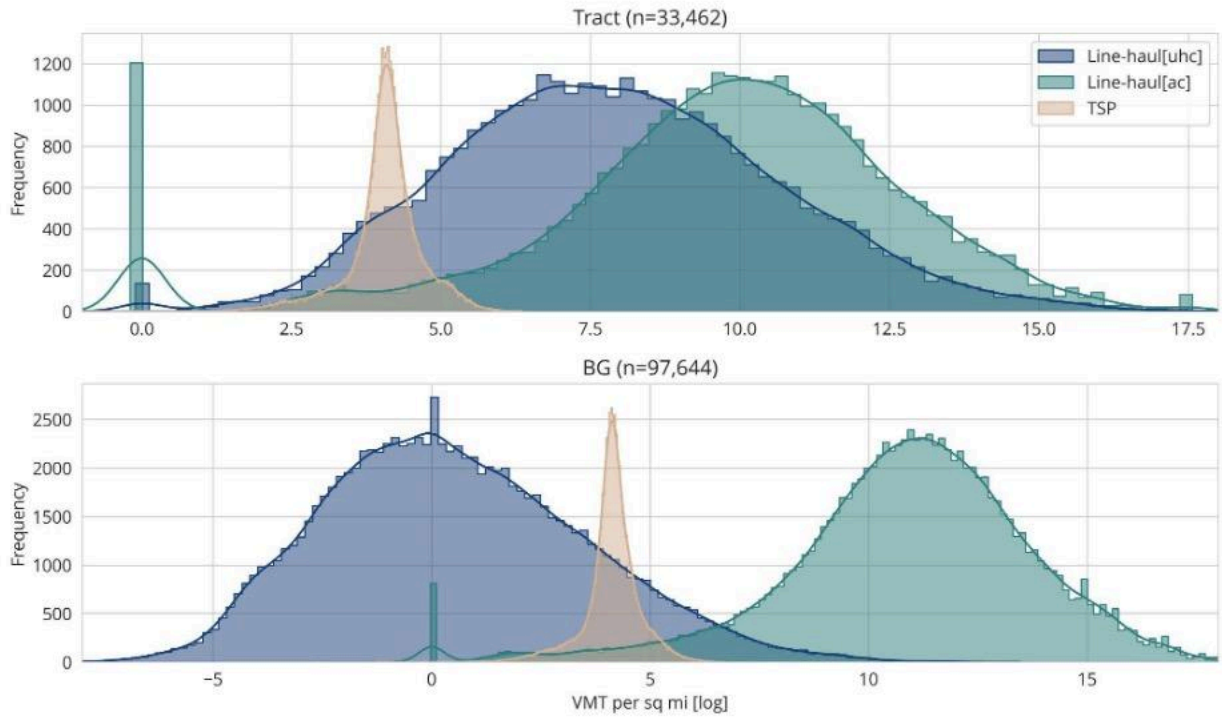


Fig. 4.3: Histograms of natural log-scaled cargo van VMT density by spatial unit and delivery segment, with smoothed density curve.

Aside from skew, line-haul shows substantially higher variance compared to TSP, which presents a normal distribution. As expected, TSP only accounts for a small fraction of total delivery VMT density compared to line-haul. Across spatial units and join types, TSP VMT constitutes less than 0.1% of total delivery VMT, with one exception. For block groups with join type UHC (bg.uhc), TSP constitutes 29.7% of total VMT. The explanation for this higher share is again geometric: bg.uhc spatially captures far less line-haul routes than larger tracts and the wider spatial join, AC.

High-incidences of zero values and line-haul and TSP discrepancies result from the spatial aggregation of delivery routes. AC catches more VMT than UHC, since delivery routes can only coincide with one unit at a time but contain multiple units. However, the empirical gap between UHC and AC joins is substantially larger for block groups than tracts. The percent difference between the two line-haul averages for tracts and block groups is roughly 75% and 200%, respectively. The mean line-haul VMT density for UHC joins is also substantially lower for block groups compared to tracts, as well as presenting a smaller variance. The mean line-haul density for bg.uhc is only 110% higher than its respective TSP density, while its median value is

much smaller. In other words, bg.uhc mitigates the discrepancy between line-haul and TSP VMT, while presenting less extremely high outliers and allowing for more stable comparisons across scenarios.

4.4.2 Sensitivity and significance of population segmentation

This subsection introduces population segmentation to the spatial metrics to explore statistical differences between target and control groups. *Fig 4.4* presents the socio-spatial distribution of total VMT per sq. mi across the 12 measurements. The figure orders the boxes by highest median to smallest, given the skew in the data, although the mean is also visualized. The target group median (*lowPOC* for RT and PW, *povertyPOC* for AT) is larger than all control groups in eleven out of 12 measurements.

The exception is the population-weighted bg.uhc measurement (PW.bg.uhc), in which *lowPOC* is behind *midPOC* then *highPOC*. This discrepancy links to the higher TSP share inherent to bg.uhc, which this study dissects further in the scenario evaluation. For now, it is important to note that PW.bg.uhc suggests that POC are still exposed to more cargo van VMT density than white populations, regardless of income. For PW.bg.uhc, POC are exposed to roughly 20% and 35% higher median and mean VMT density, respectively, than their white counterparts.

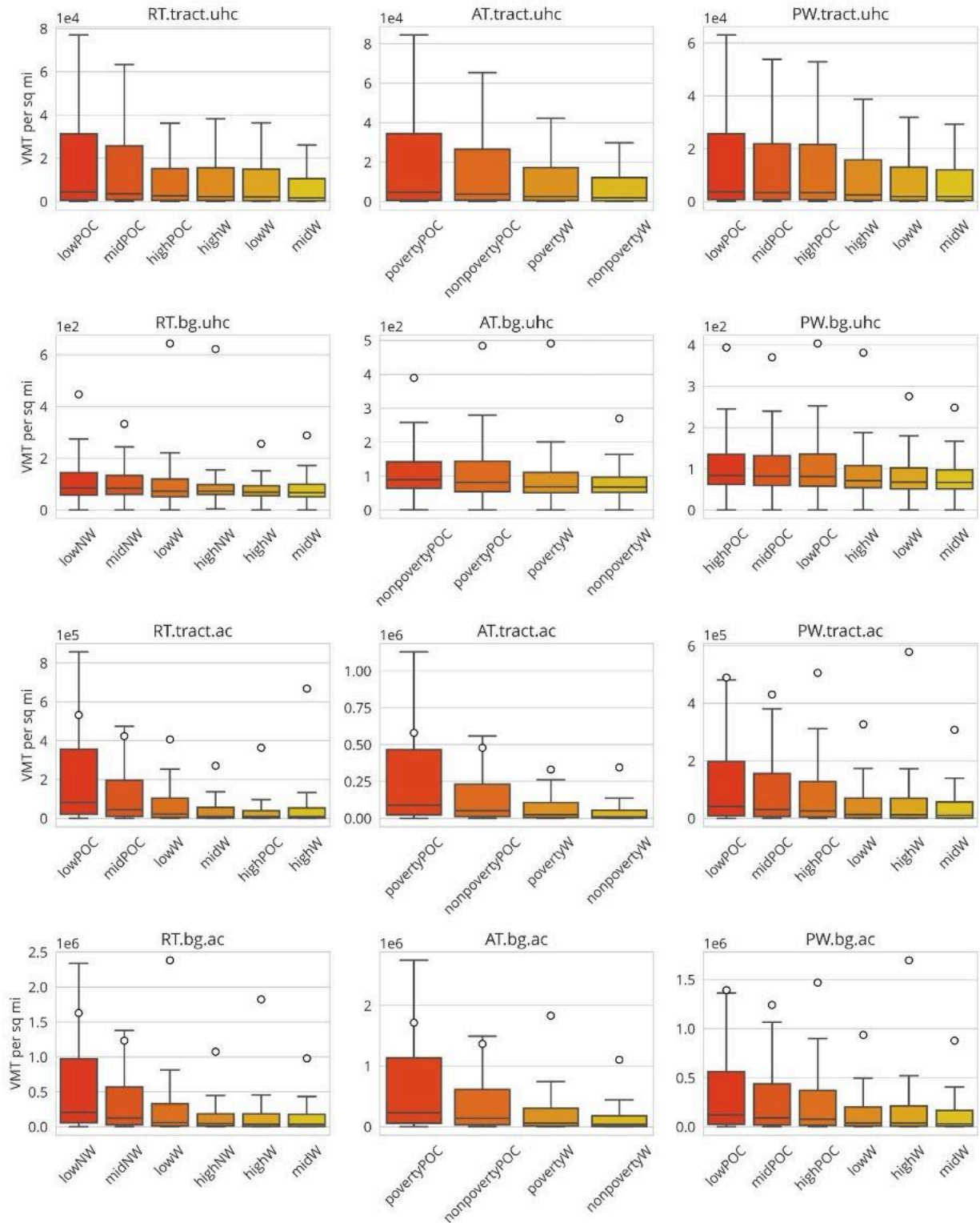


Fig 4.4: Boxplot matrix presenting the socio-spatial distribution of output metrics for all 12 measurements. NOTE: white dot represents mean value, which is too large to visualize in the top row.

Table 4.5 displays the percent change in medians between target and control groups and tests its significance. This study uses a non-parametric ANOVA by ranks test (Kruskall-Wallis H-test), in which the null hypothesis suggests no significant difference between group medians. All measurements rejected the null hypothesis, justifying the use of a post-hoc Dunn's test to compare differences between target and control subgroups.

The largest differences occur between the target and *highW/nonpovertyW* groups. Among RT/PW segments, these percent differences ranged from roughly 735% (RT.tract.ac) to 14.1% (PW.bg.uhc). Meanwhile, AT percent differences ranged from 727% (AT.tract.ac) to 20% (AT.bg.uhc). Generally, AC captured the widest relative differences between target and control groups compared to UHC. Results imply that AC methods are more sensitive to detecting spatial inequities, as observed by other scholars (Mohai and Saha, 2015). Moreover, the post-hoc Dunn's test confirms statistically significant differences between most target and control groups.

	<i>Target group</i>			<i>Control groups</i>							
	<i>me</i>	μ	σ^2	<i>hig</i>	<i>highP</i>	<i>mid</i>	<i>midP</i>	<i>low</i>	<i>nonpove</i>	<i>nonpovert</i>	<i>povert</i>
				<i>hW</i>	<i>OC</i>	<i>W</i>	<i>OC</i>	<i>W</i>	<i>rtyW</i>	<i>yPOC</i>	<i>yW</i>
	<i>d</i>			$\Delta\%$	$\Delta\%$	$\Delta\%$	$\Delta\%$	$\Delta\%$	$\Delta\%$	$\Delta\%$	$\Delta\%$
				<i>med</i>	<i>med</i>	<i>med</i>	<i>med</i>	<i>med</i>	<i>med</i>	<i>med</i>	<i>med</i>
RT.tract	4.4	2.6	5.7	91.6	62.5	156.	21.6	100.	-	-	-
.uhc	e3	e5	e12	%	%	0%	%	4%			
				***	***	***		***			
AT.tract	4.7	3.5	8.4	-	-	-	-	-	147.2%	28.3%	85.3
.uhc	e3	e5	e12						***		%

PW.trac	3.7	2.3	5.9	51.0	10.7	94.2	10.7	88.2	-	-	-
t.uhc	e3	e5	e12	%	%	%	%	%			
				***	***	***	***	***			
RT.bg.u	85.	44	2.0	23.1	17.4	26.7	2.4%	16.6	-	-	-
hc	6	7.0	e7	%	%	%		%			
				***	***	***		***			
AT.bg.u	81.	48	2.1	-	-	-	-	-	20.1%	-8.8%	17.9
hc	6	4.3	e7						***	***	%

PW.bg.	81.	40	1.9	14.1	-3.2%	20.7	-1.2	19.6	-	-	-
uhc	3	4.0	e7	%	***	%	%	%			

				***		***	***	***			
RT.tract	8.1	5.3	2.9	734.	682.7	662.	84.4	283.	-	-	-
.ac	e4	e5	e12	8%	%	2%	%	4%			
				***	***	***	***	***			
AT.tract	9.0	5.8	3.0	-	-	-	-	-	726.7%	68.7%	244.8
.ac	e4	e5	e12						***	***	%

PW.trac	4.2	4.9	4.8	237.	61.5	288.	33.8	206.	-	-	-
t.ac	e4	e5	e12	1%	%	4%	%	4%			
				***	***	***	***	***			
RT.bg.a	2.1	1.6	3.3	495.	363.7	498.	66.9	250.	-	-	-
c	e5	e6	e13	1%	%	8%	%	7%			
				***	***	***	***	***			
AT.bg.a	2.3	1.7	3.4	-	-	-	-	-	545.7%	63.5%	288.9
c	e5	e6	e13						***	***	%

PW.bg.a	1.2	1.4	3.6	212.	55.1	282.	33.0	207.	-	-	-
c	e5	e6	e13	4%	%	3%	%	9%			
				***	***	***	***	***			

Table 4.5: Target group summary statistics and median percent change between control groups, including post-hoc Dunn test results. NOTE: * = $p < 0.01$**

4.4.4 Scenario evaluation exploring efficiency improvements

As observed spatial inequities varied largely by the share of line-haul and TSP VMT across spatial units and population segments, the study proceeds with a scenario evaluation that explores the equity impacts of altering both delivery segments. The analysis utilizes PW.bg.uhc, as it presents a more conservative estimate across spatial units and population segments. The analysis constructs a simple scenario in which efficiencies of the cargo van TSP and line-haul segments of the LDVRP are improved by 25%, *scenario 1* and *scenario 2* respectively. Since line-haul distances constitute a substantially higher proportion of total VMT, the evaluation compares percent differences between the two scenarios rather than raw VMT savings. Moreover, comparing individual difference densities grants nuanced insights into the distribution of impacts across target/control groups (Bills, 2022; Bills and Walker, 2017).

Fig 4.5 displays the cumulative distribution of percent change in total VMT density across the two scenarios. Since *Section 4.2* finds statistically significant differences between

POC and white populations, regardless of income, the evaluation redefines the target group as all POC individuals. Slightly less than half the target and control population are equally benefited by scenario 1. Since TSP VMT is normally distributed and line-haul VMT constitutes a greater share of total VMT, the control group receives higher marginal benefit from scenario 1. The inverse is true for scenario 2. Roughly half of the target group population receives outsized benefit from line-haul efficiency improvement.

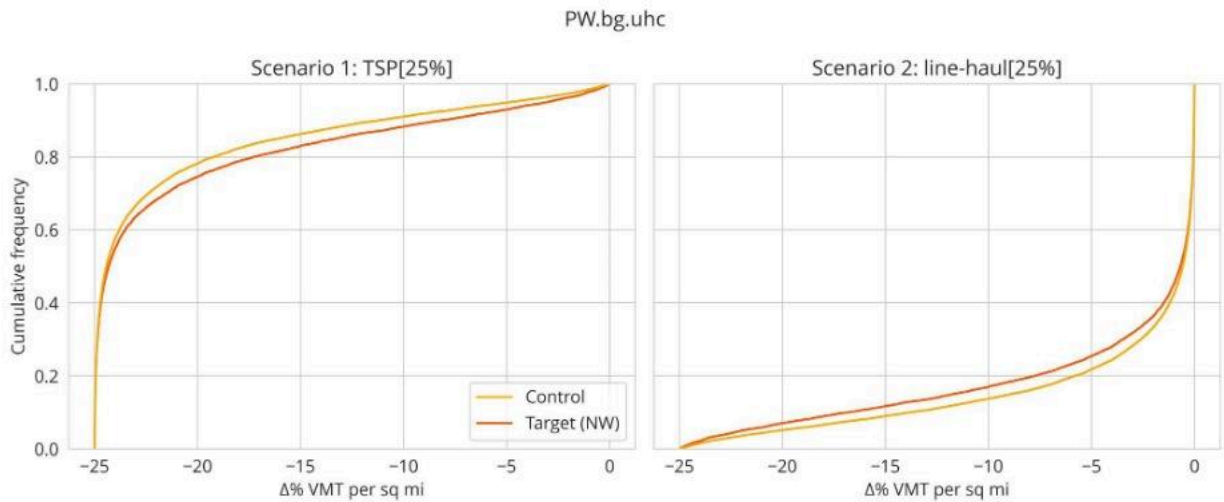


Figure 4.5: Scenario impact on cumulative frequency of change in VMT density for target and control groups

Table 4.6 validates mean differences in percentage change of VMT density across scenarios and groups using a Welch's t-test. The target group's average percentage change is only 3.4% lower than the control group in scenario 1, but 16.7% higher in scenario 2. Both differences are statistically significant, the test rejects the null that VMT savings for target and control populations are equal. However, while the target group's mean percentage change equates to 7.4 delivery miles saved *per sq. mile per person per month* in scenario 1, scenario 2 equates to 75.7 miles saved.

While TSP and line-haul improvement create equal benefits for many, the scenario evaluation confirms that POC receive significant, outsized benefits from strategies that improve delivery line-haul efficiencies compared to those that only improve TSP efficiencies.

	<i>Target group (POC)</i>				<i>Control group</i>				<i>Welch's t-test</i>
	<i>med</i>	μ	<i>range</i>	σ^2	<i>med</i>	μ	<i>range</i>	σ^2	<i>H0: target=control</i>
<i>Scenario 1</i> <i>TSP[25%]</i> <i>]</i>	0.0	-7.8	-25.0- 0.0	118.2	0.0	-8.1	-25.0- 0.0	121.9	<0.001***
<i>Scenario 2</i> <i>line-haul[</i> <i>25%]</i>	-0.6	-4.2	-25.0- 0.0	46.6	-0.5	-3.5	-25.0- 0.0	38.1	<0.001***

Table 4.6: Comparing summary statistics of percent VMT density change between scenarios and groups

4.5. Discussion & Conclusion

Evaluating 12 measures across varying population segments and spatial units, the study finds robust statistical evidence for racial and socio-economic inequities in last-mile deliveries for low-income and, especially, POC. By the most conservative estimate, POC are exposed to approximately 35% more cargo van traffic than white populations, despite ordering 44% less packages on average.

Differences between indicators are substantial enough that researchers should take care when making operational decisions that evaluate equity. For instance, the median difference in observed traffic exposure between low-income POC and high-income white populations is up to *50-times higher* for the most sensitive measurement compared to the most conservative one.

While the analysis mitigated typical geographic and social biases found in equity evaluation, such as MAUP and those arising from population segmentation, some limitations persist.

4.5.1 Limitations

First, analyzing inequities in cargo van distribution magnifies a highly visible sliver of a regionally interconnected and often opaque supply chain. Middle-mile commodity flows between regional logistics facilities is largely under-studied in urban freight literature (Tejada

and Conway, 2022). Considering many warehouses and distribution centers have historically located and continue to open in socially marginalized neighborhoods (Yuan, 2018b, 2018a), excluding inter-terminal truck flows obscures further observations of social inequity.

Data availability also constrained the study to 2017. U.S. online sales have grown by approximately 80% since then (U.S. Department of Commerce, 2023). In addition to pushing consumer shopping toward online and omni-channel retail, COVID-19's lingering behavioral effect on consumption also impacted the spatial ordering of urban logistics land uses (e.g., the emergence of “dark stores” and “micro-fulfillment centers”). Meanwhile, Figliozi and Unnikrishnan (2021) find online shopping has not increased equally across populations: wealthier and white households have ordered far more since the pandemic's start than low-income and POC households.

4.5.2 Application to private operations and public policy

The scenario evaluation demonstrates that efficiency improvements to delivery's line-haul segment presents outsized or higher marginal equity benefits than improvements to the TSP segment (see *Fig 4.6*). Enacting public policy and or private operations that redistribute or reduce traffic near warehouses and between delivery zones (i.e., distribution-oriented solutions) would have outsized equity benefits than those that consolidate delivery demand inside neighborhoods (i.e., consumer-oriented solutions), such as by curbside management and short-ranged cargo e-bicycles. Since these latter strategies require high consumer density to be cost-effective and operationally efficient (Katsela et al., 2022), they are usually not implemented outside denser residential neighborhoods with more frequent online shoppers.

The model also suggests zoning and development of warehouses and other logistics land uses present mixed efficiency and equity concerns based on their proximity to populations. Holguin-Veras et al. (2021) presents a case in Albany (New York) where the siting of an e-commerce distribution center in an exurban area added 800,000 additional VMT per year than an alternatively proposed site located closer to the city center. While it is possible that the exurban location avoided higher population concentrations, the siting traded-off operational inefficiencies that created region-wide externalities and for populations residing along the highway corridor. More centrally located urban distribution centers can build infrastructure to

buffer nearby communities from negative externalities associated with “proximity logistics” (Buldeo Rai et al., 2022).

However, if new facilities continue to open in socially marginalized neighborhoods the model would observe less marginal gain in racial equity. One application of this model would be to evaluate the distributional impact of changes in logistics land use, such as through proactive zoning policies or by integrating delivery depots into the urban fabric closer to more consumer dense neighborhoods.

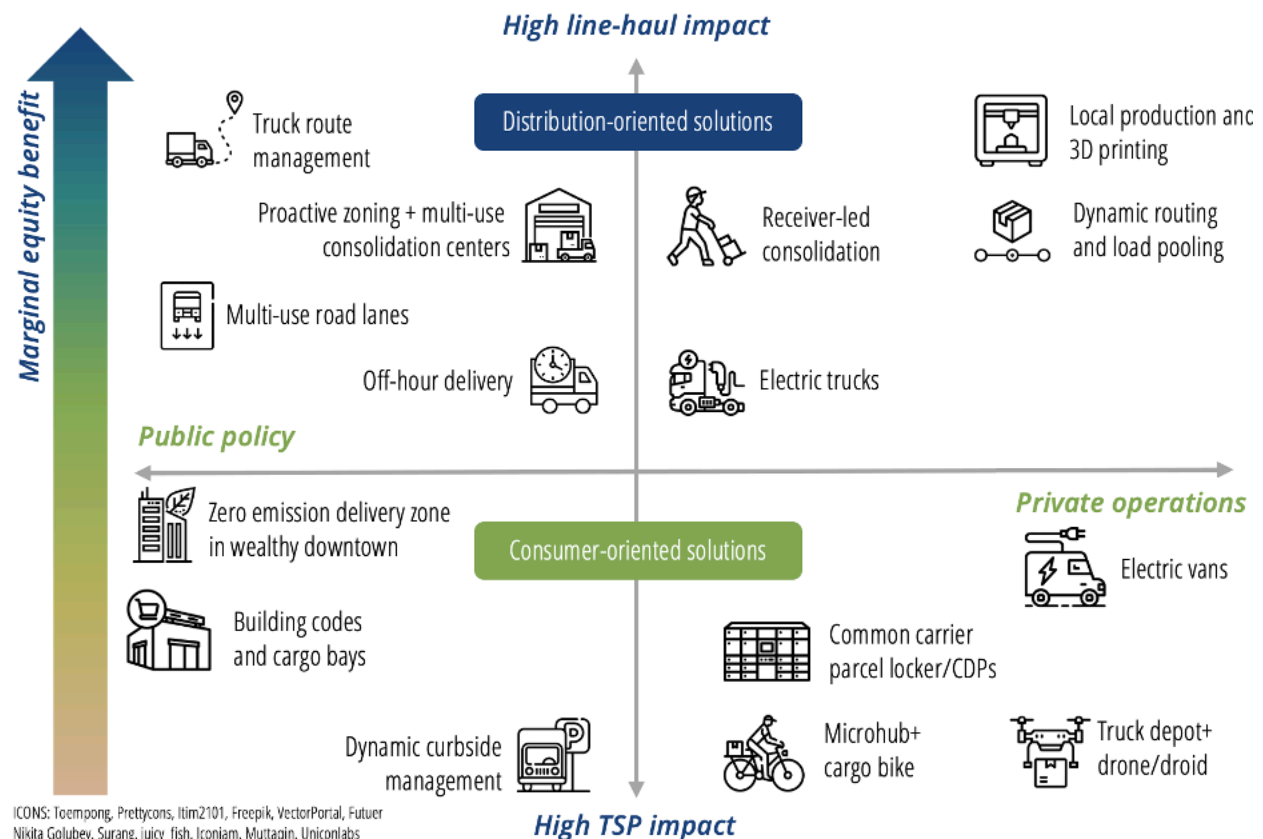


Fig 4.6: Hypothetical evaluation framework for select urban freight operations and policy strategies.

Parcel lockers are another example of this geographic trade-off. Parcel lockers reduce delivery VMT by eliminating the door-to-door milk run portion of the delivery tour. However, Schaefer and Figliozzi (2021) find that parcel lockers follow a consumer-oriented distribution that leaves cold spots in Portland’s (Oregon) socio-economically marginalized and predominantly Hispanic neighborhoods. Evaluating equity in such a spatial system would show

traffic reductions in wealthier and predominately white neighborhoods, while leaving traffic in the former neighborhoods virtually untouched.

4.5.3. Conclusion

The rise of e-commerce paralleled growing recognition of the need to sustainably manage and decarbonize urban distribution. But by failing to consider equity, companies and cities risk further entrenching historical injustices and excluding socially marginalized communities from the low-emission benefit that many innovative and sustainable urban freight practices intend to provide. While these practices can benefit all populations, solutions that prioritize efficiency improvements in upstream distribution have outsized benefits for marginalized populations. However, the subsequent discussion demonstrates that equitable urban freight practice carries nuanced geographic implications based on where and how logistics land uses spatially organize in metros.

This paper presents a first, systematic modelling approach to informing more equitable and data-driven urban freight policy and operations. The authors designed the methodology with replicability and scenario planning in mind, relying on public household travel data and adapting ABM modelling techniques. However, future work should further define model and evaluation parameters to meet local social conditions and needs. Researchers should calibrate localized models with ground-truthed traffic and survey data to mitigate the occurrence of ecological fallacies. Finally, public participatory approaches and citizen science can help ensure that evaluation outcomes reflect community priorities.

Chapter 5: Logistics Sprawl and Spatial Equity

ABSTRACT: Populations of color (POC) are disproportionately exposed to delivery-related traffic despite ordering fewer packages than White populations. This study uses structural equation modeling (SEM) to examine which urban form and socio-economic factors contribute to these racial disparities in 39 U.S. metropolitan statistical areas (MSAs). Of particular interest is “logistics sprawl,” which has lengthened distances between freight supply and demand. Prior research links sprawling urban form to the uneven distribution of externalities, social deprivation, and accessibility. This connection remains underexplored in urban freight research. Findings point to a significant spatio-racial mismatch between delivery supply and demand. In fact, a 1-mile reduction in mean last-mile delivery distance is associated with 1.9% decrease in externality disparity. However, racial segregation, social capital, and supply chain centrality fully mediate and condition the equity benefits of more logistically compact urban form, or “proximity logistics.” Though promising, urban freight management strategies alone cannot address environmental inequities without confronting the underlying socio-economic and political structures that reproduce them.

5.1 Introduction

Populations of color (POC) are disproportionately exposed to delivery-related traffic despite ordering fewer packages than White populations (Fried et al., 2024b, 2024c). It is not the neighborhoods with the highest online shopping demand that receive the lion-share of delivery traffic, but those in proximity to warehousing and distribution centers (W&D) and highways that respectively supply and channel resulting delivery trips. In other words, racial disparities in exposure to delivery traffic is intrinsically linked to the spatial organization of people, logistical facilities, and infrastructure—i.e, urban form.

Addressing racial disparities in traffic exposure most readily speaks to environmental justice (EJ) scholarship (Antoncjak et al., 2023). EJ scholars measure Black and Hispanic Americans’ disproportionate exposure to freight traffic-related air pollution (Demetillo et al., 2021; Kerr et al., 2024; Lathwal et al., 2022; Marshall et al., 2014), hazardous materials spills (Schweitzer, 2006), injuries and fatalities from vehicle crashes (Yuan and Wang, 2021), and noise (Yildirim and Arefi, 2021). The urban formation of logistics networks may be stronger

determinants of these disparities than commonly studied operational factors, including electrification. For instance, Ramirez-Ibarra & Saphores (2023) show that even if diesel drayage trucks electrify in-line with policy targets, state-identified disadvantaged communities could still bear 68% of truck pollution-related mortality in Southern California.

The persistence of disparities is not isolated to environmental quality. Few systems in the urban and market environment, including transport logistics, center fairness as the leading design principle. Schweitzer and Stephenson (2007) note researchers' tendency to decouple EJ from social and economic theories of urban inequality—be that residential sorting (Banzhaf et al., 2019), political economy (Smiley, 2020), or agglomeration (Bowen et al., 2009)—which they akin to “decanting old wine into new bottles” (p. 328). In any case, a robust accounting of environmental disparities requires an accounting of the urban spatial structures that underpin them.

Studies that identify environmental disparities without contextualizing these underpinnings risk offering or implying reductive solutions to complex problems. For example, banishing W&D to the sparsely populated hinterlands might seem a natural solution to minimizing freight traffic disparities in the city. However, relocating W&D from the urban center to the suburban outskirts has also generated unintended socio-economic and environmental consequences (Aljohani and Thompson, 2016; Holguín-Veras et al., 2021).

Furthermore, this study inspects relevant spatial and socio-economic factors that shape racial disparities in e-commerce-related delivery externalities. Of particular interest is “logistics sprawl,” or the suburbanization of freight-intensive activity. Researchers link sprawling urban form to the uneven distribution of external costs, social deprivation, and accessible opportunities (Wei and Ewing, 2018). This linkage has not been made in urban freight research (Fried et al., 2024a), despite the relevance of logistical urban form in generating unequal exposure to freight trips. This study tests if logistically compact delivery areas are more racially equitable. It also contributes insights from the urban and regional sciences by exploring the effects of residential segregation, supply chain centrality, and social capital.

The following literature review highlights key features in our understanding of urban freight and EJ, centering e-commerce delivery as a rising freight segment and case for environmental inequity (*Section 5.2*). The review identifies covariates in a generalized structural equation model (SEM) that cross-sectionally examines racial disparities between online ordering

and delivery traffic exposure in 39 U.S. metropolitan statistical areas (MSAs) (*Section 5.3*). The results show logistically compact delivery service areas are more racially equitable, but high segregation, social capital, and supply chain spread fully mediate its effect (*Section 5.4*). Findings contribute to discussions around “proximity logistics,” or policy and operational strategies that reduce last-mile distances, with implications for urban planners that seek to center equity in transport and land use decisions (*Section 5.5*).

5.2 Theoretical review

Freight is a product of spatio-economic and political structures that sort populations and businesses within and between regions (Anas et al., 1998; Giuliano et al., 2018; Hesse, 2020). As people, firms, and infrastructure are not uniformly sorted in space, freight activity inevitably concentrates in some areas more than others. Coasian economic perspectives suggest freight-intensive firms bargain with communities who accept compensation (usually jobs) in exchange for disamenities like pollution (Banzhaf et al., 2019). Efficient outcomes assume not only zero transaction costs, but arguably also perfect information of externalities and local sovereignty over environmental decisions.

In practice, however, symmetry in information and power is far from the norm. Firms may systematically locate W&D in communities with the lowest bargaining power due to an array of social, political, and economic conditions (Ataullah et al., 2023; Bullard, 2000; Cole and Foster, 2001; Maantay, 2002; Mohai and Saha, 2015; Schelly and Stretesky, 2009). This section does not revisit decades of scholarship that concern U.S. urban development and its racially disparate impact. Rather, it builds a baseline understanding of urban freight and racial inequity, three key covariates (segregation, sprawl, and social capital), and e-commerce as a contemporary case study.

5.2.1 Segregation

Longitudinal analyses link unequal pollution exposure to racial and income-based housing segregation (Shertzer et al., 2022), with debates largely concerning the extent to which exclusionary policy and/or real estate markets serve as the sorting mechanism. Competing hypotheses, “disparate siting” versus “post-siting demographic change,” concern whether

polluting land uses move toward residents or *vice-versa* (Mohai and Saha, 2015 cf. Been, 1994). Finding notable evidence for the former, Maantay (2002) reveals a history of “expulsive” industrial zoning that contributed to the encroachment of manufacturing facilities into predominantly Black neighborhoods in New York City. Whittemore (2017) applies Maantay’s methodology to Durham (North Carolina), reconfirming a pattern of disparate heavy industry siting in Black communities. However, the Durham study concludes with hope: much of the heavy industrial zones that historically burdened marginalized communities have been “downzoned” into lighter industrial land uses.

However, as manufacturing offshored and the U.S. transitioned to a globalized economy, factories and assembly lines gave way to distribution centers and sorting conveyors (Cidell, 2011; Hesse, 2020). W&D typically classify as light industrial land uses and are permitted with less environmental oversight than their more visibly noxious progenitors (Fried et al., 2025). A growing body of work has investigated patterns of disparate W&D siting (Tejada and Conway, 2024; Jaller et al., 2022; Yuan, 2018), and its environmental impact on adjacent communities due to the high volume of freight traffic these facilities generate (Kerr et al., 2024). DeSousa et al (2022) find mixed effects of W&D density on various health costs but still show substantial disparities for low-income and Hispanic populations in Southern California. As such, disparate W&D siting presents an emerging context for environmental inequities faced by racially marginalized populations today.

The mechanisms driving these patterns remain largely unexplored, particularly as it relates to residential segregation. Research links segregation to the concentration of intergenerational poverty within cities (Massey and Denton, 1993) and within the context of urban sprawl (Wei et al., 2023; Wei and Ewing, 2018), and to environmental disparities (Prasanth et al., 2024). While the spatial severity of racial segregation has somewhat lessened since the apartheid-levels of the early-to-mid 20th Century, its structural effects persist across geographies and institutions.

5.2.2 Sprawl

The outward expansion of people and firms is a focal point of urbanist debate. Research generally finds sprawled metropolitan areas are more emission intensive due, in part, to the greater spatial distances between residences and opportunities that lead to higher rates of private

vehicle travel (Jones and Kammen, 2014). Most studies that examine the movement of W&D away from urban centers reach similar conclusions regarding freight transport's increasing vehicle miles traveled (VMT) and emissions (e.g., Dablanc and Rakotonarivo, 2010).

However, urban sprawl's multi-dimensionality helps it elude first-order definitions and causations (Brueckner et al., 2001; OECD, 2018). In that sense, "logistics sprawl" presents a narrow expression of broader spatio-economic and political processes that concern locational decisions made by people and firms. Research has enriched our understanding of logistics sprawl by comparing indicators of economic agglomeration (Kang, 2020a, 2020b; Rivera et al., 2014; Rivera-Gonzalez et al., 2023), or using GPS traces from trucks to validate measures (Trent and Joubert, 2022).

These approaches paint a nuanced picture of logistics sprawl's relationship to metropolitan economies and environmental impact. For instance, Sakai et al. (2017) find decentralizing demand offsets VMT generated by sprawling W&D in Tokyo. Logistics sprawl may well be an efficient response to the sprawl of people and businesses. Gardrat (2021) suggests increasing freight-related VMT is a result of two distending forces in Lyon, France: the sprawl of freight emitting activities and the densification of freight consuming activities. Other cities do not exhibit logistics sprawl at all (Dablanc et al., 2014), or show signs of logistics centralization or "anti-sprawl" (Krzysztofik et al., 2019). Nevertheless, it may be difficult to extricate the forces that create *logistics* sprawl from those that create *urban* sprawl.

In the latter case, "Smart Growth" and "New Urbanist" researchers have increasingly analyzed the equity benefits of compact urban development. For instance, researchers have linked urban sprawl to greater inequities in income (Lee et al., 2018), air pollutant-related cancer risks (Tsoulou, 2018), social capital (Nguyen, 2010), and socio-economic mobility (Ewing et al., 2016). Environmental disparities may be less pronounced in compact urban environments, though this relationship is likely indirect.

5.2.3 *Social capital*

Putnam (2001, p. 9) famously defines social capital as "connections among individuals—social networks and the norms of reciprocity and trustworthiness that arise from them." Scholars typically conceptualize social capital as a form of resource conversion (Bourdieu, 1986), much

like factories produce physical capital or education creates human capital, and as a rubric for community governance and collective action (Bowles and Gintis, 2002; Ostrom and Ahn, 2009). Mainly, social capital refers to a community's ability to leverage social ties—both within and between groups—to achieve mutually beneficial outcomes.

One major EJ theory suggests pollution follows a “path of least resistance” (Bullard, 2000; Cole and Foster, 2001; Pastor, 2004; Schelly and Stretesky, 2009). Firms may locate W&D based on the ability of high-capital neighborhoods (presumed to be high-income, well-educated, predominantly White and homeowners) to deflect them from their backyards, and/or the inability of low-capital neighborhoods (conversely presumed to be low-income, less-educated, and predominantly Black or Hispanic) to resist them in theirs.

Nevertheless, evidence of the linkage between social capital and pollution disparities is nuanced. Ataullah et al.'s (2023) longitudinal, county-level analysis of carcinogenic waste finds high social capital can reduce certain toxic releases and facility siting, but its influence diminishes when the polluting industry plays a large role in the local economy. Ard & Fairbrother (2017) and Smiley (2020) find that not all forms of social capital are associated with pollution disparities, nor are racial minority or low-income communities always poor in social capital. Moreover, pollution may have a reverse effect on social capital—high exposure can itself corrode collective efficacy (Brown, 2022).

Operationalizing social capital's multi-dimensional complexity remains a central challenge. Researchers may produce divergent findings on social capital due to the varied definitions, proxies, and latent constructs they employ to measure it (Gannon and Roberts, 2020). For instance, Fraser et al. (2022) draw from the American Community Survey to derive bonding,

bridging, and linking indices that explain up to 49% of variation in COVID-19 outcomes, whereas Chetty et al. (2022) use Facebook data to link economic connectedness with upward socio-economic mobility. Nevertheless, the prominence of social capital in sociological theories of urban inequality—and its limited exploration in studies of traffic exposure disparities (Schwanen et al., 2015, p. 131)—warrants closer examination.

Furthermore, this analysis examines whether logistics sprawl—or its counterpoint, proximity logistics—can help explain racially disparate e-commerce externalities.

5.3 Methodology

This study estimates online ordering behavior and consequent residential freight trip generation using an activity-based model that draws on the 2017 National Household Travel Survey and Amazon facility locations. Fried et al. (2024b) detail the methodology and limitations of the approach. The study models and analyzes the distribution of cargo van VMT across race and income groups in 41 MSAs in 2017. This paper adds to their methodology in two ways. I calculate the “middle-mile” VMT by trucks between sortation centers (SC) and last-mile delivery stations (LMDS), and I introduce fixed external cost coefficients. The following sections describe the added steps and building the SEM.

5.3.1 Adding middle-mile truck flows and calculating costs per package-mile

LMDS serve as final touchpoints for most forms of urban home delivery (Fried and Goodchild, 2023). We assume diesel cargo vans exclusively serve the last-mile. Although Amazon has accelerated their procurement of electric vans (Amazon, 2023), data inputs constrain the analysis to years prior to these investments. Moreover, a substantial degree of observed inequity between racial groups occurs due to the middle-mile movement of trucks between LMDS and SC (Fried et al., 2024c).

Therefore, this study estimates the two-way VMT of truck flows between the two facilities. Most MSAs have one SC; however, six do not at the time of the observed data. In these cases, the

analysis assumes truck trips originate from a point near the MSA’s largest airport (Rodrigue, 2020). Similar to Fried et al. (2024b), the network analysis implements the open-sourced R5R package and makes static assumptions regarding vehicle utilization (see Fried et al., 2024c).

Carriers also transport packages on a diverse range of infrastructures—from quiet residential streets to congested inter-state highways—which generate distinct costs (*see Table 5.1*). Most U.S.-based cost estimates do not differentiate between vehicle classes nor urban road typologies (Demir et al., 2015), presenting difficulties when attempting to model the external costs of e-commerce. Cárdenas et al. (2017) develop external cost indices for home delivery in Belgium, which this study adapts. This study defines a block group as an “urban road type” if its population density is more than one standard deviation above the MSA mean (~3,000 people/sq. mi), and a delivery trip terminates or passes through it. The analysis also determines middle-mile truck flows occur mostly on inter-state and regional highways (Essen et al., 2020).

EU diesel emissions standards and road conditions are not equivalent to those in the United States. However, it is beyond the scope of this study to validate the *aggregate* results of external cost calculations. Rather, the subsequent model seeks to explain the *distribution* of these costs between populations.

	Road type	Air pollution	Crashes	GHG emissions	Noise	Congestion (delay)	Total avg. cost
Cargo van	<i>Urban</i>	<i>1.72*</i>	<i>2.67</i>	<i>1.54*</i>	<i>0.04***</i>	<i>23.81</i>	<i>29.80</i>
	<i>Suburban</i>	<i>1.65*</i>	<i>2.67</i>	<i>1.30*</i>	<i><0.00**</i>	<i>16.80****</i>	<i>22.42</i>
*							
Truck	<i>Highway</i>	<i>0.45**</i>	<i>0.58</i>	<i>0.53**</i>	<i>3.73***</i>	<i>1.91</i>	<i>7.20</i>

Table 5.1: Static external cost coefficients (\$-cents/package-mile) and assumptions (adapted from Cárdenas et al., 2017; Essen et al., 2020). NOTE: *Euro V, diesel light goods vehicle; **Euro V, 17T heavy goods vehicle; *day-time congestion conditions; ****less congested road conditions.**

5.3.2 What is fair? Selecting an outcome variable

Distributive justice in the liberal, Western philosophical and economic tradition encompasses an array of normative and positive frameworks. However, many common indicators used to evaluate equity provide limited insight into the actual distribution of costs/benefits. The area under a Lorenz curve (i.e, Gini coefficient), for instance, is arguably the most common measure of absolute inequality. However, it is largely uninformative when it comes to ranking outcomes between each other, comparing population groups, or determining the direction of inequality (Karner et al., 2025).

Tessum et al. (2019) proposes a more intuitive framing, suggesting an inequity occurs when a population group's pollution exposure exceeds the pollution they generate from their consumption. In e-commerce, this could mean that an inequitable outcome occurs when a population group receives external costs disproportionate to the external costs generated (or marginal benefit received) by this group's ordering share. Since consumption-based benefits are likely proportional to consumption volume, this paper adopts a novel "fair share" ratio (*FS*) shown in *Equation 1*.

Equation 1:

$$FS_i = \frac{\sum_i Cost_{POC} / \sum_i Cost_{total}}{\sum_i Delivey_{POC} / \sum_i Delivery_{total}}$$

Where:

- *i* is the service area that aggregates Census block groups.
- The numerator is the share of costs borne by POC in service area *i*.
- The denominator is the share of deliveries received by POC in service area *i*.

FS=1.0 suggests POC receive external costs in proportion to the deliveries they receive. Whereas values greater than 1.0 suggests POC bear higher external costs despite consuming less than White populations. In addition to being intuitive, the ratio also controls for the effect of delivery behavior in the model.

5.3.3 Selecting covariates and identifying relational paths

I use SEM to estimate both the direct and indirect effects of logistics sprawl/proximity logistics on racial disparities in last-mile delivery. SEM enables the evaluation of theoretically grounded models against observed data (Ewing et al., 2016). *Table 5.2* summarizes the endogenous and exogenous variables of interest. Endogenous variables represent second-order outcomes in the model and mediate the influence of exogenous variables (Hayes, 2022). The study draws on the theoretical foundations outlined in the literature review to identify variables and specify relational paths (see *Fig. 5.1*).

Since the underlying demand model assumes LMDS deterministically serve populations closest to the facility, the unit of analysis are the Thiessen-defined service areas (see *Figure 1*). The model also combines adjacent spillover facilities into singular points (Fried et al., 2024b). Consequently, the authors observe that LMDS are generally dispersed throughout their respective MSAs, often with large distances between facilities. If person x is served by closest LMDS a , it is less likely they would be exposed to the external costs generated by LMDS b serving person y , or to a lesser degree. Although a simplification, validating the impact of traffic proximity and its distance decay depend on an array of confounding factors not tested in this study, e.g., the atmospheric conditions that transport and chemically transform air pollutants. I treat service areas and the populations they contain as independent from one another (Wygonik & Goodchild, 2018).

This study hypothesizes that logistically sprawled service areas are more inequitable than logistically compact delivery areas. There are two primary variables of interest:

- Supply chain centrality or spread (s_cent) measures the Euclidean distance between LMDS and the weighted employment centroids of goods producing industries. The analysis defines goods producing industries by their two-digit North American Industry Classification System (NAICS) code: Manufacturing (*NAICS 31-33*), Wholesale Trade (*NAICS 42*), Retail Trade (*NAICS 44-45*), and Transportation & Warehousing (*NAICS 48-49*) (Kang et al., 2020b). Drawing on Bowen's (2009) theory on EJ and agglomeration, the model assumes s_cent has endogenous effects.
- Demand centrality (d_cent) measures the average delivery volume-weighted distance between LMDS and home consumers, the mean-center of which is visualized as a

demand centroid. This variable is a delivery demand-based equivalent to Rivera-Gonzalez et al.'s (2023) supply chain metric of spread.

Endogenous and control variables include:

- Residential segregation of POC (*DI*) is the frequently used Dissimilarity Index, with demographic data provided by the U.S. Census Bureau 5-year American Community Survey (ACS). The DI equation follows, where a high DI indicates higher racial dissimilarity or segregation across block groups j contained within service area i :

Equation 2:

$$DI_i = \frac{1}{2} \sum_{j \in i} \left| \frac{POC_j}{POC_i} - \frac{White_j}{White_i} \right|$$

- Social capital (*socap*) is a recent iteration of a composite index developed by Fraser et al. (2022) for 2017. The index is composed of three subindices: bonding (i.e., lower fractionalization in racial and ethnic make-up, gender, education, employment, and income), bridging (i.e., higher concentrations of religious, charitable, labor, and civic organizations), and linking (i.e., higher concentrations of voters, government employees, and political activities). *Socap* is the population-weighted mean index of Census tracts contained within a service area.
- Compactness (*compact*) is another composite index, developed by Ewing and Hamdi (2014) at the MSA-level. The index comprises of four subindices: density (i.e., employment and population densities), mixed-use (i.e., job-population balance and walkability), centering (i.e., spatial variation in density), and street factors (i.e., intersection and block density). The index centers the mean at 100, where greater values indicate a more compact urban form.
- *Size* controls for the area of the delivery service area.
- The route-distance traveled by trucks (*t_dist*) controls for the distance between SC and LMDS.
- Location Quotient (*LQ*) compares the relative employment share of goods producing industries in the MSA compared to other sectors and across the United States. LQ is defined in *Equation 3*, where a value greater than 1.0 signifies a stronger clustering of goods producing industries in the MSA.

Equation 3:

$$LQ_{MSA} = \frac{\frac{Employment_{Goods}^{MSA}}{Employment_{total}^{MSA}}}{\frac{Employment_{Goods}^{USA}}{Employment_{total}^{USA}}}$$

	Variables	Name	Theory	Relevant source
Outcome	Fair share ratio	<i>FS</i>	-	Author's elaboration
Endogenous	Residential segregation	<i>DI</i>	<i>Segregation</i>	(Ewing et al., 2016; Massey and Denton, 1993; US Census Bureau, 2017a)
	Supply chain centrality	<i>s_cent</i>	<i>Sprawl</i>	(Rivera-Gonzalez et al., 2023; Kang et al., 2020b; US Census Bureau, 2017b)
	Social capital	<i>socap</i>	<i>Social capital</i>	(Fraser et al., 2022)
Exogenous	Location quotient (MSA-level)	<i>LQ</i>	<i>Sprawl</i>	(Kang, 2020b; Rivera et al., 2014; US Census Bureau, 2017b)
	Median household income	<i>income</i>	<i>Segregation</i>	(Ewing et al., 2016; Massey and Denton, 1993; US Census Bureau, 2017a)
	Compactness (MSA-level)	<i>compact</i>	<i>Sprawl</i>	(Ewing and Hamidi, 2014)
	Demand centrality	<i>d_cent</i>	<i>Sprawl</i>	(Fried and Goodchild, 2023; Wygonik and Goodchild, 2018)
	SC distance to LMDS	<i>t_dist</i>	<i>Sprawl</i>	(Fried et al., 2024c)
	Service area size (sq. mi.)	<i>size</i>	<i>Sprawl</i>	(Fried and Goodchild, 2023; Wygonik and Goodchild, 2018)

Table 5.2: SEM variables and data sources.

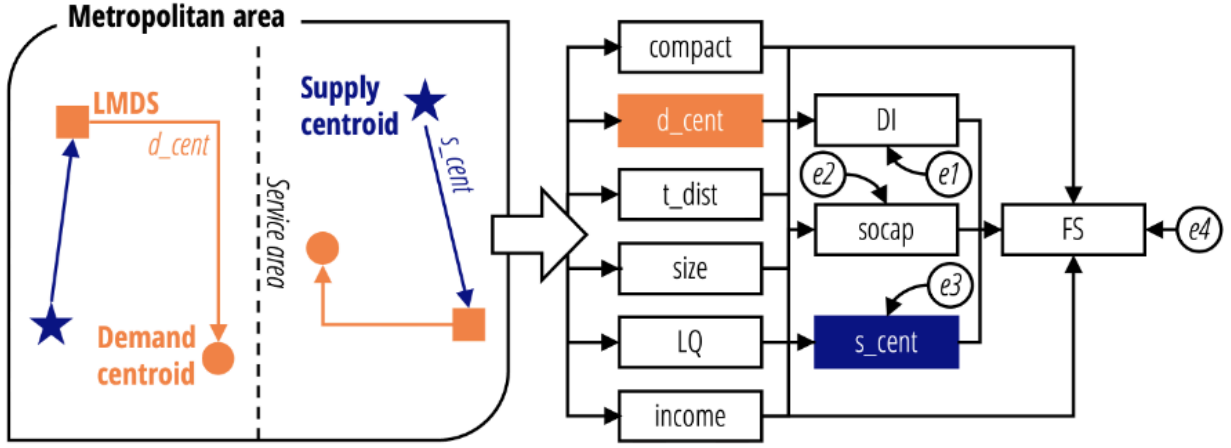


Figure 1: Visualizing variables of interest for two delivery service areas (left) and path diagram (right).

Structural equations are an integrated system of linear regression models, defined by *Equations 4-8* below.

Equations 4-8:

$$FS_i = \beta_1 DI_i + \beta_2 socap_i + \beta_3 s_cent_i + \beta_4 d_cent_i + \sum \beta_{5-9} controls$$

$$DI_i = \beta_{10} d_cent_i + \sum \beta_{11-15} controls$$

$$socap_i = \beta_{16} d_cent_i + \sum \beta_{17-21} controls$$

$$s_cent_i = \beta_{22} d_cent_i + \sum \beta_{23-27} controls$$

Equation 4 represents the direct effects of all variables on FS, while *Equations 5-8* show the indirect effects of the exogenous variables. Not represented by the base equations, the model finds significant interaction between the endogenous variables. The next section discusses these moderated and conditional effects further.

5.4 Results

I hypothesize that large distances between delivery supply and demand partially explain racial disparities in delivery externalities. This section examines this spatial and racial mismatch across two geographic-levels, MSAs and service areas, drawing on descriptive statistics and SEM respectively.

5.4.1 Spatial and racial mismatch across MSAs

Fig 5.2 plots the POC external cost exposure and ordering behavior in 41 MSAs analyzed by Fried et al. (2024b). The mean FS across MSAs is 1.55: POC are exposed to 55% more external costs relative to their delivery share. Among the most unfair MSAs are those in the industrial Midwest: St. Louis, MO (STL, FS=3.72), Cleveland, OH (CLE, FS=3.59), Cincinnati, OH (CVG, FS=3.40), Indianapolis (IND, FS=2.89), and Milwaukee (MKE, FS=2.65).

All five MSAs exhibit above-average LQ, exceeding both the sample mean (LQ=0.93, see *Table 5.3*) and the 1.0 threshold—indicating that goods producing employment is more concentrated in these areas compared to the broader national economy. MKE has the highest LQ in the sample at 1.21. These MSAs' compactness indices are also lower than the sample mean (*compact*=97.41, see *Table 5.3*) and the mean-center at 100, except for MKE (*compact*=130.35). Additionally, three MSAs (MKE, CLE, and STL) are the most racially segregated regions in the sample (*DI* between 62.47 and 63.08). *Fig. 5.3* illustrates that high LQ, DI, and low compactness are significantly correlated with a higher FS indicator. Regions with strong specialization in freight-intensive sectors, sprawling urban form, and entrenched racial segregation may accentuate last-mile delivery disparities.

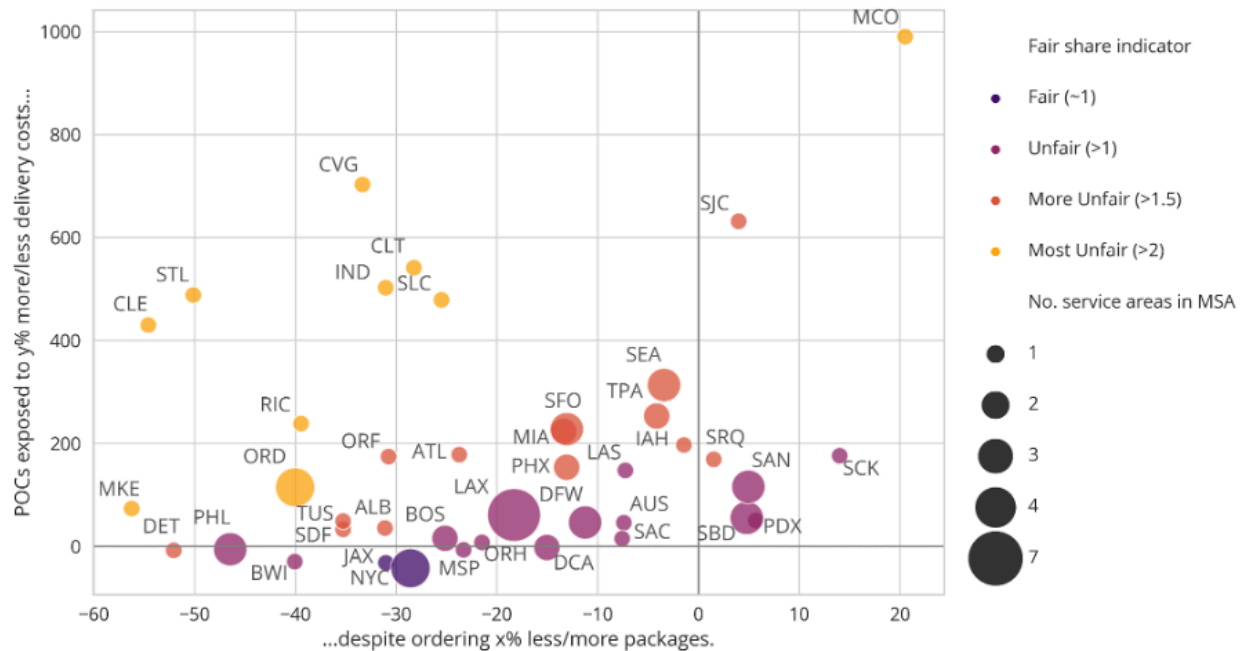


Fig. 5.2: Plotting POC fair share indicators across MSAs. NOTE: Labels represent the IATA code of the MSA's largest city for better visualization.

	Mean	Median	Variance
<i>FS</i>	1.55	1.49	0.43
<i>DI</i>	43.16	42.25	94.90
<i>socap</i>	49.60	49.61	33.23
<i>s_cent (mi)</i>	8.14	8.25	16.02
<i>income (\$ thou.)</i>	72.87	69.81	2.46e5
<i>d_cent (mi)</i>	19.63	19.16	44.23
<i>t_dist (mi)</i>	23.04	21.85	214.63
<i>size (thou. sq. mi)</i>	3.07	2.13	942.14
<i>compact (MSA-level)</i>	97.41	98.88	543.78
<i>LQ (MSA-level)</i>	0.93	0.93	0.02

Table 5.3: Summary statistics of outcome, predictor and control variables.

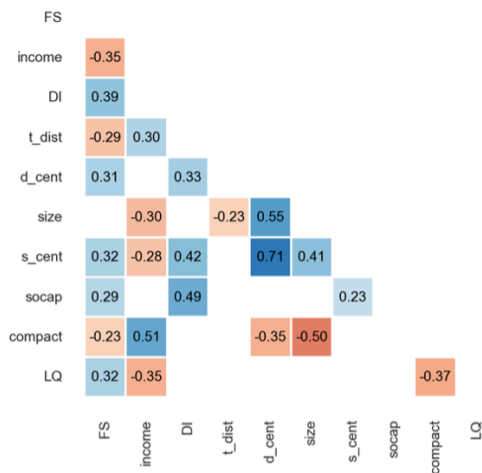


Fig 5.3: Pearson's correlation matrix showing significant correlations only ($p < 0.1$)

Only two MSAs in the sample exhibit a “fair” distribution of delivery externalities: Jacksonville, FL (JAX, $FS=0.99$) and New York City (NYC, $FS=0.87$). However, their relationship to MSA-level attributes is less clear. Both have LQ below 1.0, though JAX is above the sample mean ($LQ=0.96$). Urban form also differs: JAX is highly sprawled ($compact=80.85$), while NYC is among the most compact MSAs in the sample ($compact=131.70$). Additionally, NYC's delivery environment is moderately more compact. NYC's mean last-mile delivery distance (d_cent) between supply and demand is 20.5 mi compared to 26.1 and 28.0 in CLE and STL, respectively.⁵

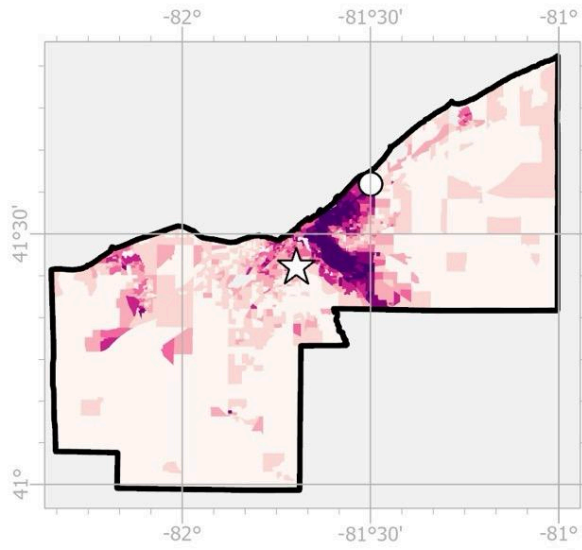
Fig. 5.4 maps the POC share, LMDS locations, and delivery demand centroids in CLE, STL, and NYC. CLE and STL show a clear spatial and racial mismatch between where delivery demand is centered and LMDS are sited. Across Census block groups, the share of POC within a half mile of LMDS is 76.8% versus 27.3% within a half mile of the demand centroid in CLE (64.5% lower near the centroid), and 70.5% versus 12.8% in STL (81.8% lower).

In fact, this spatial and racial mismatch holds across the entire MSA sample. Table 5.3 reports the population-weighted share of POC in block groups within a half mile of an LMDS versus those within a half mile of the delivery demand centroid in the service area. *On average, block groups near LMDS contain 32.6% more POC residents.* These patterns provide important

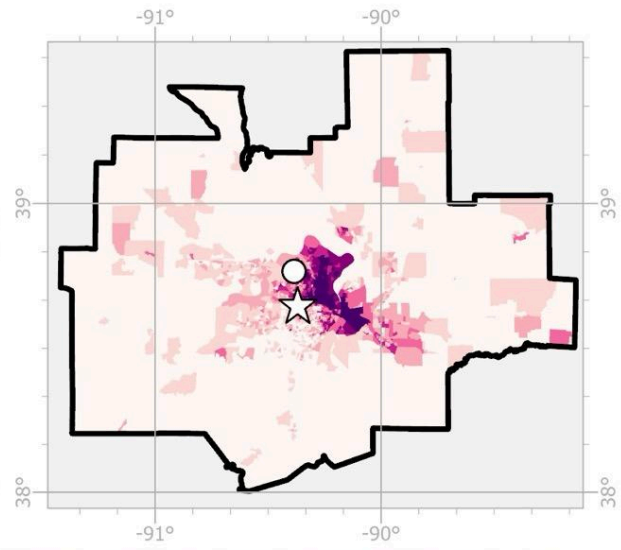
⁵ The 2017 Manhattan (NYC) location was the business address of a last-mile delivery pilot that is no longer operational as of 2025 (confirmed via personal communication with the company). There is currently no LMDS operating in Manhattan.

context for the SEM analysis, which will partially explain how proximity logistics and segregation affect these racial disparities.

Cleveland, OH



St. Louis, MO



New York City, NY

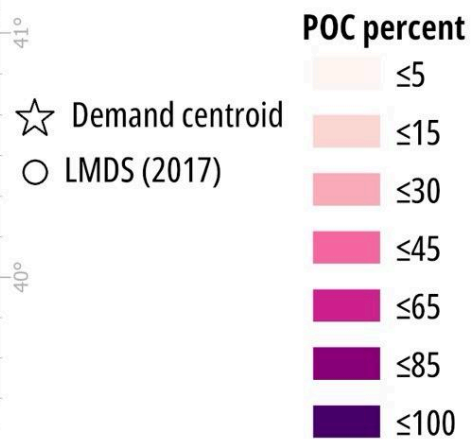
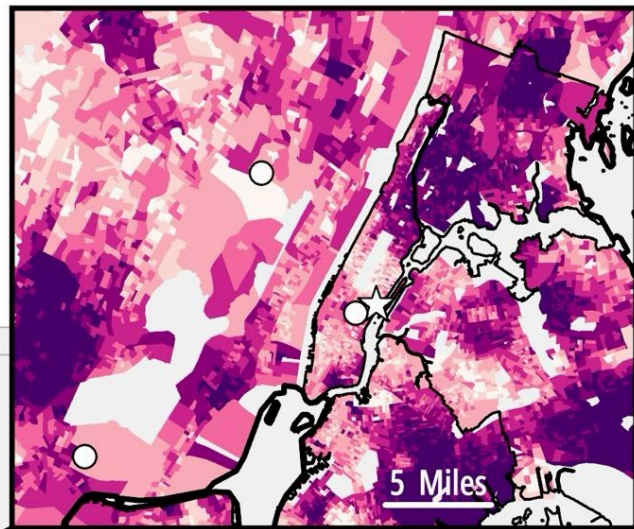
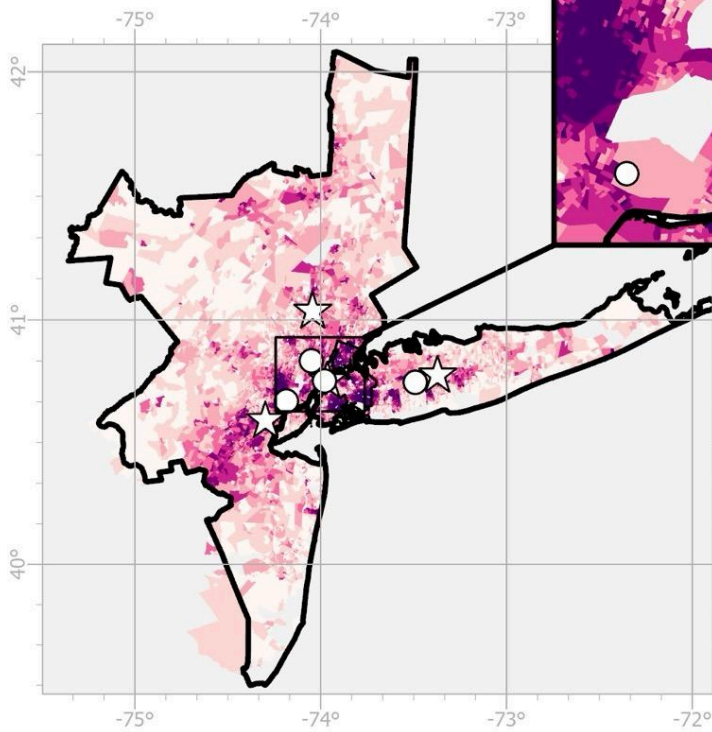


Fig. 5.4: Maps of POC percent share, LMDS locations and delivery centroids in fair (NYC) and unfair MSAs (CLE and STL) in 2017.

		Population-weighted POC percent share			
	Block groups w/in 0.5 miles	mean	median	variance	Welch's t-test (H0: LMDS=Demand)
LMDS	247	47.72	45.84	603.82	<0.001***
Demand	252	35.99	30.56	639.78	

Table 5.3: Summary statistics of population-weighted POC percent share for block groups within 0.5 miles of an LMDS and demand centroid.

5.4.2 SEM findings

Table 5.4 presents the final model with standardize variables to allow direct comparison of coefficients. Standard errors and significance levels are estimated using percentile bootstrapped confidence intervals to enhance robustness and correct bias (Tibbe and Montoya, 2022). As discussed, the unit of analysis is the LMDS-based service area, of which there are 69 across the 41 MSAs. Due to gaps in Massachusetts employment data that produces null values for the *compact* variable, the analysis excludes two MSAs, Boston (*BOS*) ($n_{LMDS}=4$) and Worcester (*ORH*) ($n_{LMDS}=1$). As such, the final model includes 65 service areas.

Because a model specified with all direct and indirect paths and covariances is just-identified ($df=0$), conventional fit indices (e.g., χ^2 , CFI, RMSEA) are not informative (Hayes, 2022). To evaluate the contribution of interaction terms, I compare a baseline model without interactions (see *Figure 1*) to a more complex model that includes them (see *Table 4*). The lower Bayesian Information Criterion (BIC) value for the interaction model indicates that the additional parameters improve model fit. I highlight major findings below.

Variable paths	Coef.	Std. e	Variable paths	Coef.	Std. e
FS←DI	2.38	2.61	DI:s_cent←d_cent	0.78***	0.11

FS←socap	1.44	1.12	DI:s_cent←t_dist	0.05	0.09
FS←s_cent	11.49**	6.49	DI:s_cent←compact	0.27***	0.11
FS←DI:s_cent	-13.67**	7.70	DI:s_cent←LQ	0.13	0.09
FS←DI:socap	-3.47	3.33	DI:s_cent←income	-0.28***	0.10
FS←socap:s_cent	-14.00**	7.10	DI:s_cent←size	-0.14	0.11
FS←DI:socap:s_cent	16.78**	8.37	DI:socap←d_cent	0.61***	0.14
FS←d_cent	0.09	0.19	DI:socap←t_dist	0.07	0.12
FS←t_dist	-0.23**	0.12	DI:socap←compact	0.29***	0.15
FS←compact	-0.01	0.17	DI:socap←LQ	0.11	0.12
FS←LQ	0.10	0.12	DI:socap←income	-0.24**	0.13
FS←income	-0.12	0.14	DI:socap←size	-0.32**	0.14
FS←size	0.07	0.17	socap:s_cent←d_cent	0.70***	0.11
DI←d_cent	0.62***	0.12	socap:s_cent←t_dist	-0.01	0.09
DI←t_dist	0.12	0.15	socap:s_cent←compact	0.18*	0.11
DI←compact	0.38***	0.12	socap:s_cent←LQ	0.03	0.09
DI←LQ	0.17	0.13	socap:s_cent←income	-0.19*	0.10
DI←income	-0.32***	0.14	socap:s_cent←size	-0.03	0.11
DI←size	-0.29**	0.14	DI:socap:s_cent←d_cent	0.77***	0.11
socap←d_cent	0.37***	0.15	DI:socap:s_cent←t_dist	0.03	0.09
socap←t_dist	-0.08	0.12	DI:socap:s_cent←compact	0.23**	0.12
socap←compact	0.05	0.15	DI:socap:s_cent←LQ	0.11	0.09
socap←LQ	-0.07	0.12	DI:socap:s_cent←income	-0.25**	0.10
socap←income	0.03	0.14	DI:socap:s_cent←size	-0.19*	0.11
socap←size	-0.25**	0.15	R²		
s_cent←d_cent	0.69***	0.10	socap	0.13	
s_cent←t_dist	0.01	0.09	DI	0.34	
s_cent←compact	0.22**	0.11	s_cent	0.56	
s_cent←LQ	0.05	0.09	FS	0.47	
s_cent←income	-0.21***	0.10	DI:socap	0.30	
s_cent←size	0.05	0.10	DI:s_cent	0.56	
			socap:s_cent	0.56	
			DI:socap:s_cent	0.51	
			BIC ₀	710.94	
			BIC _{interaction}	103.83	

Table 4: Standardized direct and indirect effects in the delivery service area interaction model (n=65). NOTE: * $p < 0.1$, ** $p < 0.05$, * $p < 0.01$**

5.4.2.1 Racial segregation, supply chain centrality, and social capital

Table 5.5 reports the total effects of the endogenous and exogenous variables. *DI* and *s_cent* exhibit expected, positive associations with *FS*: externality disparities in service areas are larger when segregation is higher and supply chains are more spatially dispersed. *Socap* has a weaker, positive relationship. These variables significantly interact, meaning their effects on *FS* are conditional on one another.

	Direct	Indirect	Total
DI	2.38	0.00	2.38
socap	1.44	0.00	1.44
s_cent	11.49**	0.00	11.49**
DI:socap	-3.47	0.00	-3.47
DI:s_cent	-13.67*	0.00	13.67*
socap:s_cent	-14.00**	0.00	-14.00**
DI:socap:s_cent	16.78**	0.00	16.78**
income	-0.12	-0.11***	-0.23**
d_cent	0.09	0.21***	0.30**
t_dist	-0.23**	0.05	-0.18
size	0.07	-0.13*	-0.05
compact	-0.01	0.09**	0.08
LQ	0.10	0.13	0.23**

Table 5: Standardized total effects on delivery fair-share (FS). NOTE: * $p < 0.1$, ** $p < 0.05$, ***

$p < 0.01$

Fig. 5.5 probes this three-way interaction by examining the relationship between *FS* and *DI* at high (↑) and low (↓) levels of *s_cent* and *socap* (defined as the mean ± 1 standard deviation). The most notable effect occurs when *s_cent* and *socap* are high. These conditions substantially accentuate the correlative strength between racial segregation and externality disparity.

At first glance, the conditional effect of high social capital appears to contradict the “path of least resistance” theory. Prior research suggests that high social capital may mitigate concentrated environmental burdens (Ataullah et al., 2023). However, as Ataullah et al. (2023)

and others note (Gannon and Roberts, 2020; Schwanen et al., 2015), the effects of social capital are heterogeneous, context-dependent and, at times, can produce negative externalities.

For instance, Ataullah et al. (2023) find social capital's protective effects diminish when the employment share of the polluting industry is high. Communities may be less willing (or less able) to oppose a siting when that industry constitutes an important source of livelihood. This study's results appear aligned with this observation. The total effects of *LQ* and *income* are positively and negatively associated with FS, respectively. This relationship may reflect weaker resistance to LMDS siting, and thus a greater spatial and racial concentration of delivery costs, in areas with agglomerated freight-sector employment and lower household incomes.

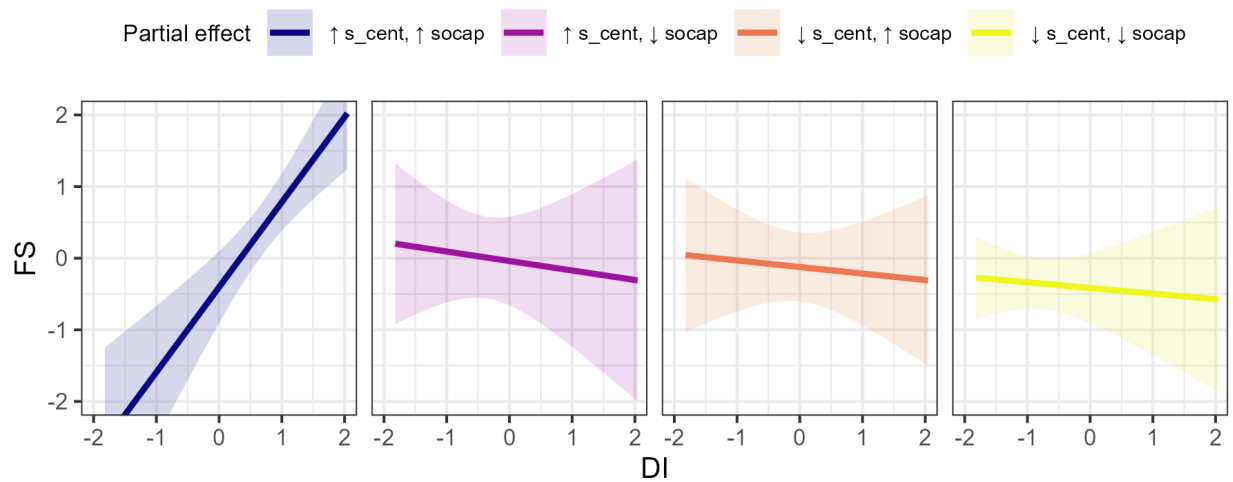


Figure 5: Partial effects of supply centrality and social capital on the relationship between racial segregation (DI) and delivery disparities (FS). NOTE: high (↑) and low (↓) indicate the mean $\pm$ one standard deviation.

5.4.2.2 Demand centrality

Demand centrality (*d_cent*) has a significantly positive, indirect and total effect on observed racial disparities in delivery externalities. This finding suggests that logistically compact service areas tend to be less inequitable, but the above endogenous relationship fully mediates the impact. Based on *d_cent*'s standardized total effect ($\beta=0.30$), the model estimates that a 1 standard deviation reduction in mean last-mile delivery distance (6.7 mi) within a service area is associated with a 12.7% decrease in FS (95% CI: -23.4%, -2.0%). I discuss the implications and limitations in the following section.

5.5 Discussion & Conclusion

This study examines the direct and indirect effects of supply and demand centrality—determinants of logistics sprawl—on racially disparate e-commerce externalities in 39 MSAs. As expected, sprawling urban form, decentralized supply chains, and high racial segregation are associated with disparate externalities. Results echo the findings of other authors (Ewing et al., 2016), as well as Smart Growth, New Urbanist, and EJ advocates for inclusive land use and transport reform (e.g., Quattro, 2024).

Perhaps surprising, however, is the conditional role played by social capital. High social capital is associated with higher disparities, despite some studies finding the contrary (Ataullah et al., 2023), or limited effect (Ard and Fairbrother, 2017; Ewing et al., 2016). The finding may suggest a “dark side” of social capital (Gannon and Roberts, 2020; Schwanen et al., 2015), in which strong social and institutional ties create negative externalities.

One possible explanation is that low-income communities or those reliant on freight-intensive sectors for employment expend social capital to encourage LMDS siting, accepting traffic-related disamenities in exchange for perceived economic opportunity (Banzhaf et al., 2019). De Lara (2018) details an example of this dynamic in Moreno Valley (California) where local representatives and developers leveraged Hispanic labor organizers’ economic concerns to fast-track council approval of a W&D (pp. 127-146).⁶ In fact, municipalities and polluting industries may frequently “dangle” low-wage jobs as a trade-off for local health impacts (Bullard, 2000). Yet such trade-offs do not always yield the economic benefits they promise. Chapple (2018), for instance, links local fiscalization of greenfield industrial development to wage decline in California.

Another explanation could lie in exclusionary land use politics. Fried et al. (2025) find wealthy, single-family jurisdictions enact most W&D-related land use restrictions. More advantaged communities may leverage high social capital to block freight-related projects in their neighborhood and redirect siting into disadvantaged communities, echoing research on not-in-my-backyard (NIMBY) movements and policies (Sally and Tighe, 2015; Trounstone, 2020).

Finally, results point to an indirect association between proximity logistics—i.e., smaller distances between delivery supply and demand—and reduced externality disparities. Strategies

⁶ The author reports, three years after opening, the W&D had yet to fulfill its job creation targets or environmental commitments.

to better integrate logistical facilities into high-demand, high-density neighborhoods include microhubs (Gunes et al., 2024), urban consolidation centers, and logistics hotels (Kin et al., 2024). Improving proximity logistics compatibility with surrounding neighborhoods may counteract NIMBY opposition, with strategies including mixed-use warehouse design, architectural buffering and place-making, and Complete Streets that integrate goods and people mobility (Buldeo Rai, 2024; Conway, 2024; Lane and Rappaport, 2020). These approaches likely require flexibility in zoning codes and incentives to enable W&D siting outside conventional industrial zones. Cities should also broaden policies to support EJ and prevent economic displacement (Anguelovski, 2016), given the apparent link between reduced W&D density and gentrification (Qin et al., 2024).

Community benefit agreements (CBAs) offer another path forward by linking logistics development to tangible neighborhood benefits, including local hiring, union protections, freight vehicle electrification and mode-shift, and investments in housing, transit, or greenspace (Buldeo Rai, 2023; Fried et al., 2025). However, adversarial or avoidant tensions that often govern community-developer interactions can hinder both CBA adoption and effectiveness. For instance, a W&D development in Detroit (Michigan) narrowly avoided a financing threshold that would have triggered a CBA required by city ordinance, leading residents to question the policy's credibility (Saha et al., 2024). Participatory planning can help build the trust needed for effective CBAs, but mitigating freight impacts ultimately requires regulations ensuring environmental protections and accountability.

5.5.1 Limitations

Similar to broader challenges in the EJ and transport field, variable definitions and measurements can sometimes alter the interpretation of outcomes (Karner et al., 2025; Noonan, 2008). For instance, defining “target” groups, equity indicators, spatial units and joins can influence observed disparities in delivery VMT exposure (Fried et al., 2024b). This study also relies on static external cost coefficients (Cárdenas et al., 2017) and secondary indices (Ewing & Hamdi, 2014; Fraser et al., 2022), whose validity this study does not independently assess. Future research can enhance robustness through sensitivity analysis of stochastic outcomes, alternative control selections, racial/ethnic group comparisons, and scenario testing.

Another key assumption—that delivery benefits are proportional to the number of deliveries received—also overlooks potential positive externalities that could “even out” observed racial disparities (e.g., job growth, faster access to goods). Fried & Garcia (2024) complicate these benefits by showing, for example, access to goods is unevenly distributed and that labor conditions across trucking and warehousing sectors remain poor. Additionally, while W&D may generate jobs, it does not require nearby residents to work them (Eom, 2022; Kain, 1992).

Future studies can operationalize positive freight externalities considering these caveats. However, as Pastor (2004) argues, the “vicious choice” between economic security and physical health may be less a Coasian bargain and more a product of structural power imbalances. It is a choice no community should have to make, and neither does this study.

5.5.2 Conclusion

This study is among the first to identify urban form as a determinant of racial disparities in freight-traffic externalities. It integrates inter-disciplinary theories of urban inequality with a novel, structural equation modeling approach to examine e-commerce as a contemporary case of environmental injustice.

Racial disparity in e-commerce externalities is partially attributable to a spatial mismatch between delivery supply and demand: smaller distances between them correlate with smaller disparities. *The model estimates that a 1-mile reduction in mean last-mile delivery distance is associated with a 1.9% decrease in externality disparity.* Meaningful reductions seem plausible for most proximity logistics initiatives. One microhub pilot in downtown Seattle demonstrates mean cargo van VMT-per-package reductions up to 74% (Gunes et al., 2024). However, racial marginalization and urban form factors present significant, mediating conditions. Microhubs may fail to reduce disparities if, for example, upstream distribution chains remain sprawled or they are sited in POC-segregated, low-demand neighborhoods. These scenarios warrant future study.

Chapter 6: From Logistics Sprawl to Compact Logistics

“Main thoroughfares give an opportunity for inclusion of offices and stores on the ground floor of the [warehouse], which may be rented at prices... greater than the return per square foot from storage.”

Excerpt from *Household Goods Warehousing in the United States* by
Clarence A. Aspinwall (1925)

ABSTRACT: W&D expansion has raised concerns about the disproportionate exposure of nearby communities to freight traffic. Although equity is a seldom stated goal, recent initiatives have sought to address freight traffic concerns through densifying and spatially reordering consolidation nearer to end consumers. Two such examples exist, which this thesis up to now has collectively referred to as Compact Logistics (CL): Urban Consolidation Centers (UCCs) and microhubs. This chapter offers a definition of CL, distilled from a co-authored paper (Katsela et al., 2022), and identifies a key regulatory barrier (and enabler): zoning.

In fact, few regulations may be as consequential to logistics-related development (and environmental disparities) as zoning. This study synthesizes the state of recent U.S. zoning actions related to W&D, examining their role as tools—or barriers—for mitigating environmental impacts in communities historically burdened by freight traffic. Specifically, this chapter investigates 92 zoning actions at 67 locations (51 municipalities, 9 counties, and 7 states) and assesses the level at which CL considerations and Environmental Justice (EJ) principles inform these actions. Ultimately, achieving equitable and compact logistics requires balancing strategic land-use priorities and environmental safeguards for vulnerable communities with regulatory flexibility—and even targeted incentives—that encourage logistics innovation beyond conventional industrial zones.

6.1 Defining Compact Logistics (CL)

Globalized supply chains and a growing consumer economy have catapulted warehouse and distribution centers (W&D) to immense levels of development. Between 2003 and 2018, W&D building stock and floorspace increased 67%, and surpassed office and retail as the dominant commercial and industrial land use in the United States (U.S. EIA, 2021). Fueled in part by online retail’s increasing market share, some W&D opened close to urban centers to more

reliably set and meet expectations for fast home delivery, raising equity and justice concerns. The need—and opportunity—for sustainable and equitable urban freight management strategies has never been greater.

One such strategy is “proximity logistics” (Buldeo Rai, 2023; Buldeo Rai et al., 2022), “freight efficient land use” (Holguín-Veras et al., 2022), or, alternatively, Compact Logistics (CL). Though differing in their framing and recommendations (see *Table 6.1*), all three seek to densify delivery networks through operational consolidation and land use reform. Under this umbrella, two facility types have gained prominence: Urban Consolidation Centers (UCCs) and microhubs (Katsela et al., 2021) (see *Fig 6.1*). These consolidation practices are distinct from pickup points, such as parcel lockers, where receivers complete the last leg of delivery themselves, and may have little effect in communities historically burdened by freight traffic (Schaefer & Figliozzi, 2021).

	Geography	Land use actions discussed	Recommendations/strategies
(FHWA, 2012)	U.S.	• Euclidean zoning • Overlay districts ◦ Form-based zoning, performance zoning • Preferential/incentive zoning	• Context-specific solutions ◦ Buffers & containment, loading door orientation, truck staging and parking, Light/noise mitigation • Preserve industrial land
(Holguín-Veras et al., 2022)	U.S.	• Long-term planning • Regulatory controls • Discretionary approaches	• FELU ◦ Densify W&D in urban core, preserve existing W&D, Reserve/bank land, Co-locate near gateways, foster mixed-use, relocate some “large traffic generators”
(Yuan, 2019)	Southern California	• CUPs • Land use restrictions ◦ Parcel sizes, land use definitions	• Reduce W&D impact, postpone W&D sprawl • Financial (dis)incentives • Environmental regulations
(AIANY, 2022)	New York City	• CUPs • Development standards • Environmental/transport requirements	• CUP based on impact/size • “Nuanced” by-right in industrial zones • Community-led planning and rezoning
(Buldeo Rai, 2023; Buldeo Rai et al., 2022)	New York City	• “By-right” versus CUP • Definitions for last-mile facilities • Performance zoning	• Proximity logistics ◦ Environmental regulation, context-specific design, Community Benefit Agreements (CBAs), Complete Streets

Table 6.1: Overview of zoning-related urban freight literature

Formal research on freight consolidation schemes traces back to the mid-1970’s with evidence of feasibility studies on urban ‘transshipment,’ ‘logistics city,’ or ‘joint distribution’

centers conducted in the U.K. and Europe (McKinnon, 1998), North America (Button, 1978), and Japan (Taniguchi and Qureshi, 2014). The economic viability of these early models is uncertain as most urban consolidation schemes failed to surpass the early feasibility assessment phase (Allen et al., 2012; Björklund et al., 2017). Early urban consolidation schemes required ample gray space in an urban environment where real estate is priced at a premium. They also required close collaboration between public stakeholders and competing logistics providers, which to this day present a challenge. And pathways to acquiring appropriate customer volumes and business models to reach break-even costs, let alone scale operations, were underdeveloped (Allen et al., 2007).

Interest in urban consolidation rekindled in the late 1990's and early 2000's, this time under the banner of UCCs. UCCs emerged as a popular logistics solution to reducing emissions and limiting congestion in dense pedestrian, commercial, or historical zones (Allen et al., 2012; Björklund et al., 2017). The success rate of these newer consolidation schemes is mixed. Due to the additional costs associated with transloading shipments, UCC success often hinges on government willingness to subsidize operations (Verlinde et al., 2012). In a recent study, Giampoldaki et al. (2021) found that of the 82 UCCs launched in Europe since 1990, 62 are still operational. For UCCs that succeed, researchers cite public fiscal support at the start-up phase, favorable regulatory environments, and priority infrastructure (Akgün et al., 2020; Lebeau et al., 2017); business models that incorporate value-added services, auxiliary revenue generation, and close collaboration between multi-sector partners (Björklund et al., 2017; Katsela and Pålsson, 2020); in addition to tactical considerations relating to UCC size, location and catchment area, information systems, fleet composition, handled product types, delivery densities and logistics. However, these analyses do not distinguish between the traditional, half-century old UCC concept, which is often retail- or construction-focused, and microhubs.

Microhubs provide smaller, more localized forms of consolidation better suited for serving fragmented, door-to-door e-commerce markets in dense urban environments. These facilities can be static on-street staging areas, off-street sorting facilities, or mobile depots where a specialized truck serves as a resupply node for door-to-door distribution using cleaner, smaller vehicles (e.g., TNT Express Mobile Depot Pilot in Brussels, Verlinde et al., 2014). As the name implies, microhubs are small. Global examples range in sizes from two parking spots in an under-utilized lot (see Seattle's microhub pilot, Gunes et al., 2024) to a 20,000 sq ft multi-use

facility that host offices, urban farms, and package sorting (see Paris’s *Chapelle International* ‘Logistics Hotel’). Studies most frequently explore microhubs as a facilitator for last-mile delivery via cargo bicycles, small EVs, and handcarts (Janjevic and Ndiaye, 2014; Lee et al., 2019).

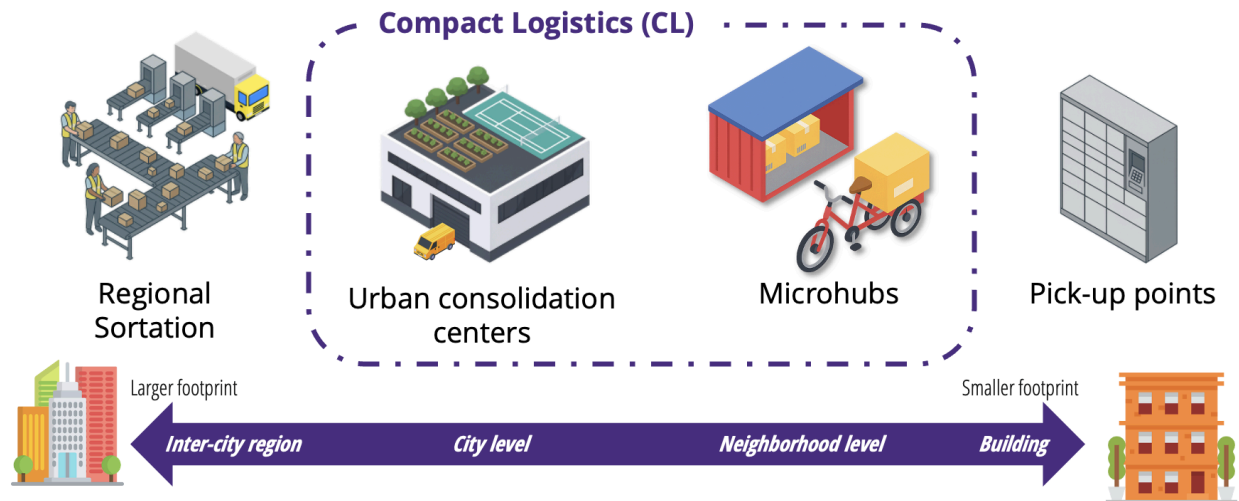


Fig. 6.1. Consolidation practices in urban deliveries. Icons generated by ChatGPT.

But much like the electric streetcar and paved bicycle trail (Longhurst, 2015), mixed-use and urban-integrated consolidation facilities have a long history in U.S. cities (Eaton, 1982). As Aspinwall (1925) writes, warehousing once supported mainstreet retail and commercial services, often sharing the same space within multi-story buildings. Today, most cities classify logistics-related land uses as *light industrial*, which excludes them from the mixed-use development opportunities granted to high-density commercial zones while also exempting them from stricter environmental standards applied to heavy industry (Tejada & Conway, 2024). These exclusionary zoning policies may not only preclude microhubs from locating in high-demand urban neighborhoods, but also reinforce sprawl and inequitable patterns of urban development.

6.2 Logistics of zoning, zoning for logistics

For over a half-century, planners have charged *exclusionary zoning* with contributing to excessive sprawl, racial and socio-economic segregation, public health disparities, housing shortages, and gentrification (Whittemore, 2021). Renewed efforts to reform land use policies range from overlays and density incentives that encourage compact, transit-oriented

development, to larger overhauls that introduce environmental performance standards and form-based codes (Forman et al., 2023). However, many reforms present mixed effectiveness in addressing stated policy goals, such as curbing sprawl (Ewing et al., 2022), preventing gentrification (Davis, 2021), or preserving industrial jobs in the urban core (Chapple, 2014; Davis & Renski, 2020; Ferm & Jones, 2017).

In fact, exclusionary zoning remains largely intact in most local jurisdictions (Imbroscio, 2021), even in cities taking steps toward denser, mixed-use development (e.g., Packer, 2024). Some scholars argue that regulators yield to competing pressures—from powerful real estate interests (Logan & Molotch, 2010; Stein, 2019) to parochial “homevoters” and Not In My Backyard (NIMBY) groups (Fischel, 2015; Scally & Tighe, 2015; Hall & Yoder, 2022; Sclar et al., 2020)—leading to decisions that prioritize short-term fiscalization or political gain. Others advocate for zoning’s wholesale repeal or partial deregulation on market-libertarian, neoliberal, or constitutional grounds (e.g., Braver & Somin, 2024; Glaeser et al., 2005; Gray, 2022). Yet, among the “Smart Growth” and “New Urbanist” standard-bearers for zoning reform, industrial uses—and W&D by extension—remain an under-explored topic (Leigh & Hoelzel, 2012). Moreover, while a few studies acknowledge the role of zoning in urban freight planning (see *Table 6.1*), there is limited research examining how zoning explicitly governs the siting and spatial organization of freight-intensive land uses. This research gap is especially salient from an EJ perspective (Fried et al., 2023; Tejada & Conway, 2024).

The purpose of this paper is to synthesize the state of recent U.S. zoning action responses to W&D development, with a focus on actions that center EJ principles. Our study:

- analyzes 92 zoning action cases at the municipality, county, and state levels;
- builds a typology that captures the breadth of discretionary and regulatory zoning actions taken, including considerations for long-term planning;
- assesses the level at which EJ principles feature in or inform these actions; and
- discusses the integration of “zoning for [FELU/proximity] logistics” into a broader EJ context.

What this study labels as “zoning actions” are elements of local and regional land use policies that can constitute a broader approach to managing urban freight transport, controlling emissions, and enhancing public participation. *Fig. 6.2* presents these actions as hierarchical: a long-term plan may introduce “Place Types” that include new W&D definitions, development standards,

and use conditions. Denying a rezoning permit, on the other hand, may not result in any higher-level change.

Analyzing zoning actions present challenges distinct from similar, national-level approaches to synthesizing urban freight planning strategies (e.g., Maxner et al., 2025). Despite state standardization laws homogenizing many jurisdictions' zoning codes, local regulations shaping W&D development can vary widely (Yuan, 2019). Neighboring municipalities typically do not coordinate freight-related land use decisions (Dablanc & Ross, 2012), sometimes using regulations and taxation in competition with each other to attract (or discourage) new industrial development (Chapple, 2018; Walker & Lewis, 2001). States also vary in the level of “police power” granted to local jurisdictions to govern private property rights, and institutional differences between zoning councils or boards can significantly influence decision-making (Moore & Caporale, 2023).

There is no unified approach to zoning for logistics, and the extent to which zoning includes EJ principles varies across geographic and regulatory contexts. The following section describes our case study methodology to capture a typology of W&D-related zoning actions across the country.

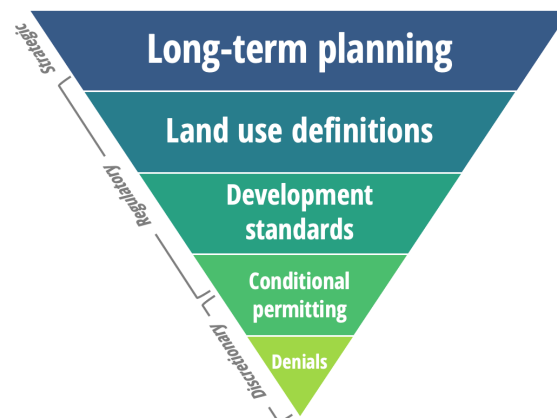


Fig. 6.2: How zoning actions (center pyramid) fit into broader urban freight planning strategies.

6.3 Methodology

“EJ principles” are central to this study’s analytical framing. Through its *Planning Advisory Service (PAS) Report 608*, the American Planning Association (APA) highlights strategies that

incorporate EJ principles into zoning codes, maps, and public participatory processes (Quattro, 2024). We distill definitions important to our approach:

- **Disparate impact** is a “discriminatory effect by a law on a [Title VI] protected class” (p.12). The discriminatory effect may often be unintentional.
- **Exclusionary zoning** restricts land uses that home-owners, typically, perceive to threaten property values (Whittemore, 2021).

A zoning action creates disparate impact if it, e.g., attracts W&D to overburdened or historically marginalized communities, or otherwise fails to mitigate its negative impacts. Exclusionary zoning can be a complementing force, e.g., prohibiting W&D in wealthier single-family towns and neighborhoods. Disparate zoning can *pull* W&D to marginalized areas or make them easier to locate there; meanwhile, exclusionary zoning can make development more difficult in non-marginalized areas, effectively *pushing* these land uses away (e.g., Rothstein, 2017; Trounstein, 2020).

Public participation is also important to this study’s approach. As the APA (2022) argues, “informed participation is critical to eliminating racism and discrimination in zoning” (p.33). Their guide highlights the importance of capacity-building, representation on zoning boards, providing early and multiple public input opportunities for major projects, expanding public notification procedures and virtual engagement opportunities, presenting equity-based review criteria, and lessening the impact of NIMBY opposition by *limiting* public hearings when disparate impacts are not a concern. Subsequently, we sample national case studies and data from multiple sources, in-line with Yin (2017), to synthesize a typology of approaches that incorporate EJ principles into W&D zoning actions.

6.3.1 Sample selection

Our sample presents the forefront of zoning responses to W&D development. It is not intended to represent all zoning-related policies for W&D in the United States. To select our sample cases, we first review policy scans relating to state and local EJ policies to identify regions taking proactive steps in regulating industrial development (e.g., Baptista et al., 2019). We also review open geospatial platforms that track W&D development (e.g., Chicago Cityscape, 2024; Phillips & McCarthy, 2024). Frequently discussed regions include Southern California, Chicago, and the New York City-Newark Metropolitan Area. Next, we review

government websites and recent media reports to narrow our selection of counties and municipalities that have recently enacted zoning ordinances or permit reviews related to W&D. To expand the sample's geographic scope beyond these starting regions, we conduct a keyword search on recent media reports covering W&D development trends. We use two news aggregators (*Newsbank Inc.* and *Google News*), and the following search string:

("environment" OR "environmental justice" OR "pollution" OR "truck traffic" OR community OR zon* OR "overlay zon*" OR moratorium OR rezon*) AND (warehouse OR "distribution center" OR "delivery station" OR "fulfillment center" OR "last*mile").*

We review online, U.S.-based articles and exclude those with headlines and abstracts that do not concern W&D-related zoning (e.g., excluding articles pertaining to labor disputes). After pulling relevant municipalities, counties, and states from the articles, we conduct a deeper review of government documents to determine their relevance. This approach systematically captures the breadth of *recent* zoning responses to W&D development, especially in suburban locales where industrial zoning environments are largely overlooked despite the regional nature of logistics (Dablanc & Ross, 2012). In total, our study identifies 92 cases at 67 locations (51 municipalities, 9 counties, and 7 states) (*Fig 6.3*). "Cases" represent a zoning amendment, discretionary council action (pending or approved), or a state law with explicit mention of W&D uses. Accordingly, some locations offer more than one case. In the appendix, we provide tables summarizing key demographic and policy information in the sampled jurisdictions (*see Tables A1-A3*).

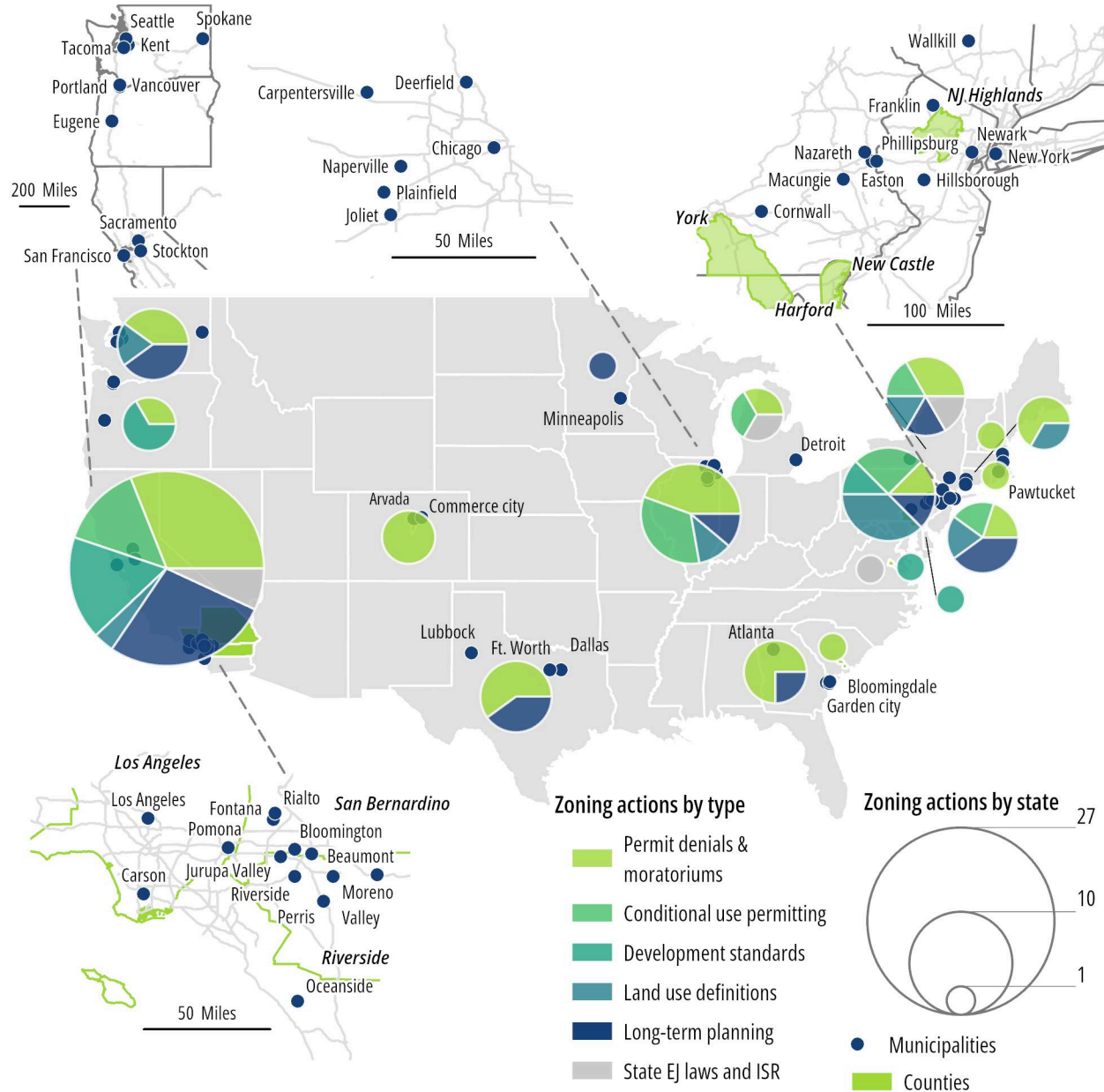


Fig. 6.3: Sampled W&D-related zoning actions (n=92)

6.3.2 Data sources

While media reporting helps narrow our case selection, we prioritize our analysis to primary sources when publicly available. Public documents serve not just as evidence for what they report, but as reflections of social contexts and meanings that require interpretation (Atkinson & Coffey, 2004). We include policy/ordinance texts, government memos, council

meeting agendas/transcripts, zoning codes, long-term plans, websites/reports from developers, legal, and advocacy groups—among other sources. In total, we use 213 documents to analyze the 92 cases.

These sources serve as data in a document analysis methodology (Dalglish et al., 2020), which is applicable to case studies that construct rich, comparative descriptions and typological frameworks (Katsela et al., 2022). However, generalizing case findings typically requires triangulation from multiple data sources. For instance, focusing solely on zoning texts and processes overlooks important supply chain and agglomeration factors that influence W&D siting (Kang, 2020; Rivera-Gonzalez et al., 2023), as well as instances of non-conformity where an existing land use does not match its designation on the zoning map (Hirt, 2013). Analyzing where W&D *can* locate is not the same as analyzing where they *are* located and *why*. Future studies could integrate mixed-methods, such as spatially analyzing zoning maps and W&D locations (Tejada & Conway, 2024) and conducting interviews (Bjørgen & Ryghaug, 2022).

This study achieves triangulation through multiple investigators. Authors each worked independently on a subset of case documents, with major policy documents reviewed by several authors to ensure robust interpretation. The authors met regularly to cross-verify interpretations and to minimize single-researcher bias, and without documented disagreement. We also provide access to our case study spreadsheet that summarizes the coding structure and contains links to analyzed documents to establish a chain of evidence that ensures replicability of findings (Yin, 2017).⁷

6.3.3 Zoning action typology

In conceptualizing FELU, Holguín-Veras et al. (2022) analyze W&D-related zoning actions. Though they identify a zoning typology that serves as an initial structure for our coding analysis, the study does not consider EJ issues. For instance, the authors suggest it is “natural” that communities support relocating major W&D away from their homes, and acknowledge the potential for unintended consequences (p. 66). They highlight the case of the Port of New York, where in the 1950s, authorities relocated major port activity from Manhattan to a less freight-efficient location in Newark. Though not discussed by the authors, this relocation also highlights the institutional, push-pull dynamics described above. Jacobs (1961) famously linked

⁷ DOI for summary of coded data and links to all sources analyzed: <https://doi.org/10.5061/dryad.qiq2bvqsm>

urban renewal efforts to the displacement—or *push*—of workers and some industry from Manhattan. Meanwhile, in Newark, a combination of factors facilitated the *pull* of industries into immigrant and working-class neighborhoods. Receiving communities, such as the Ironbound, remain *de facto* environmental “sacrifice zones” to this day (Winokur, 2020). Therefore, an EJ perspective focuses not just on where W&D are located or relocated, but on the cumulative and disparate impacts it causes.

Another significant omission of EJ perspectives in urban freight planning is the lack of consideration for meaningful public participation (Fried et al., 2023). In recent years, planning efforts have expanded to include more extensive community engagement for major freight-related projects (Fried & García, 2024, pp. 193–195). Nevertheless, discussions on integrating freight stakeholder consensus into planning focus primarily on public- and private-sector decision-makers (Holguín-Veras et al., 2022, pp. 24-26).

Integrating EJ into zoning strategies for freight-efficient development requires considerations for public health protections and meaningful participation for communities disparately impacted by freight transport. Holguín-Veras et al.’s typology serves as conceptual themes that support a structural coding analysis of selected documents (Saldaña, 2009). Structural codes segment the data into thematic typologies pre-determined by existing research, which we then supplement with additional data; in our case, by coding for *in vivo* and descriptive mentions of EJ principles. These pre-coded typologies are:

- Long-term planning (n=17) offers comprehensive land use goals and timelines for policy implementation.
- Regulatory controls (n=17) include ordinances and zoning text amendments.
- Discretionary approaches (n=45) include case-by-case decisions made by zoning boards or councils.

We also examine state-level laws that may not amend local zoning *per se*, but will impact W&D development through environmental preemption and regulatory guidance (n=13) (see *Appendix Table A3*). Our coding method identifies additional sub-typologies embedded in regulatory controls (*development standards* and *land use definitions*) and discretionary approaches (*permit denials/moratoriums* and *conditional use permitting*). Long-term planning strategies also contain nuance. In some cases, planning documents are largely vision-based or suggestive with limited regulatory requirements (e.g., model ordinances). Others align economic and

socio-environmental goals with broad overhauls to zoning codes. While the study mostly analyzes approved permit decisions and regulations (n=51), we also include proposals that are still pending decisions and strategic plans/model ordinances that inform best practices. We review the results below.

6.4 Results

Fig. 6.4 summarizes the 92 zoning actions by type, year, region, and status. Most zoning actions occurred recently (76 occurred after 2020), which may be an outcome of increased media and political attention or newer state environmental laws concerning W&D and EJ issues. In 2016, for instance, California passed SB 1000 that required local agencies to include EJ elements into strategic plans. Most approved or proposed zoning actions in the state cite the policy. However, most actions outside of California—and long-term planning documents in major cities—do not cite EJ principles. The following sections describe some notable exceptions across zoning action types.

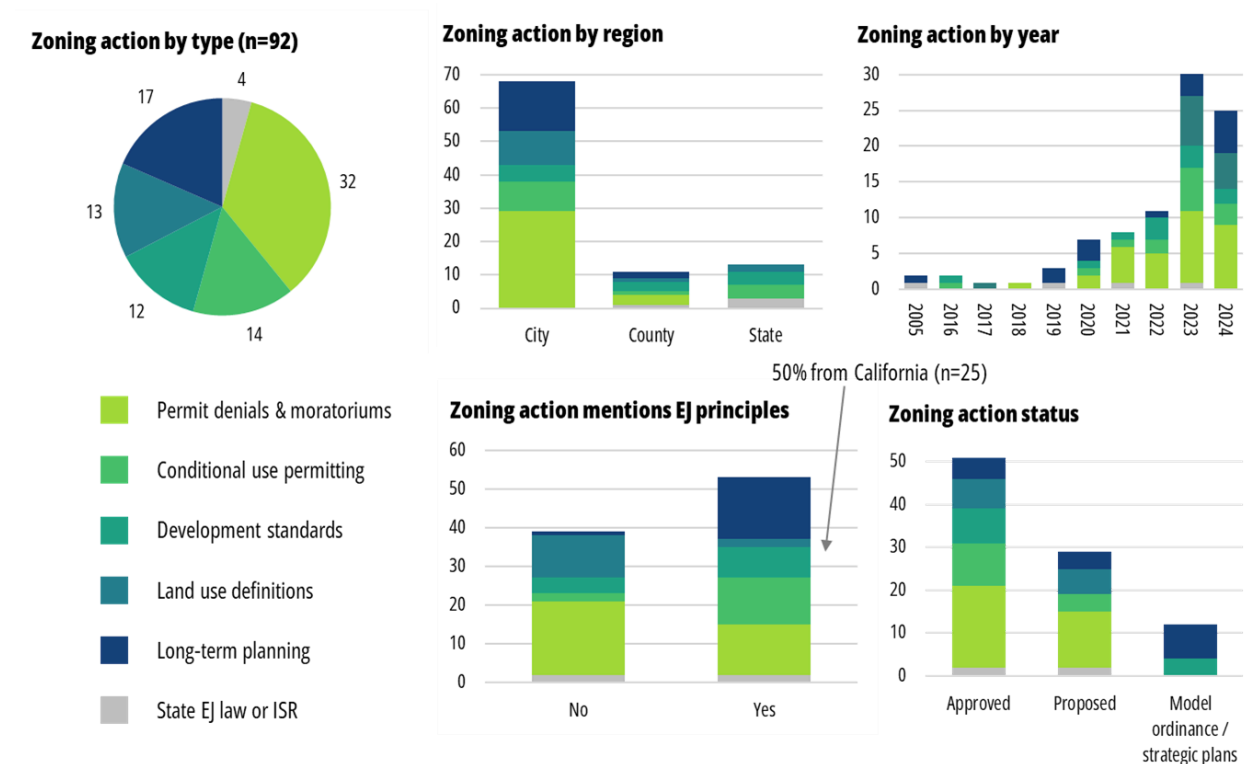


Fig. 6.4: Overview of sampled zoning actions.

6.4.1 Permits & moratoriums

Moratoriums and permit denials are the most common response to newer W&D (n=32). Denials apply to projects seeking discretionary permitting, such as for rezoning and variance applications. Moratoriums temporarily pause applications until cities enact more proactive policy measures, developers complete certain impact assessment studies, and/or implement agreed-upon traffic mitigation measures or Community Benefits Agreements (CBAs). During discretionary permitting processes, zoning councils are often required to solicit community input through public hearings. In some cases, developers revise site plans in response to community input. In Oceanside (California), the developers offered a reduced floorspace and loading zone plan for a proposed facility in an Airport Overlay Zone. In others, communities can pressure developers to withdraw projects. In West Dallas, the developer dropped a planned 277,000 sq ft distribution center after litigation from a church congregation that alleged environmental racism.

Since most zoning codes permit W&D development “by right,” the reasons for denials or conditions are project-specific. *Figure 4* summarizes denied and review-pending projects. Nearly half of projects are greenfield development (i.e., rezoning agricultural land to industrial), while a quarter are brownfield (i.e., repurposing abandoned industrial or contaminated sites). Only 9 seek to develop smaller micro-fulfillment/last-mile, mixed-commercial facilities, or adaptively reuse abandoned commercial sites. As such, most projects are expansive: the average facility size is roughly 1 million sq ft in floorspace. The largest proposal is a 6 square-mile logistics park in Will County, Illinois.⁸ The proposal’s size and infrastructure needs created an ongoing annexation dispute between nearby villages and Joliet, the state’s third largest city and a major intermodal freight hub.

⁸ Not visualized in the *Figure 3* boxplot, as expected facility floorspace is unknown.

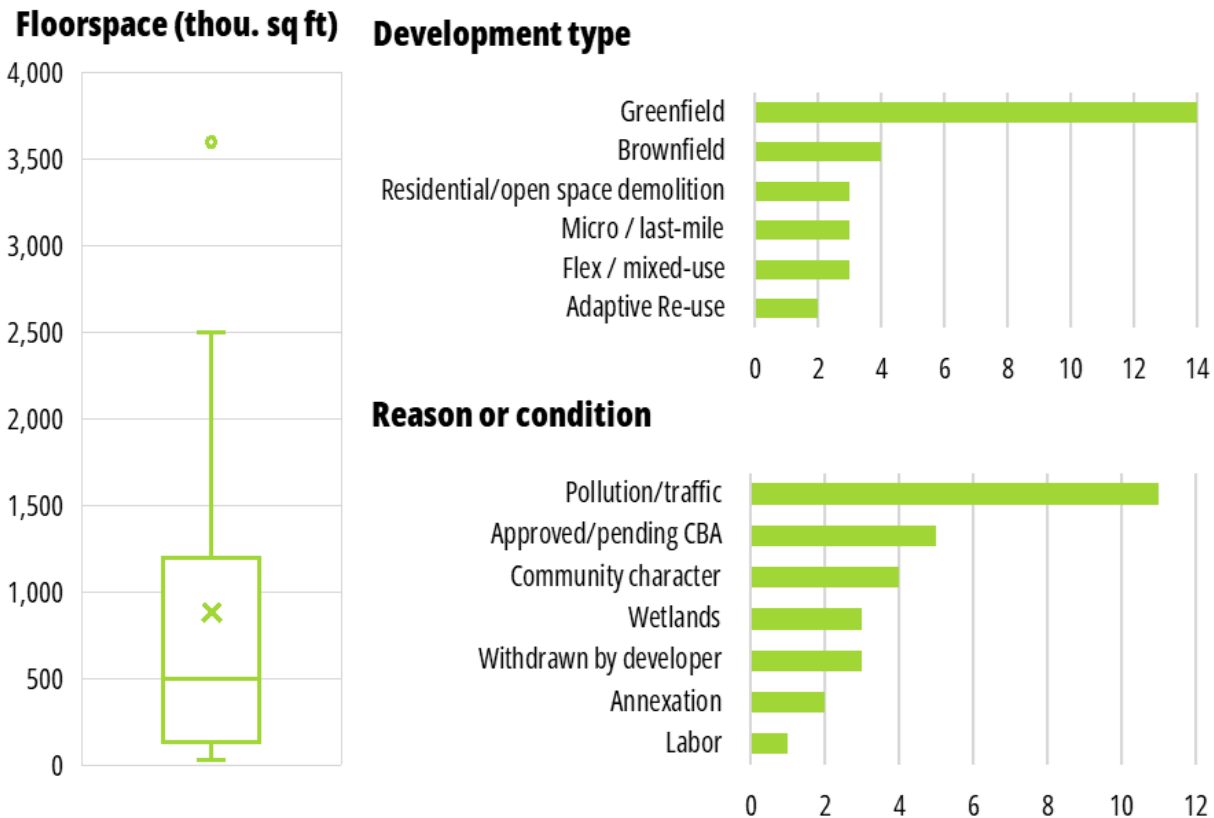


Fig. 6.5: Summary of permit denials and pending decisions by size, development type, and council-stated reasons for denial or conditional approval (n=29). Figures do not include moratoriums that are not project-specific (n=3).

Though pollution and traffic are common concerns, only 1 in 3 cases raise EJ issues. Other cases frame their opposition to new W&D around other issues. For instance, New Castle County, Delaware’s planning board emphasizes the preservation of “community character” in reviewing new W&D permits (see *Fig 6.5*). In contrast, cases explicitly citing EJ concerns include:

- **Detroit, Michigan** granted developers \$33 million in tax incentives to redevelop the abandoned American Motor Corp. headquarters with an 800,000 sq ft W&D. The project fell \$2 million shy of the \$75 million threshold that would require a CBA between the developer and the low-income neighborhood (Saha et al., 2024).
- In **Bloomington, California**, an unincorporated municipality in San Bernardino County and home to predominantly Spanish-speaking residents, developers demolished 117

houses and an elementary school to build a 213 acre logistics park. Community groups successfully litigated the County, alleging the development violated state environmental protections and that the County failed to provide Spanish-language notices and hearings. The developer must re-do the Environmental Impact Review and site plan, which will include provisions for a CBA.

- **Pawtucket, Rhode Island** is considering the sale of a public baseball field to a developer seeking a 500,000 sq ft W&D. Residents of the low-income neighborhood claim the baseball field is the only accessible greenspace in the district. State laws require permissions from state and national agencies before the council can sell public land to developers. The state Department of Environmental Management raised EJ concerns surrounding the sale.
- **Tacoma, Washington** approved a 150 acre development on an abandoned rail terminal, which neighborhood groups unsuccessfully appealed in 2023. The state Department of Ecology leveraged its authority over stormwater management to pause the project and secure a \$9 million settlement to support air quality monitoring and traffic mitigations.

In the latter 3 cases, state environmental agencies play a mediating role in development outcomes (e.g., requiring full environmental reviews or prescribing mitigations), though state agencies are limited in their ability to stop or conditionalize development without preemptive policy. However, in addition to *ad hoc* council decisions on development permits, jurisdictions also deliberate on what projects necessitate further conditions and public participation through conditional use permitting.

6.4.2 Conditional use (CUP)

Conditional use permitting (CUP) or authorization (CUA), constitutes 14 cases. CUP establishes additional criteria for development before discretionary permit approval. These criteria can encompass impact reporting, facility operations, and public participation processes. *Table 6.2* summarizes five prominent CUP provisions in major population areas.

	Ordinance	Applicable W&D facilities	Conditions for approval
Chicago	Air Quality Ordinance	- Facility lots > 10 acres; - Facilities < 660 ft from sensitive use	- Devs complete traffic study and air quality study - Devs host at least 1 community meeting in host district - Dev standards subject to Planned Development

			uses
San Francisco	Parcel Delivery Service CUA	- All uses except for cannabis-related facilities - Conditions for facilities > 5,000 sq ft	- EV charging installation - Devs complete traffic and emissions study - Commission complete economic study (jobs, public revenue) - Idling no more than 3 minutes - Facility is primary use
New York City	Last-mile Warehouse Special Permit (proposed)	- Facilities > 50,000 sq ft - Primary use is e-commerce	- Facilities > 1,000 ft from sensitive use - Facilities > 1,000 ft from other last-mile facilities - Some facilities conduct 80% of delivery via marine transport - Devs complete traffic and air quality study - Devs submit annual report on truck usage - Commission may request conditions (e.g., EV/bike adoption)
Sacramento	Truck usage in N. Sacramento (interim ord.)	- Facilities in industrial zones; - Facilities <1,000 ft from sensitive use - Major modifications of existing facilities subject to review/hearing.	- Not specified
Los Angeles County	Green Zones	- Facilities in GZ overlay - Facilities > 100,000 sq ft - Facilities < 500 ft from SR	- No outdoor loading operations 6:00pm - 8:00am - Idling no more than 5 minutes - WAIRE compliance - Zero emission off-road and landscaping equipment - 100 ft buffer on lot line closest to sensitive uses - Permitting varies by impacts determined in Site Plan Review

Table 6.2: Overview of CUP processes in major jurisdictions.

Most CUP place facility size and distance from “sensitive receptors” (SR) requirements for W&D facilities. Chicago places thresholds of 10 acres and 660 feet from housing, open spaces, hospitals, daycares, and schools. The ordinance raises criticism from both developers and EJ groups. Developers claim district-level discretion—or member deference—creates uncertainty in what traffic and air quality mitigations are acceptable for approval, and can freeze development altogether. EJ groups argue the ordinance does little to stop-gap development if burdens are high or ensure community input is captured in projects. Meanwhile, only NYC and San Francisco’s CUP provisions consider implications of last-mile delivery. While San Francisco’s implementation adds restrictions to facilities regardless of size, NYC’s version explicitly seeks to reduce development near schools, parks, nursing homes, and public housing. The latter city offers conditions for development, including the adoption of e-cargo bikes and waterborne freight modes to mitigate traffic impacts.

Green Zones (GZ) also aim to minimize industrial concentration in disadvantaged communities. Los Angeles County defines GZ as regions with a high concentration of stationary pollution sources near SR, among other demographic indicators. While the regulation sets development standards for many existing and future W&D within GZ, it also institutes a tiered discretionary process that includes public hearings and appeals for site plans deemed the most impactful.

When and *how* developers and planning boards engage the public are central facets to CUP processes. Los Angeles County requires notices for residents within 300 to 500 ft of the project and a 15 to 30 day comment period, depending on project impact. New Jersey’s EJ Law requires “meaningful” public participation within 200 ft of the project area and a 60 day comment period. The state’s guidelines recommend multi-language circulation of project plans in newspapers and social media, as well as invitations to local EJ groups, schools and daycares, and faith-based organizations for in-person and virtual meetings.

CUP offers flexibility to deny or modify development to suit local contexts and community needs. However, their discretionary nature raises concerns from both community groups and developers, especially in cases where limited state guidelines and protections exist. On the other hand, development standards and land use definitions offer firmer regulatory controls that can dictate where facilities can locate and how they operate, particularly near SR.

6.4.3 Development standards

Enhanced development standards constitute 12 observations in the sample, including 1 approved state-level policy, California’s AB-98, and 3 model ordinances from PennFuture (a Pennsylvania-based nonprofit), New Jersey, and California Attorney General Rob Bonta. Development standards offer construction, site design, and operational requirements—or best practices—that can minimize traffic-related impacts, particularly, for nearby SR. Definitions for SR vary across zoning codes and state policy. They can encompass residences, schools, daycare centers, health clinics, nursing homes, places of worship, parks, community centers, and historical sites.

Development standards commonly increase buffering and screening requirements for lot lines adjacent to SR. Observed buffers vary widely, ranging from 10 ft setbacks to a 500 ft separation between truck loading doors and an SR property line (see *Fig. 6.6*). However, the

buffer distance necessary to effectively mitigate adverse health effects from truck traffic remains an open question. Air pollution, for instance, can exceed background concentrations within 500 and 1,600 ft of major roadways, depending on wind-direction and vehicle operating conditions (Samuels & Freemark, 2022). Vegetative screening can improve pollution absorption, including for noise and ground contaminants; however, its effectiveness varies between pollutant type, vegetation density, and species composition. Standards can also require truck routing and facility entrances to orient away from SR, and place maximum times on truck idling. All 4 state-level actions and 3 local-level actions (e.g., Stockton, California for W&D >100,000 sq ft) require zero-emission offroad equipment, solar-readiness, and heavy-duty EV charging readiness—even offering regulatory exemptions for facilities serving zero-emission trucks.

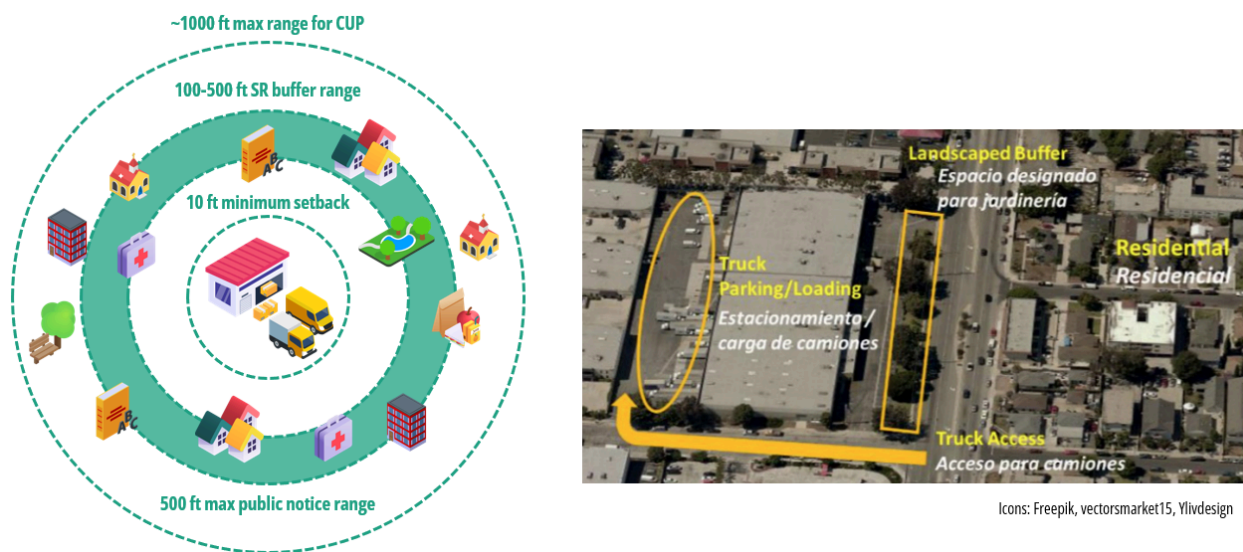


Fig. 6.6: Observed buffer ranges in sampled development standards (n=12) and example of SR-based site design for W&D (Source: Los Angeles County, 2024)

All state-level development standards enhance public participatory procedures. PennFuture proposes W&D developers submit a community impact analysis to inform council decisions. While impact analyses theoretically hold developers environmentally accountable, conflicts arise when data and methods are not openly communicated. For instance, communities in Tacoma and Commerce City, Colorado question the impartiality and accuracy of developer-determined traffic impacts. New Jersey’s model ordinance and Bonta’s (2022) W&D best practices emphasize the importance of early and robust community engagement, including

strong communication practices. They propose creating a technical advisory group with seats dedicated to community members, as well as enforcing CBAs to compensate impacted residents.

California’s AB-98 stipulates a more data-driven accountability approach. The bill calls for the deployment of mobile air monitoring systems in Riverside and San Bernardino counties to measure air pollution in communities near logistics land uses. Revenues generated from South Coast Air Quality Management District’s (SCAQMD) Warehouse ISR also fund efforts that improve air quality in areas with high W&D concentrations. Funds include rebates for zero and near-zero emission trucks, charging infrastructure, and air filtration systems in homes and SR near W&D.

6.4.4 Land use definitions

Land uses definitions determine where W&D are permitted by-right, their general purpose, and can specify development standards and CUP provisions. The sample includes 13 cases featuring 11 distinct definitions of W&D with some overlapping terminology (see *Table 6.3*). Precise definitions can be important for targeting effective site-mitigations and participatory processes for facilities with the most significant traffic impacts. However, as PennFuture argues, developers often build W&D “on speculation” with limited information about future tenants and their traffic generation. Their model ordinance, instead, recommends defining standards based on expected facility size.

Nevertheless, W&D are permitted in nearly all industrial zones regardless of definition and size. Few cases permit W&D in denser commercial and mixed-use zones. Most notably, NYC’s “City of Yes” initiative recommends “micro distribution” facilities in Manhattan’s neighborhood commercial districts (W&D <2,500 sq ft) and central business district (ground-floor W&D <5,000 sq ft) to encourage cargo bike mode-shift and improve last-mile efficiency.

Observed W&D classifications	Common use definition(s)	Typically permitted zones
Mini Warehouses, Mini Storage, Self Storage	Enclosed storage spaces for rent or lease to the general public, including self-storage facilities.	General/light industrial, commercial, some mixed-use overlays
Micro Fulfilment, Micro Distribution	Short-term storage of goods intended for on-demand home delivery; floorspace between 2,500 and 30,000 sq ft.	General commercial, light and medium industrial, some mixed-use overlays

Last-mile Fulfilment, Local Delivery Center, Parcel Delivery Service/Facility	Temporary storage, sorting, and redistribution of e-commerce goods for last-mile delivery, typically truck-to-van cross-docks.	General and light industrial areas, airport and port overlays
Fulfilment Centers	Longer-term storage of e-commerce goods, characterized by higher frequency truck traffic and extended-hour operations.	General and light industrial
High-Cube Facilities	High-automated storage or goods consolidation, characterized by higher frequency truck traffic. Can exceed 250,000 sq ft in floorspace and 50 ft in height.	General and light industrial, airport and port overlays
Retail Sales Warehouse	Wholesale retailers that emphasize the packaging and sale of products in large quantities or volumes.	General and light industrial, general and auto-dependent/highway commercial
Logistics/Distribution/Break-bulk Facilities	Storage and/or cross-docking of manufactured goods, and (sometimes) raw or hazardous materials, characterized by higher frequency truck traffic. Can exceed 250,000 sq ft in floorspace.	General and light industrial, airport and port overlays
Cold Storage	Refrigerated storage, wholesaling, and distribution facility for temperature-sensitive items. May require auxiliary power for refrigerated trucks to limit idling during loading.	General and light industrial, airport and port overlays.
Outdoor Storage	Outdoor pallet/container storage for any purpose besides display and truck terminals.	General and light industrial, general and auto-dependent /highway commercial
General\Traditional Warehousing and Storage	Indoor long-term storage of goods, which may include sorting/cross-docking/value-added services.	General and light industrial, some mixed-use overlays, airport and port overlays
Freight/Truck/Intermodal Terminals	Indoor or outdoor storage and transloading, typically serving rail and long-haul trucking, characterized by heavy truck traffic.	General industrial, some port overlays

Table 6.3: Observed definitions of W&D and permitted zones (Table created by Tejada)

In general, however, sampled land use amendments create further restrictions on W&D. Definitions are powerful tools that jurisdictions can use to “zone out” or exclude certain types of W&D from light industrial zones, or even industrial development entirely. Vancouver, Washington prohibits W&D >250,000 sq ft from light industrial zones citing air pollution and climate concerns, while Deerfield, Illinois—a wealthy Chicago suburb—removed several W&D definitions from permitted light industrial uses. These amendments, according to developers, can effectively freeze W&D development within the jurisdiction. However, there is little indication that these changes are intended to deconcentrate freight activity in historically burdened communities. For instance, we observe no regulatory cases of phasing-out W&D that stop conforming to amended land use definitions, such as through an amortization clause—a proposal

advanced by EJ groups in Lubbock, Texas. Restricting W&D expansion without relocating or mitigating the cumulative burdens of existing facilities fails to address disparate freight impacts.

6.4.5 Long-term planning

Explicit references to EJ principles in long-term planning documents vary widely. Atlanta and Dallas cite EJ principles in their “Place Type” zoning reform, a hybrid code informed by form-based principles, though only offer broad considerations for urban freight and industrial development. Meanwhile, Minneapolis adopts a GZ model, although with less regulatory control than its Los Angeles County counterpart.

Generally, secondary city/suburban plans contain less provisions for reducing disparate impacts than center cities. Plans center economic goals to preserve industrial land and encourage flexible, higher-density industrial development. Carson, adjacent to California’s San Pedro Bay Ports, designates several Flex Districts that mix commercial, residential, and light industrial uses up to 5-stories. These districts permit W&D less than 30,000 sq ft. However, the plan more explicitly promotes higher-tech manufacturing rather than freight-efficient development. This goal mirrors Kent’s (Washington) emphasis on boosting competitiveness in the aerospace sector by imposing restrictions on truck loading doors that limit W&D development. The findings are similar to other studies that observe W&D offer less attractive development opportunities for cities than commercial and manufacturing uses (Dabanc & Ross, 2012).

Newark, New Jersey’s plans encourage more flexible industrial development while enacting policies that seek to mitigate disparate impacts and improve public participation. The city’s EJ and Cumulative Impact Ordinance is a broad CUP provision that establishes public health-based review criteria. Additionally, while their plan mentions removing W&D >50,000 sq ft from light and medium industrial zones, they also propose permitting cargo bike-based micro-distribution models in non-industrial areas. Los Angeles also integrates EJ principles more holistically. The city’s hybrid zoning reform creates flexibility in development (e.g., permitting W&D <50,000 sq ft in some mixed-use zones), while strengthening CUP provisions and “health-related” development standards. It also offers avenues to deconcentrate industrial land in overburdened communities: one ordinance in Wilmington-Harbor City prohibits new truck terminals, with the exception of those using zero-emission fleets.

Meanwhile, Seattle's Industrial and Maritime Strategy highlights the economic importance of preserving industrial land, while also recommending some industrial rezones in historically marginalized neighborhoods. Seattle also proposes specialized urban industrial zones to buffer neighborhoods from intensive maritime and logistics activity. However, it is less clear whether these zones will permit freight-mitigating W&D and micro distribution uses.

6.5 Discussion and Conclusion

Scholars have long explored the public health effects of disparate industrial zoning (Quattro, 2024), and state-level policy responses (Baptista et al., 2019). When it comes to W&D-related impacts and zoning, however, we observe most local actions rely on or enhance discretionary procedures. Of these, a minority of non-California cases consider EJ principles. While our study offers examples of councils and developers aligning with EJ groups—usually following litigation—these processes come with drawbacks. For instance, appealing a W&D development at a public hearing may require a level of participation (e.g., attending a workday meeting at City Hall) that presents barriers for many marginalized population groups. Moreover, public hearings may have little bearing on council decisions (Moore & Caporale, 2023; Whittemore & BenDor, 2019). As such, the statutory minimum for public participation and council discretion does not guarantee EJ outcomes.

On the other hand, zoning regulations can enhance standards for development and public participation, as well as redefine industrial uses near marginalized populations. We outline several measures that intend to mitigate traffic-related impacts for nearby SR. However, it is unclear whether protections are sufficiently robust. A 100-foot buffer around a new W&D may not reduce chronic hazard exposure for nearby populations, especially near industrial areas and major truck routes where concentrated freight activity generates pollution and other cumulative impacts that can extend well beyond property lines. While most observed zoning actions restrict by-right W&D development, improving health outcomes in communities most affected by freight traffic is a rarely cited goal. Exceptions typically cite state laws and long-term planning objectives, pointing to the important role played by state environmental preemption and planning in local governance (Baptista et al., 2019; Yuan, 2019).

However, tightening W&D regulations adds development costs that risk the relocation of facilities to less freight-efficient areas (Holguín-Veras et al., 2022), and—if EJ is not

considered—into economically and politically marginalized communities. Long-term planning can help identify scenarios for when to stop or conditionalize W&D development in overburdened communities, and when to relax controls and apply incentives to encourage FELU and proximity logistics. These strategies will vary by context, as jurisdictions must frequently balance competing political, social, and economic pressures—such as demands to preserve urban industry or expand housing supply through rezoning industrial land (Chapple, 2014). *Fig. 6.4* outlines pathways toward equitable development for urban freight in cases of disparate and significant impacts. These cases require public participation measures that identify how FELU/proximity logistics can meet local needs, including those of marginalized communities.

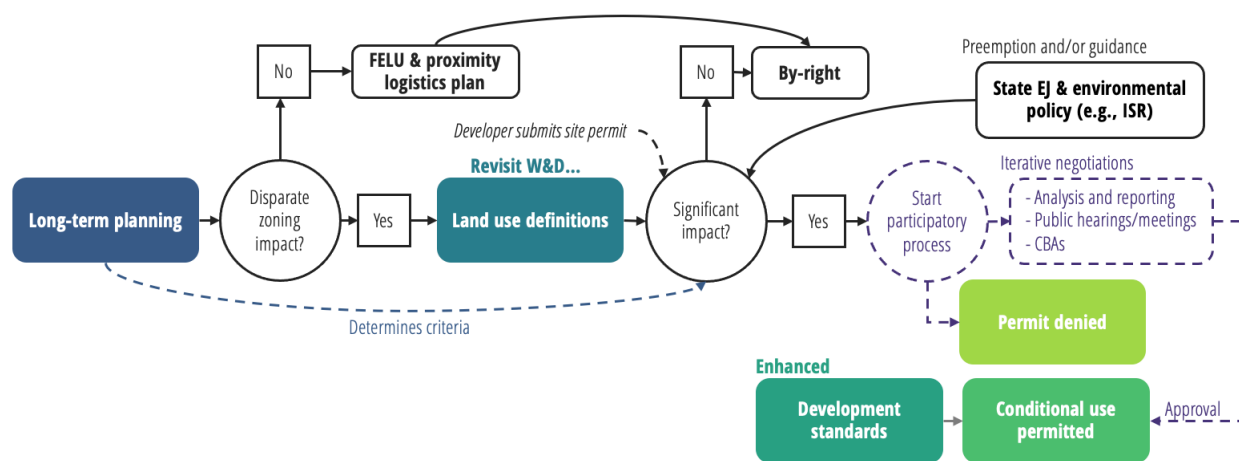


Fig. 6.4: Decision pathways toward equitable and healthy development for urban freight

6.5.1 Implications for Compact Logistics

Better integrating W&D into urban areas, particularly outside of industrial zones, will face challenges. Since its inception, zoning has served to shield homeowners from the noise, pollution, and working-class apartment buildings that industrial activities entailed (Hirt, 2014). Our results suggest these exclusionary dynamics persist today. EJ activists in Newark and coastal Georgia—where low-income and minority communities have long borne a disparate share of freight impacts—argue that serious policy attention toward “warehouse sprawl” emerged only after W&D began encroaching on wealthier, predominantly single-family towns. This observation echoes findings from Scally and Tighe (2015), who show how homeowners can leverage environmental concerns to oppose developments they perceive to threaten property

values, namely those associated with increased traffic or low-income housing. For example, Bloomingdale, Georgia’s moratorium includes both W&D and multi-family residential development. In another instance, a Connecticut state legislator used a budget amendment to restrict W&D in towns with populations between 6,000 and 8,000—effectively blocking a W&D project in a high-income town within their district. The same legislator later opposed a mandated housing density bill, citing the need to preserve home rule.

NIMBYism is also likely to challenge W&D in some freight-efficient areas. Partially in response, “new industrial urbanist” scholars propose strategies for improving the compatibility of industrial uses with nearby residents and businesses (Ferm et al., 2021; Hatuka & Ben-Joseph, 2022). Research offers context-specific designs for mixed-use industrial facilities and their architectural interfaces with neighborhoods (Boeck & Ryckewaert, 2020; Lane & Rappaport, 2020), and for Complete Streets and place-making strategies that integrate people and goods mobility (Buldeo Rai, 2024; Conway, 2024). E-commerce, in particular, has spurred developers to re-urbanize some W&D, at times transforming them into “chic,” low-carbon and mixed-use facilities to blend into neighborhood environments (Marshall, 2020). In that vein, cities should also broaden policies to support EJ and prevent economic displacement (Anguelovski, 2016). Research has only just begun to explore the linkage between reduced W&D density and gentrification (Qin et al., 2024).

One promising strategy involves CBAs, which establish concessions between developers and communities near proposed facilities (Buldeo Rai, 2023). One proposed CBA in San Francisco, for example, includes local hiring quotas, union protections, vehicle electrification requirements, and funds for greenspace, solar roofs, transit, and affordable housing. By providing tangible benefits, CBAs can supplement the oft-problematized economic promises associated with logistics-related development (Fried & García, 2024), while also better integrating W&D into urban environments.

6.5.2 Conclusion

The rapid expansion of W&D prompted a wave of local and state regulations seeking to mitigate urban freight’s disparate and adverse impacts. Our study is a first effort to synthesize the state of recent W&D-related zoning actions as a tool for protecting public health, particularly, in areas historically burdened by freight traffic. We offer the following takeaways:

- **Local jurisdictions lack a unified regulatory approach to W&D.** Discretionary permitting is the most common response to new W&D development. These approaches can offer important opportunities for public participation and enhanced development conditions; however, without higher-level policy, development may not align with planning or community priorities.
- **Zoning actions largely restrict W&D.** Most regulatory controls add definitions, standards, and conditions intended to limit by-right development. Some exceptions include cities updating zoning codes to allow for mixed-use, micro distribution.
- **EJ principles are not a central feature in most observed restrictions.** Most actions cite aesthetic or environmental concerns unrelated W&D's disparate impacts—a possible indicator of broader exclusionary zoning practices that research links to contemporary socio-economic and racial segregation (e.g., Rothstein, 2017; Trounstein, 2020), and health disparities (e.g., Prasanth et al., 2024).
- **Local jurisdictions with EJ-explicit actions have supporting long-term plans, as well as state policies and guidelines.** To borrow from Yuan (2019), local planning matters. But, so does state policy (Baptista et al., 2019). Ensuring EJ factors into freight-related land use decisions require clear strategic priorities and environmental safe-guards for vulnerable communities.

Our study comes with limitations that offer future avenues for research. First, we do not analyze zoning maps, which one would need to determine the extent of disparate zoning in our sample (Quattro, 2024). Including zoning maps, however, would have made it difficult to evaluate the quantity and heterogeneity of jurisdictions included in the study, especially given the limited availability of open land use data. Ongoing initiatives like the National Zoning Atlas can help support nationally comparative zoning analyses (Safavian et al., 2024). However, the Atlas offers limited information for non-residential land uses as of 2024.

Second, we do not consider spatio-economic and supply chain factors that influence W&D siting decisions (Kang, 2020; Rivera-Gonzalez et al., 2023). As Bowen et al. (2009) suggest, economic agglomeration factors may outweigh institutional and socio-demographic factors in explaining disparities in industrial facility siting. Moreover, developers and property owners can play an important role in mitigating freight's negative externalities (Brettmo & Sanchez-Diaz, 2022). Future studies can explore the role of incentive zoning, e.g., Tax Increment

Financing, which can potentially support these private-led actions (Holguín-Veras et al., 2022). After all, zoning for more equitable and healthy urban freight does not guarantee that such development will occur.

Appendix

	Long-term planning count	Regulatory action count	Discretion ary action count	Tot. pop (thou.)*	Justice 40%*	LQ 2022**	HH Median Income 2023	POC%
New York (NY)	1	1	1	7,783	54.8	1	\$79,713	68.2
Los Angeles (CA)	1	1	-	4,056	56.2	1.1	\$80,366	72.4
Chicago (IL)	1	1	1	3,028	54.7	1.5	\$75,134	65.5
Dallas (TX)	1	-	2	1,215	55.7	1.4	\$67,760	67.3
Detroit (MI)	-	-	1	804	82.4	0.9	\$39,575	78.3
Fort Worth (TX)	-	-	1	736	45.2	3.6	\$76,602	60.2
San Francisco (CA)	-	-	2	666	34.1	0.8	\$141,446	60.6
Portland (OR)	-	-	1	617	16.5	1.6	\$88,792	28.9
Sacramento (CA)	1	-	1	499	47.3	0.9	\$83,753	65.2
Seattle (WA)	1	-	-	493	15.6	0.9	\$121,984	37.5
Minneapolis (MN)	1	-	-	480	28.6	0.8	\$80,269	36.6
Newark (NJ)	1	-	1	415	80.7	5.1	\$48,416	86.4
Riverside (CA)	1	-	-	380	34.8	1.7	\$88,575	71.5
Atlanta (GA)	1	-	-	342	55.4	2.8	\$81,938	65.8
Stockton (CA)	1	1	-	274	76.2	2.2	\$76,851	76.0
Tacoma (WA)	-	-	1	258	40.9	1.2	\$83,857	42.1
Vancouver (WA)	-	1	-	237	17.5	2.7	\$78,156	27.7
Spokane (WA)	-	-	1	203	39.8	1.7	\$65,745	17.9
Naperville (IL)	-	-	1	203	0	1	\$150,937	32.3
Pomona (CA)	-	1	1	201	37.1	1.7	\$78,869	81.2
Joliet (IL)	-	-	1	196	29.5	4.3	\$88,026	42.6
Fontana (CA)	-	1	-	196	60.7	8.7	\$98,187	87.0
Moreno Valley (CA)	-	1	1	194	55.9	9.7	\$87,477	84.2
Oceanside (CA)	-	-	1	191	27.4	0.6	\$93,724	48.2
Eugene (OR)	-	1	-	181	30.4	0.4	\$63,836	19.9
Arvada (CO)	-	-	1	175	3.9	0.4	\$113,396	25.6
Rialto (CA)	-	-	1	171	64.2	9.6	\$85,521	88.6
Kent (WA)	1	1	-	170	22.5	1.9	\$90,416	49.1

Jurupa Valley (CA)	-	-	2	167	31.3	8.3	\$96,190	79.6
Carson (CA)	1	-	-	141	43.7	3.8	\$107,391	92.8
Pawtucket (RI)	-	-	1	135	41	0.5	\$67,436	45.3
Colton (CA)	-	1	-	116	58.7	4.3	\$69,581	82.5
Lubbock (TX)	1	-	-	110	33.1	0.8	\$60,487	46.6
Easton (PA)	-	-	1	85	26.6	0.6	\$63,775	31.1
Commerce City (CO)	-	-	1	71	75.9	6.7	\$106,756	65.9
Beaumont (CA)	-	-	1	69	27.5	1.4	\$105,164	59.2
Perris (CA)	1	1	-	69	45.8	8.3	\$82,523	75.1
Carpentersville (IL)	-	-	1	58	14.4	0.9	\$86,327	52.3
Phillipsburg (NJ)	-	-	1	44	22.3	0.6	\$67,782	25.5
Ithaca (NY)	-	-	1	42	0	0.2	\$48,617	28.5
Andover (MA)	-	-	1	42	0	0.9	\$167,591	24.6
Deerfield (IL)	-	1	-	36	0	0.2	\$189,705	13.7
Hillsborough (NJ)	-	1	-	31	0	0.7	\$142,275	34.2
Franklin (NJ)	-	-	1	24	0	0.4	\$90,152	14.7
Cornwall (PA)	-	-	1	21	0	0.4	\$87,917	10.7
Plainfield (IL)	-	-	1	20	0	0.9	\$142,265	25.3
Macungie (PA)	-	-	1	19	0	3.1	\$74,056	14.0
Nazareth (PA)	-	-	1	10	0	1.1	\$57,551	12.9
Bloomington (GA)	-	-	1	8	0	7.6	\$55,427	19.9
Garden City (GA)	-	-	1	8	74.8	4	\$41,735	76.9
Port Wentworth (GA)	-	-	1	6	0	3.8	\$78,861	18.0
Wallkill (NY)	-	-	1	4	0	0.8	\$94,002	37.0

Table A1: Sampled municipalities

	Long-term planning count	Regulator y action count	Discretionary action count	Tot. pop (thou.)*	Justice 40%*	LQ 2022**	HH Median Income 2023	POC%
Los Angeles (CA)	-	-	1	8,645	49.8	1.1	\$87,760	74.6
NJ Highlands Region (6 counties)	-	1	-	2,741	11.7	0.8	\$119,301	20.2
Riverside (CA)	2	-	-	1,965	41.8	2.9	\$89,672	64.8
San Bernardino (CA)	-	-	1	1,618	46.2	3.9	\$82,184	72.6
Jefferson (CO)	-	-	1	702	6.5	0.3	\$107,800	9.3

New Castle (DE)	-	-	1	532	15.5	1.3	\$89,901	39.3
York (PA)	-	1	-	441	11.4	1.7	\$82,238	16.2
Harford (MD)	-	1	-	302	0.8	1.4	\$111,317	21.0
Dorchester (SC)	-	-	1	181	35.7	1.4	\$76,896	40.0
Hanover (VA)	-	-	1	137	2.4	1.6	\$109,504	25.7

Table A2: Sampled counties

* = Data from the Climate and Economic Justice Screening tool (v2.0) and Census Designated Place (2022) boundary files. Justice40% refers to percent of population belonging to a federally defined disadvantaged community; the archived data and indicator definition is accessible here: <https://edgi-govdata-archiving.github.io/j40-cejst-2/en/#3/33.47/-97.5>.

** = Location quotient for transportation and warehousing sector employment (NAICS 48-49), where a value >1.0 suggests high regional employment in the sector relative to sectoral and overall employment in the United States.

	Preemption/environmental, model ordinances, and other policies
Illinois	- HB 5013: Warehouse Pollution Insights Act (proposed)
Michigan	- HB 5901 (proposed)
Connecticut	- State budget amendment blocked W&D permit in Middlebury, CT
New Jersey	- Warehouse best practices (model ordinance) - Environmental Justice Law (enacted/approved)
Pennsylvania	- PennFuture's warehouse best practices (model ordinance) - HB 1960 (proposed) - HB 782 (proposed)
California	- AB 98 (enacted/approved) - Attorney General Bonta's (2022) warehouse best practices (model ordinance) - South Coast ISR (enacted/approved) - San Joaquin Valley ISR (enacted/approved)
New York	- SB S2127A: Clean Deliveries Act (proposed)

Table A3: Reviewed state policies

Chapter 7: Toward Equitable and Just Spatial Planning for Urban Freight

This dissertation employed an exploratory and sequential, mixed-method approach to examining spatio-racial inequities in residential deliveries—a rapidly growing urban freight segment. Contributed studies not only build an empirical framework for evaluating spatial equity, but an operational and policy framework toward more compact spatial planning for urban freight.

Research and practice in this area are growing quickly. However, there is a need to understand and interrogate the distributive, scalar, and political conflicts that inform freight planning and create barriers for truly equitable outcomes. Doing so raises questions: how do we fairly distribute freight's costs and benefits? How do we balance the market drive for cheap goods and fast delivery, with community demands for good jobs and a clean environment? And who are we (not) including at the negotiating table?

Asking these questions does not reveal simple, socio-technical fixes. Success requires collaboration across geographic scales, public agencies, and the leadership of communities and workers. By way of conclusion, I offer the following considerations for freight planners seeking more equitable outcomes and just processes: follow the goods up, put accessibility first, promote a Just Transition, and partner with communities.

7.1 Follow the goods up

Environmental and health costs do not fall evenly across the distribution chain. Improving the efficiency of receiving and consuming goods disproportionately benefits wealthier, more educated consumers in higher income countries. In fact, the financial competitiveness of some of these delivery models, like sidewalk drones and cargo bikes, often hinge on high customer density (Katsela et al., 2022). By contrast, distribution-oriented strategies target spaces where freight activity is most intense, such as near logistics parks and along commercial corridors.

Other strategies fall outside the boundary of regional and local political jurisdictions. They intertwine with the upstream/downstream power dynamics that define global supply chains. These strategies require a broader political-economic purview. They task local policymakers and even consumers to push companies to adopt greener supply chains and fairer labor practices, and promote those that do.

Commonly, policies promote vehicle and operational efficiency improvements to mitigate the environmental impact of logistics. However, the preeminence of *place* in determining exposure-related health costs suggest aspatial forms of transport-related environmental policy may do little to resolve disparities between marginalized and non-marginalized groups. For instance, Ramirez-Ibarra & Saphores (2023) model the health impacts of electrifying drayage trucks serving Southern California's San Pedro Bay Ports based on the Clean Air Action Plan's 2035 fleet electrification targets. Though electrification reduces the overall health effects of chronic air pollution exposure, they find that disadvantaged communities would still bear 68% of truck pollution-related mortality. That estimate is only 3% less than the disparity presented in the 2012 baseline. Meanwhile, Jaller et al. (2021) find *in situ* route efficiency improvements, such as off-peak delivery, does little to reduce exposure disparities. They recommend using geofences to route trucks around disadvantaged communities.

Other promising environmental strategies target emissions at warehouses located in historically marginalized neighborhoods. For instance, Southern California's South Coast Air Quality Management District (AQMD) passed the Warehouse Indirect Source Rule (ISR) in 2021. The ISR enacts a point-or-fee system for warehouse tenants who operate more than 100,000 square feet of working floorspace. Tenants earn points by selecting from a "menu" of pollution mitigation items: procuring natural gas or zero-emission trucks, installing on-site solar panels, improving facility air filtration, or by paying a \$1,000 mitigation fee. New York has introduced similar legislation with considerations for "zero emission delivery zones" in disadvantaged communities.

7.2 Put accessibility first

However, these policies presume warehousing will continue to concentrate in historically marginalized communities to serve consumers and businesses in farther reaches of the city. Research is exploring the role of land use in compact and freight-efficient development (Buldeo Rai et al., 2022; Holguin-Veras et al., 2021), which conflicts with exclusionary zoning policies that segregate residences, commercial, and logistics land uses. As such, proactive zoning policies are an important area for environmental justice policy (Campbell et al., 2015), sustainable compact development, and integrating logistics into the neighborhoods that demand the most goods.

Cases in Paris and Rotterdam demonstrate how distribution centers can mesh into the community fabric, improve delivery access to nearby businesses and residents, stage cargo bike delivery, and host mixed-use opportunities, such as restaurant wholesalers, recreation centers, and rooftop community farms (Kin et al., 2024). Buldeo Rai (2023) emphasizes warehouses can and should be “good neighbors,” and doing so requires developers and cities to pursue a mix of place-based zoning and environmental policies, community benefit agreements, educational outreach, and Complete Street design strategies.

The delivery services themselves, however, are likely not a silver bullet for improving accessibility for marginalized communities without expanding public support to programs already operating in this space. In the food access sphere, programs could include expanding food purchasing assistance to cover delivery fees on digital grocer platforms. Additionally, while companies demand freight on transit be profitable (Cochrane et al., 2017), economic shutdowns during COVID-19 spurred the expansion of no-barrier grocery delivery by transit agencies in metropolitan Denver, San Antonio, and rural Michigan—all of which continue to operate at the time of this chapter’s writing (Benedict et al., 2020). These examples demonstrate the political will to publicly invest in home-based accessibility.

7.3 Promote a Just Transition

It is difficult to envision a winning scenario where planners mobilize freight systems to enhance accessibility to food or improve public health outcomes while simultaneously destabilizing the workforce that services these benefits. Workers in the logistics sector, especially sub- and independent contractors, are lower income on average, increasingly people of color, gender minorities, non-citizens, and are exposed to more air pollution and workplace safety risks than workers in any other commercial sector. In other words, they well-encapsulate the vulnerable population segments that equity approaches often intend to target.

Since freight transport is a locally derived demand, logistics companies do not offshore like manufacturers to escape the costs associated with labor and environmental regulations. Instead, companies outsource internally to third-party contractors or nearby regions with local policy environments more amenable to low-road practices. This avoidance shifts the regulatory burden of green fleet and road safety policies onto workers and leads to higher rates of non-compliance.

Planners and policy can address these market structures, but doing so can face resistance. In response to the labor and environmental violations prevalent in the logistics sector, California passed Assembly Bill 5 (AB5) in 2019 to prevent further misclassification of workers as contractors. AB5 faced immediate and expensive opposition from gig delivery companies, including Uber/UberEats, InstaCart, and Doordash. Proposition 22, which exempted these companies from AB5, passed a year later by ballot measure after a \$205 million, privately funded ad campaign. The sum was the most ever spent on a ballot initiative in California history (Walker, 2020).

Labor economists find Proposition 22's perpetuation of the gig economy results in subminimum wages for drivers, despite counter-evidence presented by Uber- and Lyft-sponsored studies (Jacobs and Reich, 2020). Uber and Lyft's pull out of Minneapolis—after a driver-led initiative prompted the city to enforce a rideshare driver minimum wage—demonstrates companies are willing to withhold pay and services at signs of industry-standard labor protections. However, this also opens the door for workers and cities to “flip the gig” and introduce locally grown and worker-owned last-mile delivery models with fairer wages, safer labor conditions, and greener modes (Atkinson, 2021; Bates et al., 2021).

Given the freight sector's labor precarity, and the uncertain effects of future warehouse automation and driverless vehicles (Jaller et al., 2022), we echo worker calls for a “Just Transition.” Just Transition was born from labor movements in industrially transitioning regions like the Ruhr Valley and Appalachia. Its policies synchronize environmental and climate targets with robust labor protections (Abraham, 2017; McCauley and Heffron, 2018). Actions can include withholding public EV incentives while maintaining penalties for carriers and shippers that do not raise labor standards or procure vehicles from “high-road” manufacturers (Zabin, 2020). Additionally, policymakers can prioritize investments that make green procurement and transitional training affordable for employees, small businesses, and those who choose to work as independent owner-operators.

7.4 Partner with communities

Without meaningful engagement and a set of shared community goals, projects risk sidelining community needs. A robust community engagement process can ensure that planning goals, such as thriving economic activity and safe streets, reflect community priorities.

The most successful examples of meaningful engagement share a common approach. They establish a shared conception of project goals between planning professionals and the community the project most directly affects. Though the depth of engagement required varies by the project's level of community impact (e.g., City of Burlington, 2017), projects with the highest impact have community members sitting at the table from the earliest possible stages and are full stakeholder-partners throughout project realization (Farrell and Falkenburger, 2023).

Traditional approaches to engagement have focused on bringing stakeholders into the planning process at specific, limited points via online surveys or other easily disseminated means. Nabatchi and Leighninger (2015) refer to this as the “thin” approach: low-effort for participants to provide their two-cents, but lower quality engagement and commentary overall. Public meetings, held at municipal buildings, with political and planning officials speaking from a dais are another form of thin engagement. Advocacy and community groups critique this approach as allowing planning authorities to check a box that legally mandated engagement and consultation had been performed. Attendees to these public meetings will often be residents or stakeholders who are already well-informed, have time to attend the few meetings scheduled, and do not represent all the potential road users, small business owners, workers, or residents that would be affected by the proposed project (Scally and Tighe, 2015).

The freight sector's temporary and contract workers who are not represented by a formal organization or union, as well as residents whose homes abut industrial land uses, are key stakeholders in freight planning exercises. But their lived experiences, on-the-ground expertise, and concerns will not factor into government policy unless they have a seat at the table and a say over their community's future. However, there are limited examples of how community engagement shaped freight planning processes. Planners typically define freight stakeholders as “key decision makers,” or upper level management, in the private sector (Fried et al., 2024a). For instance, a new warehouse campus in Suffolk, VA faced opposition from nearby residents, business owners, and school officials voicing their discontent with being shut out of project planning efforts until late in the design stage (LaRoue, 2022). While community groups recognized the benefits of added logistics spaces and jobs, they point out government officials reserved limited engagement opportunities until after the developer completed designs.

More meaningful methods of participation yield greater levels of interest and participation in future projects. It bolsters skills and knowledge sharing across community and

stakeholder groups and fosters a sense of social inclusion among historically marginalized community members. Additionally, research highlights the improvements on environmental, congestion, and land-use priorities borne from more meaningful engagement strategies compared to programs adopted with only thin public participation (Gaventa and Barrett, 2010; Karner et al., 2020).

These approaches serve as tools for more equitable outcomes in freight planning. One promising example includes Portland's (Oregon) 2040 Freight Plan, which elevated a diverse array of workers, industry and community leaders, and activists to the level of full stakeholder-partner (PBOT, 2023). Through iterative discussions across groups, PBOT yielded a thorough account of freight needs, opportunities, and shared indicators for success.

7.5 Conclusion

This thesis finds strong evidence for a spatio-racial mismatch between delivery supply and demand, and that smaller distances between those two are indirectly associated with more equitable delivery environments. Subsequently, the dissertation outlines regulatory and operational pathways toward achieving more compact logistics. This dissertation contributes studies that are among the first to:

- Identify major theoretical and empirical gaps in evaluating spatial equity in urban freight, and offer research avenues and methods to fill them.
- Link logistics sprawl to the development of e-commerce facilities for residential delivery.
- Present evidence for spatio-racial disparities in delivery traffic exposure and online ordering.
- Establish logistics sprawl and urban form as determinants of spatio-racial disparities in residential delivery-traffic externalities.
- Offer preliminary evidence of CL's role in spatially planning more equitable urban freight systems.
- Identify zoning-based factors that enable and conditionalize its adoption.

Importantly, however, I underscore the limits of focusing solely on spatial equity. Confronting environmental injustice in freight systems must ultimately confront the deeper entanglement of social, political, and economic inequalities that shape the urban landscape.

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