Last-Mile Warehousing and Fulfillment Development in North Carolina

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16. Abstract

Warehouse and logistics facilities have increased significantly in the recent decade in response to ongoing shifts in consumer and firm behavior. This increase in facilities impacts communities and roads. We use a multiple methods approach to analyze spatial patterns of logistics facilities in North Carolina from 2015 to 2024 and combine this with semi-structured interviews with practitioners involved in the siting of logistics facilities. We find growth in facilities with the sites continuing to be near interstates and transport network infrastructure. Most warehouse facilities in North Carolina are constructed by-right on industrial land. This means municipal zoning decisions, which govern the availability of this land, are critical to location decisions. However, municipalities in North Carolina have limited input on specific site selection. Instead, consultants and brokers, along with economic development officials, are often the planners of modern logistics facilities. This understanding of the siting process is critical to managing the downstream impacts of logistics facilities on roads and communities. This paper also assesses how large distributions centers in North Carolina have impacted crash outcomes using a propensity score matching methodology. This approach allows comparison of areas with distribution centers to similar areas without a facility. The similarity of the areas is critical since distribution centers tend to locate in areas with high levels of access to highways and airports. The results show that areas with distribution centers have similar crash outcomes to areas that do not. The exception is that more crashes involve commercial vehicles. We conclude that the existing mechanisms for coordination between freight land uses and transportation have been effective and should be maintained. These include siting reviews particularly around driveways and ingress and egress as well as traffic impact assessments. Involvement of NCDOT in long-range land use planning processes is also helpful. We recommend continued monitoring of crash patterns as this is an evolving area.

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EXECUTIVE SUMMARY

Warehouse and logistics facilities increased significantly in the recent decade due to ongoing shifts in consumer and firm behavior. The scale of this shift is impressive. According to data from the US Census Bureau, over half of private commercial construction is for warehouses, and expenditures on this type of construction increased by over 800% from 2013 to 2026. This construction has reshaped supply chains and the resulting trip patterns with impacts on North Carolina communities and roads. This project addresses these shifts by:

- Reviewing land use planning and economic development practices that influence the siting of large-scale warehouse facilities,
- Developing models of warehouse location that confirm the continued importance of access to transportation infrastructure, especially airports and major roads,
- Analyzing road crashes to assess if areas containing a distribution center displayed differences in crash patterns,
- Highlighting the current land use and transportation planning practices that are important to manage the downstream impacts of warehouse construction on North Carolina communities.

To do this, we used a multiple methods approach. We reviewed city and county land use plans and combined this information with semi-structured interviews with practitioners involved in the siting of logistics facilities. We also conducted a detailed spatial analysis of the location of warehouse facilities and crashes. We developed models to assess the factors associated with warehouse location, including transportation infrastructure and socioeconomic characteristics. We combined these location models with crash data from the North Carolina Department of Transportation (NCDOT) to compare crashes from 2015 to 2024 in areas with a large-scale distribution center and otherwise similar areas without a distribution center.

We find most warehouse facilities in North Carolina are constructed by-right on land zoned for industrial uses. This means municipal zoning decisions which govern the availability of this land are critical to location decisions, and this highlights the importance of long-range land use planning. Decisions about what land is zoned industrial and how water and sewer infrastructure are provided to these areas have the most influence. In a case study of Orange County, we show the multi-decade work involved in developing logistics hubs. However, municipalities in North Carolina have limited input on specific site selection. Instead, consultants and brokers, along with economic development officials, are often the planners of modern logistics facilities. Instead, planners and transportation practitioners often become involved during the site review including assessment of ingress and egress as well as transportation impact analyses.

Road safety is a paramount concern. Warehouses have the potential to increase freight trips in the local area. However, we found no statistically significant difference in the total crashes or crashes per road mile between areas with a distribution center and similar areas that did not have a distribution center. The only statistically significant difference in crashes between these areas is that places with distribution centers have a higher share of crashes that involve a commercial vehicle.

The findings reinforce the importance of NCDOT's current practices and planning for freight. Site review continues to offer a place for NCDOT to assess safety impacts of proposed developments and to review whether the development is likely to impact traffic conditions on nearby roads and intersections. Given the practice of by-right development of logistics facilities, coordination with local officials around economic development plans focused on warehousing and supply chains also continues to be an important area of engagement. Finally, given the rapid changes in supply chains, we recommend continued monitoring of road safety impacts.

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Chapter 1. Introduction

In recent years, a rapid rise in online shopping and a resulting uptick in logistics facilities across American and global communities have been seen. Evidence suggests that the spatial patterns of these facilities have changed as the volume increases require ever larger distribution centers, and rapid delivery windows require facilities proximate to population centers.

Less clear is how land use planning and development approval processes are responding to this shifting logistics landscape. This study assesses these processes in North Carolina to capture how local governments and planners are responding. To do this, we examine spatial patterns of warehouse development in North Carolina from 2015 to today and interview municipal planners to capture planning and approval practices in jurisdictions across the state.

We find municipalities have the most influence on the siting of logistics facilities through their zoning functions. Most warehouse facilities are constructed by-right on industrial land, therefore the availability of this land is critical to location decisions. Outside of zoning decisions, municipalities often play a limited role in the development of these facilities. Because most logistics facility development is speculative, consultants and brokers along with economic development officials are often the planners of modern logistics facilities. Municipal and NCDOT review is part of the development approval process but generally occurs after the planning phase and without information on who will own or operate the facility.

1.1 Background

Warehouse and Distribution Center Spatial Patterns

Warehouse construction has surged in the United States and globally. American private expenditures on warehouse construction rose from $9 billion in 2013 to a high of $76 billion in 2023 (FMI Corp. n.d.). Since 2021, warehouse construction has accounted for over half of total U.S private commercial construction spending—an all-time high (FMI Corp. n.d.). A prominent cause of these trends is the dramatic increase in freight volumes resulting from the rise in online shopping that accelerated with the pandemic. The rise of e-commerce and manufacturing patterns also means that logistics facilities today hold lower commodity inventories and must facilitate rapid replenishment (Xiao et al. 2021).

Two countervailing, but linked, trends influence the spatial patterns and size of today's distribution and logistics facilities. "Logistics sprawl" describes a global trend for warehouse facilities to increase in size and locate further from metropolitan centers (Charters-Gabanek et al. 2025; Wygonik and Goodchild 2018). Square footage of typical warehouses, often built for use as freight distribution centers, continues to increase. Logistics spawl is linked to lower land costs, higher availability of land, and fewer land use controls at the periphery of communities (CBRE n.d.; Woudsma et al. 2016). These patterns have been observed in studies of Los Angeles, Seattle, Atlanta, Toronto, and in several urban contexts across the globe (Aljohani and Thompson 2016; Dablanc et al. 2014; Woudsma et al. 2016).

Scholars have noted that rapid delivery windows coupled with a desire to minimize the environmental impacts of goods movement have created a need for distribution nodes near urban markets. This "proximity logistics" infrastructure is located in denser and more mixed-use parts of communities (Fried and Goodchild 2023; Good Jobs First 2020). Proximity logistics came into significant focus during the COVID-19 pandemic, as e-commerce surged and, as unprecedented levels of customers wanted goods delivered to residential homes, and fast. A resulting surge occurred in developing distribution centers to facilitate high volumes of last-mile deliveries.

The simultaneous observation of sprawl and infill logistics facility development reflects the complex and hierarchical nature of goods movement. Available information on the strategic practices of freight, e-commerce, and logistics industry players shows that large-scale warehousing owners, notably Amazon and rival e-commerce giants, have created a diversified hierarchy of warehouse types in a vast network. For example, Amazon's facilities play distinct roles in the company supply chain, and data shows a functional hierarchy between last-mile, regional and airport facilities, as well as grocery delivery facilities operated in tandem with its Whole Foods Market subsidiary (Fried and Goodchild 2023; MWPVL International n.d.). Accordingly, some Amazon's facilities are purposefully sited to serve high concentrations of subscribers to their rapid delivery services, while others serve as cross-network nodes. With some last-mile urban-adjacent, and other more remote regional mega DC's, Amazon has a flexible network of logistic nodes which offsets supply chain disruption and allows adaptation in facilities as seasonal demands and stocking patterns shift (Fried and Goodchild 2023).

Role of urban planning

Beyond these broad trends in spatial patterns and their dependence on transport networks and customer access, governmental policies at the local, regional, state, and federal levels influence the siting of logistics facilities (Xiao et al. 2021). Some of these impacts are direct with companies taking advantage of incentives to locate facilities in particular states or municipalities. For example, Amazon located 171 facilities within Opportunity Zones where they or the investors benefited from capital gains tax breaks (Good Jobs First 2020). In other cases, communities encourage, or discourage, warehouse and logistics facilities through land use controls particularly zoning (Dablanc et al. 2014; Dablanc and Ross 2012; Woudsma et al. 2016). Warehouse facilities are generally an allowed use on land zoned industrial, and much of the logistics infrastructure has been developed "by-right" on land zoned for industrial use in many places (Yuan 2019). However, cities vary considerably in the availability of industrial land. To illustrate, a 2014 comparison of Seattle and Los Angeles found that in long term planning, planners in Seattle had ensured land remained available for freight development in key transportation zones. But in Los Angeles, urban land was scarce and expensive, with prices incentivizing sprawl to neighboring counties (Dablanc et al. 2014).

Existing development approval processes often do not reflect the modern goods movement ecosystem, and the tools employed may fail to appropriately estimate impacts. One such example is traffic impact assessment (TIA). TIA may inaccurately predict incoming truck traffic and outgoing delivery vehicles because the estimates are based on an era when warehouses were smaller and consumption patterns were different (Yuan 2019, 2021). Similarly, building codes related to provision for goods movement in many cities have not been updated and fail to provide space for this function (McDonald et al. 2019).

Emerging scholarship seeks to understand how fiscal zoning concerns are influencing decisions on logistics facility locations. In Chicagoland, Nolan (2026) found that the communities approving warehouse facilities were often struggling financially. Schmahmann (2025) has looked at how cities in California have used sales tax rebates to attract warehouses to their community and shown the substantial sales tax windfall cities with e-commerce facilities have experienced.

1.2 Research Objective and Scope

For this study, we examine the development approval and long-term planning for logistics facilities, identify the spatial patterns of warehouse and distribution center facilities from 2015 to 2024 and analyze road safety impacts.

1.3 Research Approach

We used multiple methods to assess and analyze the impacts of warehouse construction in North Carolina. This includes review of zoning and land use plans, semi-structured interviews with individuals involved in siting, and spatial and statistical analysis of warehouse locations and crash patterns.

1.4 Report Organization

Chapter 2 presents the land use planning process for warehouse and distribution centers. Chapter 3 provides a detailed case study of Orange County, NC. Chapter 4 addresses the spatial and statistical analysis of crash patterns. Chapter 5 summarizes lessons learned and useful practices. Chapter 6 is the implementation plan.

Chapter 2. Development of Warehouse and Logistics Facilities in North Carolina

2.1 Methods – Land Use Planning

The qualitative data analyzed in this study were drawn from semi-structured, in-depth interviews, conducted between November 2024 and November 2025. We reached out to several municipal planners by accessing public directories and by using snowball sampling. In our outreach to planning offices, we asked to be directed towards planners with experience overseeing warehouse development or broader issues that impact it. The Institutional Review Board at the University of North Carolina at Chapel Hill reviewed the interview protocol and determined that the study did not constitute human subjects research as defined under federal regulations. All interviews were conducted virtually via Zoom. The interviews ranged in length from 20 to 40 min and were recorded and transcribed with respondents' permission. While not a representative sample, the study included variation in geography, level and type of jurisdiction, and between governmental, and non-governmental employees. The participants worked in municipal planning offices, MPOs, for the NCDOT, or as real estate brokers, and practiced in various regions of North Carolina. Select respondent characteristics are summarized in Table 1: Interviewee characteristics.

Table 1: Interviewee characteristics

Job Title/Role	**Count**
Municipal Planner	7
Transportation Planner/Engineer	2
Real Estate Developer/Broker	2
Land Use Lawyer	1
Area of Jurisdiction/Practice	
Statewide	4
Metropolitan region	1
Municipality, population ≥100k	4
Municipality, population <100k	3
Gender	
Male	8
Female	4
Total	12

Semi-structured interviews allowed for gathering information from multiple respondents, while allowing the flexibility to pursue interesting threads stemming from in-depth conversations on the topic (Gubrium et al. 2012). The interview protocol included open-ended questions related to the following themes: observed trends in warehouse development in recent years in their area or zone of jurisdiction, the factors that influence warehouse siting, the local typical oversight and approval processes for warehouse developments, or local attitudes among leaders and residents towards warehousing as a land use. Questions were informed by the literature on freight planning as well as our initial and ongoing findings. Additionally, the protocol was developed through several background discussions with experts and peers in the planning field in NC.

Audio recordings of the interviews were digitally transcribed using Otter.ai, before being uploaded to Dedoose, a qualitative data analysis (QDA) software. Using the flexible coding method (Deterding and Waters 2021), the text was divided into larger sections with broader structural (i.e., index) codes; these sections were then further parsed using more granular, conceptual and thematic (i.e., analytic) codes. This approach allows for analysis of subsections of the data, as answers to semi-structured interview prompts often reveal further insights. When uploaded to Dedoose, transcripts were ascribed attributes related to the respondent (e.g., region, the population of their locale, professional role, etc.). Next, index codes were applied according to the questions in the interview protocol. Examples of index codes applied included "Public objection: noise", "Siting factor: Rezoning required/SUP," "Speculative development," and "Population 100k+" referring to key topics of interest that interviews showed shape trends in warehouse siting and development in North Carolina. The analytic codes comprised of a combination of codes informed by the research questions as well as themes that emerged inductively.

2.2 Results: Summary of Logistics Facility Planning and Review

In North Carolina, as in much of the United States, developers speculatively build logistics facilities to meet the needs of global consumer companies. Early-stage siting for logistics facilities is often handled by real estate brokers who identify viable plots for logistics use development. The primary early feasibility indicators are twofold: water and sewer access, interstate highway proximity, and land zoned or that can be rezoned as light industrial, where logistics facilities are generally an allowed use.

One of the main roles of third-party brokers and developers in the logistics facility siting process is quantifying and pricing out the necessary exactions for a parcel, using local connections and knowledge, something clients looking to open a distribution center often do not have. Brokers who work on industrial projects scope available land in the region and assess the feasibility of potential sites. This includes assessing the availability and cost of the parcel, installing water and sewer infrastructure, and whether local support would exist for the development.

"We're boots on the ground," one broker said, "and obviously, a lot of developers are from out of town." Local brokers know the market for developable sites that would be attractive to distributors. Their role is to find and assemble parcels that are large enough for large warehouses, and where necessary, get approval for light industrial use. They can then market these sites to potential developers and tenants, marketing the sites for their proximity factors and "off-the-shelf" ready nature for development.

Preemptively creating speculative sites that would be amenable for logistics facilities requires craftmanship. Modern distribution centers designed to facilitate rapid processing of high volumes of goods require very large profiles that often exceed 500,000 square feet. "The buildings have gotten a lot bigger," one planner said. "It used to be developers trying to accommodate 200,000 to 300,000 square foot buildings. Now, we're seeing a lot of buildings being built, 500,000 to 700,000 square feet, to be able to accommodate logistics and fulfillment centers." Finding large enough sites, especially with the proximity factors desired, prompts a challenge. Distribution centers need to be sited near highways and airports. A site closer to a large city appeals to companies looking to facilitate faster delivery times and shorter trucking distances. The land becomes scarcer and more expensive for sites closer to a city. Look further out, and land may be available, but the issue of water and sewer infrastructure quickly rears its head.

Industrial sites located outside of town limits typically require a build-out of water and sewer access, at cost to the developer. The feasibility of doing so is often the difference between a potential site for a warehouse and a non-starter. Like the zoning environment and land availability, water and wastewater infrastructure feasibility is a topline factor guiding real estate brokerage for warehouse development. "The

utilities are huge drivers of where development will occur," a Raleigh-area planner said. "Because we have Triassic basin soils, which are just pure clay, they don't perc. So, folks who want to develop typically will go to whichever community has the closest water and sewer." Developers commonly look to sites just outside of a town boundary, where water lines do not yet exist, but where a water utility exists nearby. The intention, which land developers make clear to planners, is for the site to be ultimately annexed into the nearest town, once the utility lines are extended. As the development team approximates the water and sewer feasibility of a site, they must determine not only the feasibility of the pipeline buildouts, but also water consumption allowances, and whether the nearest town would be willing to annex the site. Towns stand to benefit from the arrangement. By annexing an industrial site, the town gains a stream of tax revenue. The site operator benefits from lower utility costs. In North Carolina, 53% of water rate structures and 48% of wastewater rate structures charge higher rates for users outside service boundaries. On average, outside water rates are 54% greater than inside water rates and outside wastewater rates are 57% greater than inside rates (El-Khattabi et al. 2025).

Local zoning and input

Most logistics facilities are developed by-right meaning the zoning plan put in place by local communities is a key component of location decisions. Logistics facility developers generally want to locate on industrial land where distribution centers are allowed uses. This simplifies the development approval process and reduces the opportunity for public comment.

Exceptions to by-right development exist. Some projects, particularly in populous regions, can require additional steps such as rezoning. As real estate brokers look to assemble land parcels that are large enough to meet modern logistics needs, and zoned to permit it, they may need to approach local officials to rezone. Conditional zoning is a tool commonly used by planners looking to tailor the scale of logistics facilities in their jurisdictions. This process is legislative, meaning that a local elected body must approve the changes. Endorsement of these changes by town planners is helpful, but insufficient to gain zoning changes that can only be made by city council vote. Conditional zoning allows local officials to stipulate specific conditions for use, creating a site-specific zoning category tailored to what the town wishes to allow.

In some cases, municipal planners may exercise additional review over warehouse developments by requiring special use permits through "trigger ordinances." The town of Garner located in the Raleigh metro area has seen significant warehousing development in recent decades. The town requires a special use permit for any "nonresidential or mixed-use development encompassing 100,000 or more square feet of gross floor area" (Town of Garner 2022). Requiring a special use permit (SUP) allows town officials to conduct a detailed review of proposed developments and offers greater leverage over characteristics of the proposed development that may have significant effects on traffic, stormwater management, and local services. The SUP process also includes public hearings, allowing community members to voice concerns and participate in the decision-making process. Where development occurs by-right, which is typical for less populous areas, the public lacks a dedicated space to voice concerns. Special use permit processes are unlikely, nor intended to, fully block logistics facilities from gaining development approval. Rather, they empower town authorities to seek more significant exactions in the form of traffic infrastructure or tree buffers or conditions such as a traffic management plan that seeks to contain truck traffic to specific routes.

However, the existence of these types of trigger ordinance can be enough of a hurdle to incentivize developing elsewhere. Consultants looking to close a deal want to offer sites that are as ready to develop as possible. In the words of one planner: "The way business recruiters see it, these companies want to make a decision, and they're in a hurry. They don't have time to wait for rezoning. If they're looking to go

and open a fulfillment center, they may have a six-month window to search sites, find sites, and be operational. So, they can't wait for a special use permit, which in some places, can take six months."

Planners and the public have limited information about who the site owner or operator will be until operations commence (Yost 2024) since the development approvals are often sought by private parties that will subsequently sell or lease the facility. Developers and consultants contracted by an interested tenant act as proxies and typically wish to preserve confidentiality of their interest in the project development, and any ongoing negotiations around it, until finalized. This can occur as Department of Commerce officials negotiate potential incentives for an interested user, who can often be weighing multiple options for their site. Economic development discussions occur beyond the scope of local planners, frequently before they are made aware of the interest in a potential development in their jurisdictions.

Some planners acknowledged that speculative developments for undisclosed clients posed an issue for their ability to adequately plan for a project's impact, limiting their foresight and ability to mitigate nuisance. "We're guessing into the future, who knows? We hope the developer doesn't bait and switch on us tell us one thing and then end up opening something else." This concern is why municipalities may utilize "trigger ordinances" and apply conditions on rezoned parcels. While planners have little power to prevent properties from being bought and sold to future users, they try to mitigate future issues as best they can in the development approval process. Planners are not ultimately responsible, or able to stipulate who can operate an industrial site. In areas with fast residential growth, competing priorities—between needing a commercial tax base and optimizing quality of life for residential areas—can pose a challenge. Planners are aware that noise and traffic impacts of a distribution site are unpalatable for residents. In interviews, planners echoed the challenge of needing to create industrial sites, while being ultimately unable to prevent distribution center operators from opening in their jurisdictions, even if they wanted to.

However, most local planners expressed largely positive opinions about the development of logistics facilities in their communities. Attitudes reflected the view that as industrial uses go and freight distribution is less troublesome than other industries that could locate on industrially-zoned land. Understanding the need for industrial tenants' tax revenues, distribution centers were not their greatest worry. "They're not noxious uses," a planner said in an interview. "They're not posing a huge, you know, environmental threat in terms of, you know, emissions or noise or anything like that, other than, I guess, truck traffic. But you know, that's relatively minor for an industrial use." This sentiment was shared among nearly all interviewees. Even those who were lukewarm on distribution centers as a desirable land use to have in their jurisdiction understood the appeal, in relative terms, of distribution centers. As one planner stated, "Other than a lot of traffic and their hours of operation, they're not a heavy industry, so to speak. They're just moving product." Still, interviewed planners were aware that attracting large scale freight distribution would garner local opposition. For them, though, local opposition was par for the course. "I think mostly, people just hate change. We've gotten past the environmental thing; it's not the heavy smokestacks and that kind of stuff anymore. We're kind of past that conversation. It's more about what is the physical impact from the operations of the freight and warehouse distribution," another planner said.

Role of Incentives and Fiscal Zoning

While planners are largely unable to decide whether distributors can operate in their towns, the private sector and economic development offices can play a larger role in siting distribution firms in places where their impact would be tolerated by the public, if not embraced. For real estate developers, the concern in bringing disruptive industrial user to operate on a site was that it would depress later interest by other firms in adjacent parcel. But freight distribution was not one of these potential uses. "You don't want to

exclude future leasing opportunities by being kind of ridiculous in what you allow to be done there." Property brokers prize their personal relationships with local officials and economic development officials. Knowing where interested logistics firms could best be suited to open, is a core part of doing business. Creating unwanted uses is worth avoiding.

Early stage planning also regularly involves garnering economic incentives through tax credits, facilitated through the NC Department of Commerce, and where applicable, a county Economic Development Office. In some counties that do not have an economic development office, a Chamber of Commerce may play a local role. The Department of Commerce can offer incentives to interested freight firms, in coordination with their county-level counterparts, and has provided grants and tax exemptions to several logistics companies doing business in North Carolina (Good Jobs First n.d.).

Discretionary grants to attract warehouse developers are typically funneled through the state's Job Development Investment Grant (JDIG). Grants, typically between 1 and 10 million dollars, are awarded by the NC Department of Commerce which describes it as "the state's flagship program for both retention and expansion of existing North Carolina companies and recruitment of new companies to the state. Funds are dispersed annually for a period of up to 12 years. The program uses a tiered structure to offer higher incentives to sites located in economically distressed counties. The Commerce Department ranks the economic well-being of NC's 100 counties. The 40 poorest performing counties are designated as Tier 1, where the highest incentives can be offered. The next 40 are Tier 2, and the best 20 performing counties are designated Tier 3 ("Job Development Investment Grant (JDIG)" n.d.).

In article 3, State tax credits can be awarded to new developments for wide-ranging purposes, from operating properties that use renewable energy, creating jobs, or "investing in business property." Like much of planning for warehouse development, discussions on available tax incentives are typically backchanneled in early discussions between potential corporate tenants, consultants with state economic development professionals. Retail logistics firms including Amazon and Walmart have benefitted from job training tax credits. By partnering with local technical colleges for on-site job training at Amazon fulfilment centers, the company has received over $150,000 in tax reimbursements.

Additionally, since 2017, distribution centers have been exempted from state sales tax on purchases of "equipment, or an accessory, an attachment, or a repair part for equipment" used for operating the facility. The exemption applies to "large distribution centers," defined under state law as facilities "used primarily for receiving, inventorying, sorting, repackaging, and distributing finished retail products for the purpose of fulfilling customer orders," which also, within their first five years, have at least $100 million invested in the property, and achieve "an employment level of at least 400" (Economic Development Partnership of North Carolina n.d.). Qualifying businesses are expected to maintain at least 400 employees throughout their duration of operation.

Planners also share the desire to attract commercial tenants, including freight and retail distribution centers, to support local tax revenues. Some locales, especially those that believe they have a competitive edge with their location and regional proximity, enact this priority by creating long-term economic development strategies to entice warehouse development. Counties in such areas may create a county-level economic development office to deepen partnerships with NC Commerce Department officials, consultants, and developers—and act as a front-door towards carrying out their strategy. This was particularly notable in the Triad region, where regional proximity (between Charlotte and Raleigh and at the junction of several interstates) has been a purposeful selling point in a now-decades long economic development strategy to enticing freight firms to the region.

Longer term and larger scale planning
Some localities engage in proactive long-term planning for "logistics parks," multi-building sites that can be home to multiple warehouses, often with optional plans for future phased expansions. The logistics park model typically originates with real estate brokers who assemble land parcels, and then seek economic development incentives, water and sewer access and roadway connections to site. This model of planning for freight logistics facilities requires assembling a greater amount of land but allows for proactive planning and strategic siting of denser warehouse development. Real estate developers typically handle utility access, negotiating pricing for water and sewer extensions, and have this as an inclusive cost when reaching potential site tenants. Involved professionals in interviews also said that logistics parks have the additional benefit of often being in more populous settings that offer better workforce attraction, as opposed to singular warehouses in exurban settings where firms may struggle to retain staff.

In the alternative scenario, developers purchase a singular parcel to develop a warehouse there. However, industrial zoned land, especially in rural settings, may not have water and sewer facilities, and therefore a lower land cost may belie further necessary expenditures to bring utilities to the site.

NCDOT Role in the Development Approval Process and Planning for Logistics Facilities
Completing a traffic impact analysis (TIA) for a warehouse site is another step in attaining development approval for a distribution center. These documents, typically prepared by consultants, measure the impacts of traffic volumes that a site development may create. If operating on a state-owned road or interstate, which is typically the case, developers must obtain approval from NCDOT for a driveway permit. NCDOT holds widespread jurisdiction on major roadways across the state. The department's District Engineers, spread over 14 transportation divisions in the state, review traffic impact analyses (TIAs) in development applications, which are required for developments expected to generate at least 1000 daily trips or 100 peak hour trips.

Some municipalities have local ordinances requiring TIAs at lower projected thresholds and can require greater transportation-related improvements for developments seeking approval locally. Mebane, for example, has a lower trips-per-hour TIA threshold to require a TIA and, also, requires that developments install sidewalks, per local ordinance. The town also contracts with third-party reviewers to consider any traffic study submitted in a development application. The leverage sought by municipalities on traffic impact exactions varies, depending on adopted comprehensive plans, and what planners believe they can require while maintaining competitivity. Local ordinances can stipulate specific requirements, but state traffic engineers also negotiate exactions with developers to mitigate the traffic impacts of a development. "A good developer hires a good consultant who's been around the block a few times and kind of knows which way this is going to go. There's a little bit of gamesmanship—they're really trying to save their client money," an engineer said. "They're kind of anticipating what the district engineer will say, and they have a sense of the boundary line. So, they will try to stay just, just on the correct side of that."

With distribution centers, the high volume of trucks presents a unique challenge to traffic permitting. As a result, a traffic management plan is often implemented, stipulating where trucks may enter and leave the facility. This is typically meant to divert truck traffic away from residential areas, and onto interstates as quickly as possible. Interviews revealed that this procedure can, at times, have limited utility due to little enforcement.

With speculative development, and the wide range of uses that can occur within a warehouse, the traffic impacts can be ultimately difficult to predict and quantify. The length of storage time of goods bears heavily on the truck volumes that will serve the site; with rapid delivery distribution seeing round-the-clock truck movements, while a light manufacturer might see shipments only every couple of days. The

ITE Trip Generation Manual publishes the industry standard for trip generation rates, used to project the traffic impacts for proposed developments, depending on their land use type category. NCDOT uses this manual to assess TIAs and determine necessary transportation improvement measures for a site. Beginning in 2020, the guide introduced a new category for "High-Cube Fulfillment Center Warehouse" (Land Use 155) and has two subcategories for "sort" and "non-sort" facilities. ITE defines sort facility as "a fulfillment center that ships out smaller items, requiring extensive sorting, typically by manual means," whereas a non-sort facility is a "fulfillment center that ships large box items that are processed with automation rather than through manual means." An additional category, Land Use 156, is designated as a "High-Cube Parcel Hub Warehouse," which ITE states "typically serve as regional and local freight forwarder facilities for time sensitive shipments via airfreight and ground carriers." In the overall general warehousing category, ITE estimates .19 trips per 1000 square feet of Gross Floor Area (GFA) at peak hours. The specific High-Cube Fulfillment Center Warehouses designation carries a much higher trip rate estimate—generating 1.37 trips per 1000 sq. ft. GFA at peak hours. The same peak hour rate for "High-Cube Parcel Hub Warehouses" is 0.64 (Institute of Transportation Engineers 2021).

While the breakdown in specific industrial land use types is helpful for transportation officials to better approximate the impact a development may have on local roadways, the wide range of trip generation rates illustrates the core difficulty in doing so. Moreover, developers typically do not share the company name of the incoming user for a project, if one exists. With the high instance of speculative development, no such user may be secured once a TIA reaches NCDOT's desk.

Roadway safety is a consideration, but not a priority of the TIA review. "The calculation is almost exclusively on satisfying demand for travel, efficiency, and level of service, and nobody wants to do unsafe things, but we don't quantify [safety]," one traffic engineer said. Roadway approvals are the jurisdiction of NCDOT on state owned roadways and interstates. The ability to move vehicles in and out of a facility is critical for a site to be viable for freight distribution use, and a steep cost for roadway improvements can be make-or-break for a potential warehouse site. In interviews with road engineers at DOT who oversee issuing driveway permits, officials said that their goal is to work with the developer on a solution that is feasible to both parties, without sacrificing baseline acceptable standards. "We could insist on roundabouts, but we don't. We settle for signals. Signals are less safe than roundabout," the engineer said. "Signals are okay, and in some sense, they're not unsafe. There's just happens to be a safer thing that we're not we're not willing to pay for and we're not willing to make them pay for it." As for where transportation exaction agreements typically land, in balancing feasibility, cost, and safety: "we end up asking them to build something that is not demonstrably unsafe," the official said.

According to interviewed officials, developers' responsibility for traffic impact mitigation measures can typically only extend to the side of the state-owned road that the development will gain access to. This limits transportation officials' ability to seek exactions that account for interactions with the lanes of traffic in the other direction. This also makes it difficult to fully account for a development's impact on pedestrian travel patterns. Improvements for crossings, for example, would fall outside of the developer's domain. As the NCDOT traffic engineer put it, "Talk about some roundabout, and you're going to need right-of-way across the street. That is a problem. It's a physical restriction on what we can actually do."

Chapter 3. Case Study of Industrial Land Development: Orange County, NC

The interviews suggested a complex role for land use planning in the development of logistics facilities. Planners noted that they are often not involved in decisions about where to site facilities until plans are at an advanced stage. However, many developers of logistics projects utilize land zoned for light industrial uses. This means that long-range planning along with decisions about extension of sewer and water systems are critical logistics for facility development. To explore this, we conducted a case study of Orange County, NC's efforts to promote economic development through light industrial uses. The case study shows how a forty-year effort to promote industrial development has resulted in significant, but uneven, outcomes. This example highlights how even where geographic factors can be attractive to logistics and distribution firms, long-range planning and building utility capacity makes the difference between a planned economic strategy and implementation.

3.1 Background

In 2025, Orange County had a median household income of $90,089, significantly above the statewide median of $72,388 (U.S. Census Bureau n.d., n.d.). The largest employer is the University of North Carolina at Chapel Hill and over 70% of employment is concentrated in higher-income professional sectors such as health care, academia, and real estate. The County's two largest landowners, Duke University and UNC, hold much untaxable land due to institutional status.

As peer counties began to see accelerating logistics development in recent decades, the County began to face the reality that it would need to diversify its tax base and use light industry as part of the strategy.

> "You're either willing to be a rural community right in an urban setting and have a very high cost of living to be here, and then the resulting gentrification and out migration of lower income people...Or you're, willing to accept that, you need to face the facts that the quality of life we have in Orange County has costs and requires them. We have had to play catch up."
>
> *- An Orange County Economic Development planner*

Indeed, Orange County has trailed regional peer counties—especially its western neighbor Alamance, who embraced light industry earlier on and benefitted from more built-out utility systems near the I-40 corridor. A 2018 report prepared for Orange County Economic Development tracked some of the recent business recruitments that Orange County lost out on to its neighboring counties, given the lack of infrastructure that could support development (Britt Nance Collaborative et al. 2018).

> "Between September 2012 and November 2017, Alamance County announced six (6) economic development projects, mostly in the logistics/distribution sector, with investments totaling $392.8 million, that created 1,304 jobs with average annual wages ranging from $35,374 to $80,000 per job on sites ranging from 10 to 186 acres. It's important to note that Orange County had a legitimate opportunity to recruit and potentially land these same projects in Orange County but didn't have either adequate sites or adequate incentives to close the deal."
>
> (Britt Nance Collaborative et al. 2018)

Planning for Industrial Development: 1980s to today
This case study chronicles the four-decade process Orange County has taken to tap its once-unwanted segment of I-40 for their potential to produce industrial tax revenues, as logistics and distribution development in North Carolina has accelerated.

Forty years ago, Orange County did not fashion itself as an attractor of light industrial businesses. In fact, the county unsuccessfully sued the North Carolina Department of Transportation in the 1970s to prevent I-40 from being routed through the county (*Orange County v. NC Dept. of Transp.* 1980). But once the highway was constructed, long-range planners in Orange County began to consider how the County might be able to benefit from Interstate adjacent development while working within a growth management framework. Surrounding counties had begun to recruit European and Asian manufacturers and distributors as the NC Department of Commerce began to offer incentives to multinational businesses for locating in the state.

Motivated to grow its non-residential tax base and compete with growing industrial development in neighboring counties, Orange County created three Economic Development Districts (EDDs) in 1981 as well as five Commercial Industrial Transition Activity Nodes (CITANs) in surrounding areas. These were established and zoned for industrial activities in 1984. The development districts were identified by evaluating multiple factors. The highest weighted factors were water and sewer access, Interstate proximity as well as the presence of large developable acres of 100 or more. The three selected sites – Eno, Buckhorn, and Hillsborough -- are along the I-40/I-85 corridor and are highlighted in blue in Figure 1.

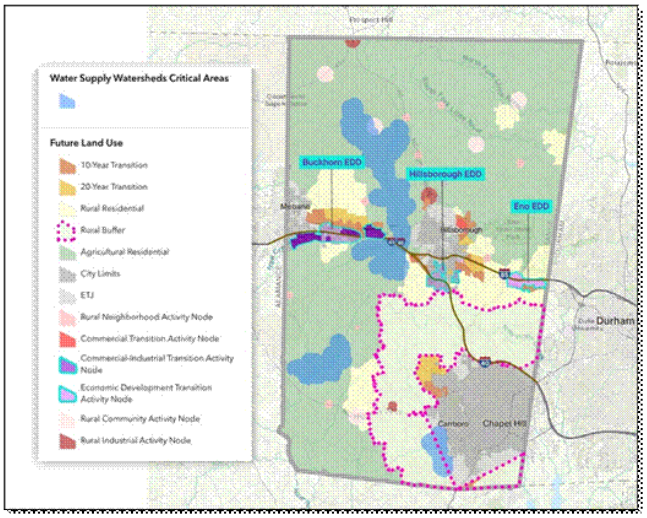


Figure 1: Orange County NC Land Use Map

The three sites identified for development in the early 1980s – Eno, Buckhorn, and Hillsborough – remain foci of industrial development planning today. Yet, the development at each varies from substantial to non-existent. This section explores the reasons for these varied outcomes highlighting the role of long-term planning especially around water and sewer services. When created, none of the development sites had readily available water and wastewater infrastructure and supply. Much of the I-40 corridor in Orange County—especially more exurban areas which are amenable to logistics development—lies outside of the original service areas of water utilities.

Extending water and sewer service is a fiscal challenge, but Orange County faced a unique situation. Due to growth restrictions codified into a rural buffer, the County's largest water provider, Orange Water and Sewer Authority (OWASA), was restricted from providing service. This required Orange County to coordinate among multiple agencies in a long-range planned service agreement to extend water and sewer. Ultimately, Buckhorn EDD would be served by the City of Mebane; Hillsborough by a southward extension from the Town of Hillsborough; and Eno EDD by an extension from the City of Durham system. OWASA was precluded from providing the industrial sites water, in part due to the low-density rural buffer placed between its service area and I-40 (Figure 2).

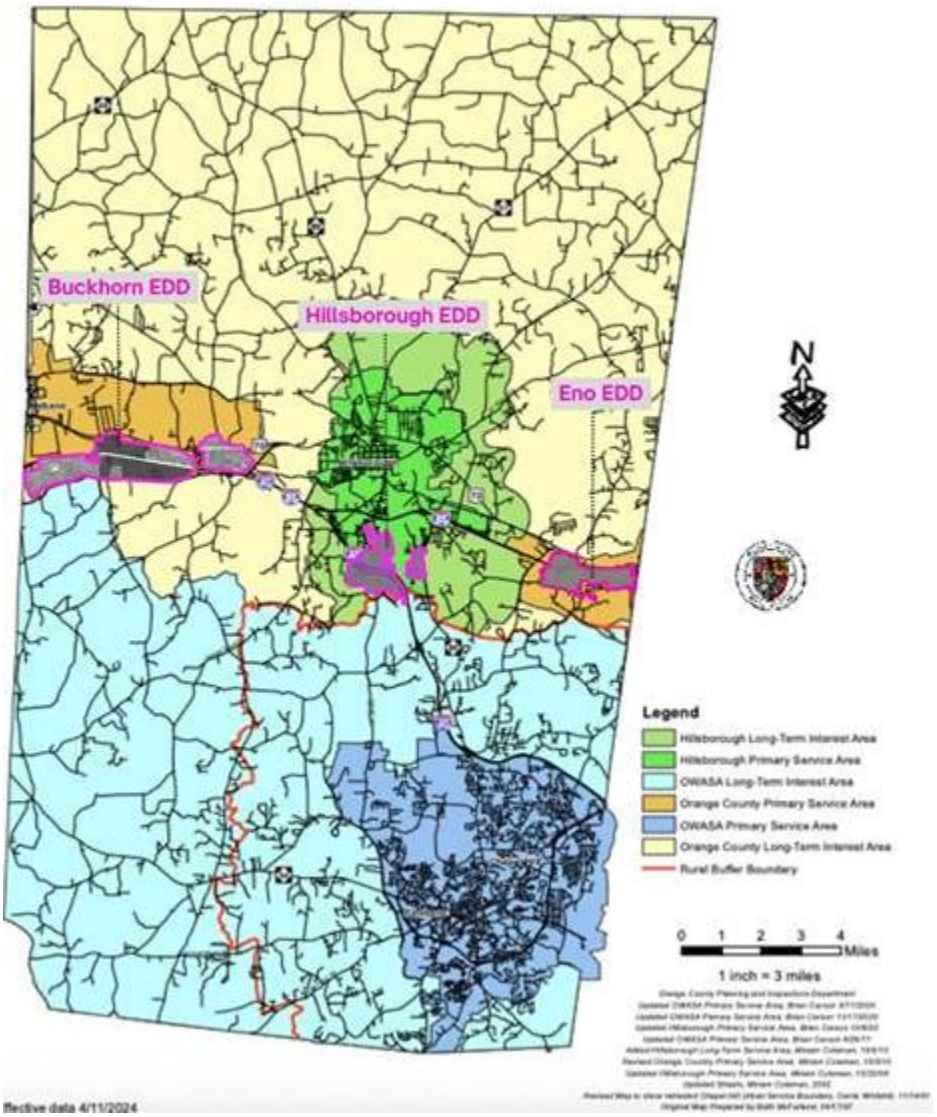


Figure 2: Orange County Water and Sewer Management Planning and Boundary

Identifying water and sewer service responsibilities allowed planners to focus on the issue of how to finance improvements. In 2007, the North Carolina legislature authorized counties to levy sales and use taxes of 1/4 cent by county referendum under Article 46. Orange County proposed such a sales tax to finance construction of water and sewer lines to the economic development zones. When placed on the

ballot first in 2010, voters narrowly rejected the measure. Orange County tried again a year later. The second version of the proposed tax included funding for K-12 schools. With the education measure included, the sales tax passed and went into effect April 1, 2012. The Orange County Board of Commissioners oversees the revenues and must approve expenditure programs for each fiscal year.

The tax currently generates roughly $6.4 million annually. At 31% of the Economic Development budget's yearly expenditure, the utility buildout was the largest share of outlays from the fund. The largest share of the revenues earmarked for economic development have gone toward financing the capital expenses for connecting the Buckhorn and Hillsborough Economic Development Zones to nearby municipal water grids. In 2022, the Board of Commissioners voted on a resolution to continue the sales tax and its funding structure for another 10 years and stated:

> Orange County has invested $5.5 million in Article 46 funded infrastructure cost since 2014 to construct 2 multi-year phased Buckhorn Mebane CIP utility projects. The County also had a 10-year Utility Service Agreement with Mebane, at a total cost of $500,000 to guarantee 250,000 gallons per day of sewer capacity. This was also Article 46 funded. Completed work included sewer lines, gravity lift stations, force mains, and a large water main loop to engineer a primary "utility "backbone" system. This system helped to accommodate redirecting the Efland public sewer flow to Mebane, which stabilized rates, and reduced Orange County costs.

3.2 Outcomes

Economic development in the Buckhorn district has outpaced the other two. Analysis by the Orange County Economic Development Office found that since 2019, the EDD areas had attracted 2.3 million square feet of new construction, $540 million in taxable investment, and 1,858 new jobs (Britt Nance Collaborative et al. 2018). The companies involved include ABB, Medline, Stihl, Sports Endeavors, Wegmans, Fisher Scientific, and others. Water infrastructure has much to do with this economic success. Orange County entered into a Utility Service Agreement with the City of Mebane to deliver water and wastewater service to much of the Buckhorn Economic Development District and was thereby able to ensure initial and upgraded provision of sewer infrastructure. Under the agreement, Orange County built and financed the improvements. Once complete, the City of Mebane became the owner and operator. Between 2014 and 2025 the County spent $5.5 million of Article 46 local sales tax to improve water and wastewater capacity in the zone.

The other sites – Eno and Hillsborough – have been less successful at attracting economic activity. The Eno site has seen little developer interest. The Hillsborough site has emerged as a site for the Research Triangle Logistics Park (Figure 3) which includes up to five large high ceiling light industrial warehouses. The developers cited booming e-commerce and supply chain issues during Covid-19, the need for domestic supply of medical products, the expected sustained increase in e-commerce, and the "strategic" location on logistics corridors (Orange County 2020). A previous project planned for the site, Settler's Point, faced community opposition and did not move forward. This site has also benefited from interchange improvements which have reduced some site development costs and simplified the extension of the trunk sewer line from the Town of Hillsborough.

> "Ironically, our project started before the work was planned out here on the highway. But it is going to really help. Part of the infrastructure was originally going to be part of the developer's responsibility to improve the interchange at old NC 86 and I 40. That now has been moved away from the developer and put into the budget for NCDOT."
>
> - A broker representing the proposed Research Triangle Logistics Park.

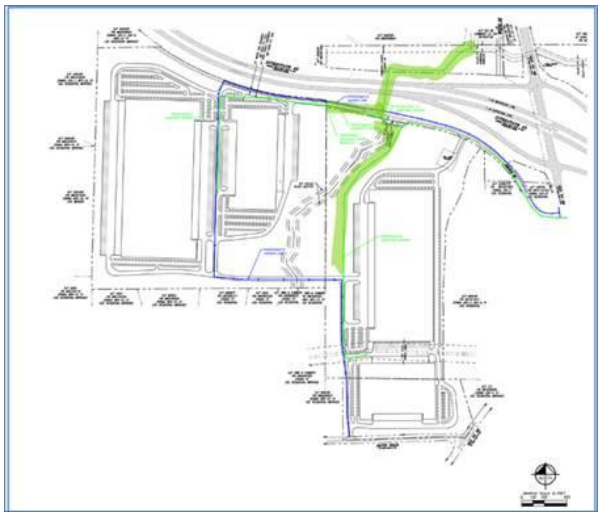


Figure 3: Proposed Plans for the Research Triangle Logistics Park (12' sewer line highlighted in green)

Orange County has worked since the 1980s to leverage the I40/85 corridor to promote light industrial development. Where the County has achieved their economic development goals, it is the result of a long process of coordinating with local governments and water agencies to finance water and sewer improvements. Forty years and a 1/4 cent sales tax have been critical to seeing the development of logistics and warehouse facilities that bolster local tax revenue. This case study shows how planning matters to the siting of logistics facilities but also exemplifies the complexity and long-term nature of that work. While brokers and developers lead efforts to select and build out sites, the choice of location is governed by zoning and sewer provision. The governmental vision must be in place before development can occur.

3.3 Conclusions

Long-range land use planning and economic development planning are central to decisions about where logistics facilities locate and ultimately their impact on North Carolina communities. Interviews with practitioners and a detailed case study of Orange County revealed that municipal zoning, along with sewer and water availability, is critical in determining general areas likely to have logistics facility development. Similarly, because most facilities are developed by-right, zoning is a critical factor. However, specific site selection and planning have limited involvement from municipal planners. Instead, experienced brokers and developers working with economic development officials often lead detailed site planning efforts. Municipal planners and state transportation officials review final site plans and can manage anticipated network impacts at that time. This understanding of the siting process is critical to managing the downstream impacts of logistics facilities on roads and communities.

Chapter 4. Examination of Warehouse Locations and Freight-Related Crash Patterns in North Carolina: A Propensity Score Matching Approach

4.1 Introduction

Changing consumption and production patterns have impacted how goods are transported and stored, affecting a large shift in the geography of the logistics sector. Warehouse construction has surged in the United States and globally. According to data from the US Census Bureau, American private expenditures on warehouse construction rose from $8.7 billion in 2013 to $74.7 billion in 2023. In 2022, warehouse construction accounted for 56 percent of total U.S private commercial construction spending—an all-time high. A prominent cause of these trends is the dramatic increase in freight volumes resulting from the rise in online shopping that accelerated with the pandemic. Researchers have studied the forces shaping warehouse and distribution center location and scale (Sakai et al. 2020). They have also considered the downstream effects of these changes on outcomes, including employment (Gutelius 2015), supply chain lengths (Andreoli et al. 2010; Wygonik and Goodchild 2018), environmental justice (Yuan 2018), emissions (Yu et al. 2026), and planning and zoning (Fried et al. 2026; Sakai et al. 2024) among others. The road safety impacts of the changing geography of warehousing are a critical topic but one that has received more limited analysis. There is evidence that injuries and fatalities involving freight vehicles are rising. McDonald, et al (2019) found that freight-involved fatality and injury rates climbed much more rapidly than the overall rates from 2009 to 2015. Research in Los Angeles and Seoul has found that crashes involving freight vehicles often occurred near freight generators such as intermodal terminals creating safety concerns in neighborhoods near such facilities (Shin 2024; Yang et al. 2021).

This paper adds to this growing literature on the impacts of warehousing facilities by analyzing whether the presence of a large distribution center is associated with higher road safety risks in the local area. Our work moves the literature forward by moving beyond the correlational approaches applied in previous work. Instead, we use a propensity score approach that allows us to explicitly account for the fact that distribution centers tend to locate in areas with certain characteristics, such as proximity to airports and major roads. We then compare crash outcomes in areas with a distribution center and otherwise similar areas that do not have a distribution center.

4.2 Data

Outcome Variable: Crashes

We obtained crash data from the North Carolina Department of Transportation. The inclusion criteria for this analysis were that the crash was 1) geocoded and 2) occurred between January 1, 2015, and December 31, 2024. The dataset also included information on injury severity as estimated by the recording officer and the types of vehicles involved in the crash. We consider a crash to involve a commercial vehicle if the vehicle types included: truck/trailer, tractor/semi-trailer, tractor-doubles, or unknown heavy truck. The dataset included information on 145,290 crashes.

Key Explanatory Variable: Distribution Centers

We used the U.S. Historical Business Database from Data Axle – Reference Solutions (formerly ReferenceUSA) for 2024 to identify logistics facilities. The inclusion criteria for a facility to be included in the analysis was 1) having a NAICS code of 4931 (“Warehousing and Storage”) or having a company name containing logistics-related terms such as “distribution center,” “distribution ctr,” “fulfillment ctr,” “sortation ctr,” “Prime Now,” and “delivery station.” From the resulting list of facilities, we excluded facilities that were duplicates or self-storage facilities. Our approach mirrors related research such as Rivera-Gonzalez and Roorda (2025).

To ensure completeness, we cross-checked our cleaned dataset with public warehouse information from MWPVL International Inc., a logistics consulting firm that maintains a well-documented inventory of major distribution and fulfillment centers, including those operated by Amazon, Walmart, and other large retailers. This additional step helped confirm that no major last-mile logistics facilities—particularly high-volume sites—were inadvertently excluded during the Data Axle-based filtering process. When discrepancies in geographic information were identified, we used MWPVL data as a supplemental source to validate or update facility locations. After cleaning, in 2024, we identified 458 warehouse facilities in North Carolina. We focus our analysis on large-scale distribution centers. We identified these facilities through keywords such as "distribution," "sortation," "fulfillment," and "Amazon." With this approach, we identified 68 locations as of the end of 2024.

Other Explanatory Variables

We included measures of transportation infrastructure and socioeconomic characteristics at the census tract level. For a subset of variables, we also computed characteristics within a 50-mile straight line buffer of the tract centroid to assess the larger spatial context. While our analysis focused on North Carolina, we do include data from South Carolina and Virginia in the calculation of the explanatory variables. For example, in northeastern North Carolina, the closest airport and seaport may be in the Hampton Roads, Virginia area. Table x shows descriptive statistics for variables used in the location choice model and the appendix shows statistics for all variables that were explored.

Transportation infrastructure was measured by assessing the length and density of the road network within the census tract and by the distance from the tract centroid to key transport facilities. Relevant spatial layers were obtained from the NC Department of Transportation and the Bureau of Transportation Statistics. For each tract, we measured distance to the nearest highway, commercial airport, seaport, inland ports, and key North Carolina facilities such as Carolina Connector Intermodal Terminal (CCX); North Carolina Global TransPark (GTP); and Charlotte Transload Facility (CTP). The appendix details the specific facilities. Due to high correlation amongst several of these measures, we used three measures in the models: distance to nearest airport; freight facility (defined as inland port, coastal port, CCX, GTP, and CTP); and highway (defined as Interstate, US or NC route).

We obtained socioeconomic and demographic tract-level variables from the U.S. Census Bureau's American Community Survey (ACS) 5-Year Estimates (2019–2023) and the U.S. Census Bureau's Longitudinal Employer-Household Dynamics (LEHD) Origin–Destination Employment Statistics (LODES) Workplace Area Characteristics (WAC) dataset from 2023. Measures include tract-level median income; number of households; population; population density; percent population white, black, Asian, and Hispanic; the counts of all jobs, manufacturing jobs, transportation warehouse jobs, wholesale trade jobs, and retail trade jobs; and the percent of each of these job categories for the tracts. We established a binary variable assessing whether the tract falls within a Census-derived Metropolitan Statistical Area (MSA).

4.3 Methods: Propensity Score Crash Analysis

Identifying the impacts of distribution centers on freight-related crashes is challenging. Naive comparison of crash rates between tracts with a distribution center and those without a distribution center would be misleading as distribution centers are more likely to be located in places with better transport access and infrastructure. To overcome these issues, we employed a propensity score matching framework (Heinrich et al. 2010). This approach compares crash rates in a census tract with a distribution center, i.e. treatment area, to census tracts without distribution centers but with a similar propensity of having a distribution

center, i.e. control areas. We use a matched pair t-test to calculate the statistical significance of the difference in means.

We utilize several road safety outcome measures including total crashes in a census tract, annualized crashes, crashes normalized by major road density, crashes normalized by total road density, the fatal and severe injury proportion (K+A), and the commercial-vehicle involved proportion. We compute crash outcomes for the full study period (2015-2024) and for 2022-2024. We selected 2022-2024 range because research has shown crash patterns were significantly different during 2020 and 2021 particularly when stay at home orders were in effect (Doucette et al. 2021).

To calculate the propensity score of a census tract having at least one distribution center, we developed a binary logit model that calculates a predicted probability for each census tract. The explanatory variables in the model include transportation access and socioeconomic characteristics of the census tract and a 50-mile straight line buffer. We selected a binary outcome measure, i.e. presence/absence of a distribution center, since few tracts had more than one distribution center. Specifically, the concentration of warehouses per census tract were as follows: 1 tract contained 5 warehouses; 1 tract contained 4 warehouses; 2 tracts contained 3 warehouses; 1 tract contained 2 warehouses; and 47 tracts contained 1 warehouse. The propensity score model includes 4,139 census tracts in North Carolina with non-missing data from the Census Bureau. Of these tracts, 52 contain a distribution center and 4,087 do not. 4 warehouses were dropped due to gaps in census tract data. This excludes 4 tracts, likely those that are designated as National or State Forests, other natural areas, or otherwise qualify as Census Designated Places (CDPs), which follow unique reporting requirements.

For each census tract with a distribution center, we sought to identify the three nearest-neighbor tracts that have a similar propensity to have a distribution center but do not currently have one. We consider as potential matches those census tracts where the absolute difference in the probability of having a distribution center lies within the standardly-recommended caliper width of 0.2 standard deviations of the logit of the propensity score, resulting in a caliper of 1.14 (Austin 2011). To avoid matches that might be exceptionally distant geographically, we calculated the straight-line distance between the centroids of each matched pair. We excluded any matches where distances were greater than the 95th percentile (78,903 meters). After applying both matching criteria, 139 matched pairs remained. Forty-five warehouse tracts retained three matches; two warehouse tracts had two matches; no warehouse tracts had one match.

4.4 Results

Propensity Score Model of the Probability of a Census Tract Having a Distribution Center

Visual inspection of distribution centers in North Carolina shows strong clustering along interstate routes and proximity to major population centers (Figure 4), a pattern consistent with the literature. The propensity score model confirms that transportation infrastructure access is significantly correlated with distribution center locations (Table 2). Distance to an airport and distance to a major road both have statistically significant and inverse relationships with the presence of a distribution center. Measures of employment density in transportation and warehousing sectors additionally show meaningful relationships, suggesting co-location of distribution centers with existing logistics activity. In contrast, socioeconomic and demographic variables (e.g., income, race/ethnicity composition, and population characteristics) do not exhibit strong or consistent associations with distribution center locations. For each NC census tract, Figure x shows the propensity score, i.e. probability, of a distribution center being in the tract.

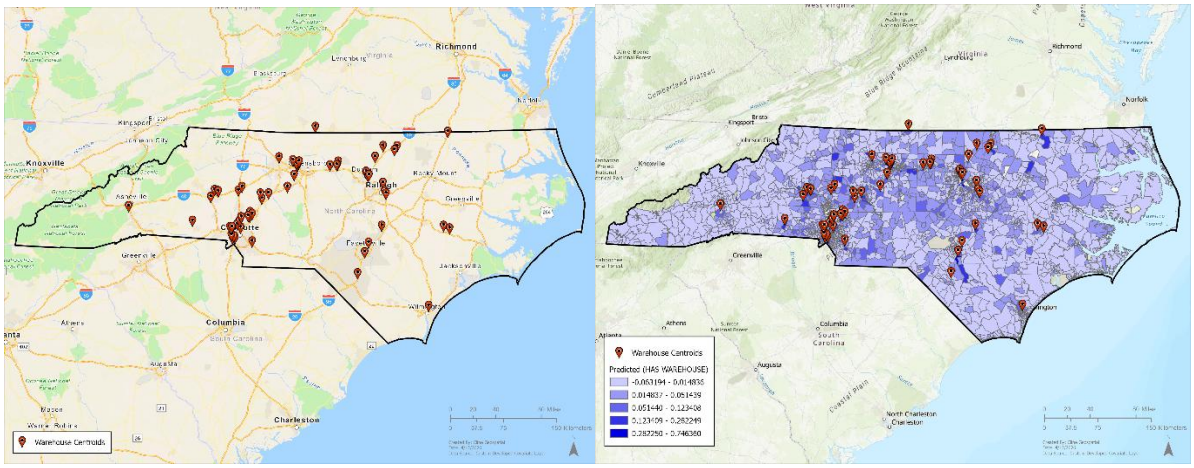


Figure 4: Map of North Carolina Distribution Centers and Map of the Probability of Census Tract Containing at Least One Distribution Center

Table 2: Binary Logit Model, Probability of Census Tract Containing at Least One Distribution Center

Variable	Coefficient	p-value	Odds Ratio
Intercept	-9.55439	0.043	0.00007
Tract Median Income	-0.00001	0.283	0.99999
Tract Population	0.00012	0.310	1.00012
Tract Percent Hispanic	0.00678	0.754	1.00680
Tract Percent Black	0.00731	0.574	1.00734
Tract Percent Asian	-0.01909	0.677	0.98109
50 mi Median Income	0.00005	0.498	1.00005
50 mi Population Density	-0.00018	0.891	0.99982
50 mi Percent Black	0.03222	0.568	1.03274
50 mi Percent Asian	-0.08046	0.871	0.92269
50 mi Percent Hispanic	0.06863	0.700	1.07104
50 mi Road Density	0.45054	0.323	1.56916
Distance to Airport	-0.03703	0.026	0.96365
Distance to Freight	0.00194	0.842	1.00195
Major Road Length	-0.03702	0.415	0.96365
Total Road Length	0.00397	0.659	1.00398
Major Road Density	-0.23321	0.559	0.79199
Total Road Density	-0.03173	0.779	0.96877
Population Density	-0.00083	0.108	0.99917
Distance to Major Road	-0.50866	0.004	0.60130
Within MSA	-0.39712	0.506	0.67225
Total Jobs	0.00005	0.565	1.00005

Manufacturing Jobs	0.00058	0.018	1.00058
Wholesale Jobs	0.00095	0.159	1.00095
Retail Jobs	0.00092	0.044	1.00092
Transport/Warehouse Jobs	0.00028	0.465	1.00028
% Manufacturing Jobs	0.02166	0.070	1.02190
% Transport/Warehouse Jobs	0.07437	0.000	1.07721
Job Density	-0.00001	0.961	0.99999
% Wholesale Jobs	0.04901	0.017	1.05023
% Retail Jobs	0.01917	0.380	1.01935

N=4,139; Pseudo R2= 0.446

The propensity score matching substantially improved the similarity between treatment tracts (those with a distribution center) and control tracts (those with no distribution center). Table 3 presents differences in characteristics between tracts with and without distribution centers before and after matching. Prior to matching, notable differences existed across several demographic, economic, and spatial variables. For example, tracts with distribution centers consistently had better access to transport infrastructure and had higher percentages and numbers of manufacturing, transport/warehouse, and wholesale jobs. Following matching, these differences were considerably reduced, and none were statistically significant at a 95% confidence level, indicating improved comparability between groups.

Table 3: Census Tract Mean Characteristics, Unadjusted and Adjusted for Propensity Score Matching

	Mean: Warehouse Tracts (n=52)	Mean: All Non-Warehouse Tracts (n=4087)	Mean: Matched Non-Warehouse Tracts (n=139)	Difference (Warehouse-All Non-Warehouse)	p-value	Difference (Warehouse-Matched Non-Warehouse)	p-value
Tract Median Income	70579	72068	67985	-1489	0.664	2594	0.515
Tract Population	4419	3897	4465	522	0.021	-46	0.862
Tract Percent Hispanic	13.6	8.8	12.6	4.9	0.000	1.1	0.422
Tract Percent Black	26.4	21.9	29.5	4.4	0.124	-3.1	0.368
Tract Percent Asian	3.7	2.6	2.7	1.1	0.133	1.0	0.201
50 mi Median Income	76748	72260	77525	4488	0.001	-777	0.573
50 mi Population Density	1520	1466	1571	54	0.353	-51	0.414
50 mi Percent Black	21.6	21.8	21.4	-0.2	0.720	0.2	0.772
50 mi Percent Asian	3.3	2.5	3.4	0.7	0.000	-0.1	0.520
50 mi Percent Hispanic	11.0	9.0	11.0	2.0	0.000	0.0	0.828
50 mi Road Density	4.0	3.1	4.1	0.9	0.000	-0.1	0.650
Distance to Airport	21.8	28.2	22.9	-6.4	0.006	-1.1	0.667
Distance to Freight	28.8	46.7	28.8	-17.9	0.000	-0.1	0.982
Major Road Length	8.5	7.6	8.0	0.8	0.358	0.5	0.653
Total Road Length	61.4	58.9	58.5	2.5	0.598	2.9	0.605
Major Road Density	0.9	1.0	1.0	-0.1	0.485	-0.1	0.235
Total Road Density	7.1	8.8	8.2	-1.8	0.000	-1.2	0.055
Population Density	756	1508	932	-752	0.000	-176	0.146
Distance to Major Road	0.8	10.2	0.7	-9.4	0.000	0.1	0.445
Within MSA	0.885	0.840	0.892	0.045	0.324	-0.0075	0.886
Total Jobs	5429	1478	3927	3950	0.005	1501	0.279

Manufacturing Jobs	1100	167	832	934	0.000	268	0.229
Wholesale Jobs	436	57	309	379	0.000	127	0.142
Retail Jobs	416	179	440	237	0.006	-24	0.809
Transport/Warehouse Jobs	602	43	411	558	0.000	191	0.174
% Manufacturing Jobs	23.2	10.2	22.6	13.0	0.000	0.6	0.873
% Transport/Warehouse Jobs	17.4	3.3	14.1	14.1	0.000	3.3	0.362
Job Density	1291	811	1050	480	0.351	241	0.647
% Wholesale Jobs	8.8	4.0	7.6	4.8	0.001	1.2	0.412
% Retail Jobs	9.6	13.3	12.1	-3.7	0.006	-2.5	0.147

Crash Analysis

To assess road safety impacts of distribution centers, we compared crash statistics for tracts with a distribution center to matched tracts with similar probabilities of having a distribution center, but where no distribution center is located (Table 4). The presence of a distribution center had no statistically significant effect on crash outcomes except for the share of crashes that involved a commercial vehicle. This result was consistent for the full study period, 2015-2024, and in the recent period of 2022-2024. While the overall crash counts were not statistically significant, tracts with distribution centers did have higher crash counts but lower crash rates after normalizing for road length. Tracts with distribution centers also had a higher proportion of crashes that involved a fatal or severe injury. However, these differences were not statistically significant.

Table 4: Crash Statistics, Warehouse and Matched Tracts

Time Period	Metric	Mean: Warehouse Tracts	Mean: Matched Non-Warehouse Tracts	Difference	p-value
2015-2024	Total Crashes in Tract	148	130	18	0.3503
2015-2024	Annualized Crashes	15	13	2	0.3503
2015-2024	Crashes/Major Road Length	25	34	-8	0.2225
2015-2024	Crashes/Total Road Length	3	3	0	0.9972
2015-2024	K+A Share (%)	28	26	2	0.4484
2015-2024	Commercial Vehicle Share (%)	73	41	32	<0.0001
2022-2024	Total Crashes in Tract	50	41	8	0.1735
2022-2024	Annualized Crashes	17	14	3	0.1735
2022-2024	Crashes/Major Road Length	9	11	-3	0.3217
2022-2024	Crashes/Total Road Length	1	1	0	0.6216
2022-2024	K+A Share (%)	30	25	4	0.2031
2022-2024	Commercial Vehicle Share (%)	71	40	31	<0.0001

Taken together, these results suggest that the presence of a distribution center has little effect on crash patterns in the local area. The one exception is that more of the crashes involve commercial vehicles – a result which makes sense given the presence of a distribution center. We recommend continued monitoring of crashes near distribution centers as these patterns are likely to evolve as retailers continue to refine logistics practices to meet consumer demand. Local governments and departments of transportation regularly consider the impacts of new developments. This analysis argues for those reviews to continue carefully considering the geometries of site ingress and egress along with likely paths to major roads and particularly interstate on and off ramps.

Limitations

Crash data are subject to several well-known caveats. Police-reported crashes may undercount less severe events and can vary in spatial accuracy, particularly in rural areas. Severity categories (e.g., K, A, B, C, and O) depend on officer judgment and reporting consistency, potentially introducing classification variability. The vehicle crashes are geolocated using largely manual methods from multiple sources, which could lead to process discrepancies. Some crashes were not manually geolocated when provided, so we developed a method to approximate location for a portion of the crashes which reduces the accuracy for those crashes (See appendix for details).

The robustness of the crash analysis results also rely on how well we were able to match tracts with a distribution center to tracts without. We showed that the propensity score matching improved the comparability of tracts along socio-economic and transportation access variables. However, unmeasured factors could differ between the tracts. If these unmeasured factors also impact road safety, that would limit the applicability of these results.

4.5 Conclusions

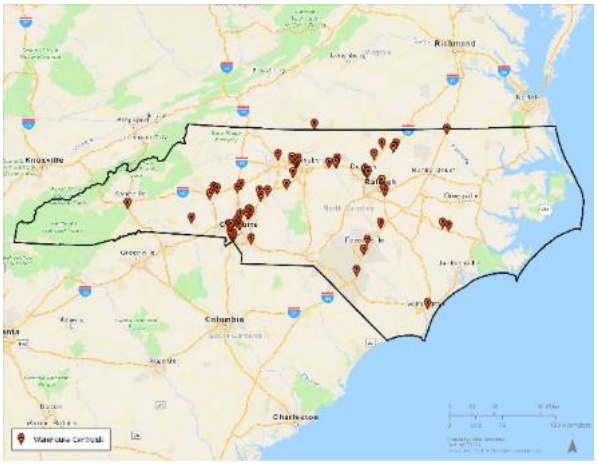
Our analysis shows that transport accessibility – primarily to highways and airports – is a key consideration in decisions in where to locate large-scale distribution centers. This finding is consistent with the literature. We find no dramatic differences in crash patterns between areas with a distribution center and areas with similar levels of transport access but no distribution center. Perhaps unsurprisingly, more crashes involve commercial vehicles. We do recommend continued monitoring of these trends and continued attention to site review through traffic impact assessments.

Chapter 5. Findings, Conclusions and Recommendations

5.1 Key Findings and Conclusions

In North Carolina, three factors matter for where large-scale warehouse facilities locate.

- Long-range land use plans: Warehouses are developed by-right on land zoned for industrial use that has water and sewer access. Decisions made by local government leaders and planning staff are critical to these outcomes.
- Transportation access: Large warehouses in North Carolina locate near major roads and airports.
- Economic development: Brokers work with firms and economic development officials to select particular sites from those that are available. Land use and transportation practitioners become involved relatively late in these processes.



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In North Carolina, we found no statistically significant differences in crash patterns between areas with a large-scale distribution center and *otherwise comparable* areas without a distribution center.

- From 2022-2024, there were 9 crashes per major road mile in areas with a distribution center compared to 11 in similar areas without a distribution center. This was not a statistically significant difference.
- The only statistically significant difference in crash outcomes was that crashes that occurred near distribution centers were much more likely to involve a commercial vehicle.
- Our results account for the likelihood of a distribution center being constructed. This avoids the problems that would arise if there was a simple comparison of areas with a distribution center to areas without one.

5.2 Recommendations

- Continued monitoring of road safety near major warehouses is warranted as firms update coordination strategies to meet consumer demand.
- Continued site review to assess ingress and egress near distribution centers and minimize conflict points should be a priority. The results of the crash analysis suggest that current practices have maintained road safety.
- Traffic Impact Assessment (TIA) remains a key process by which NCDOT and local communities can assess and mitigate the potential impacts of a warehouse facility. ITE continues to improve methodologies for analyzing trip generation from these facilities.

- On-going coordination with economic development officials and local planners can identify sites likely to serve coordination functions and coordinate access to major roads.

Chapter 6. Implementation and Technology Transfer Plan

The key research product is this report. The Executive Summary and Chapter 5 contain succinct summaries of results. Chapters 1 through 4 have the details of the analysis.

The implementation recommendations are for Dr. McDonald to offer to share research findings with organizations and individuals recommended by the Steering Committee. These include:

- Daniel Carter, Office of Traffic Safety,
- Alex Rotenberry, Division of Aviation
- Jennifer Portanova, Transportation Mobility and Safety
- Dawn McPherson, Division 7 Traffic Engineer
- Reginald Speight and Liz Parham, Rural Economic Development
- Will Best and Wright Archer III, Department of Commerce
- Garrett Wyckoff and Tracy Dellinger, Economic Development Partnership of NC
- Susan Fleetwood, Dana Magliola, and Cameron Dawson, NC Chamber of Commerce
- Patrick Woodie, NC Rural Center

There is no training needed for implementation. NCDOT already maintains the data systems, e.g. crash and freight facilities.

Knowledge transfer could occur through presentations at NCDOT's 2027 Research and Innovation conference and through journal articles.

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