

Best Practices for Local Reviews of Industrial Developments

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16. Abstract: Undesignated truck parking is one of the consequences of the growth in industrial freight activity. Truck drivers frequently park on roadway shoulders, off-ramps, vacant lots, and local streets near industrial and commercial facilities because truck stops are full, onsite staging is prohibited, and long delays at the facilities consume available hours-of-service time. Although Virginia legislation has encouraged jurisdictions to identify freight corridors in their comprehensive plans, knowledge of proactive policies for industrial developments is limited at the local level. The purpose of this research was to develop guidance for local reviews of industrial developments that will enable localities to support VTrans' goals in the areas of industrial land use, truck parking, and freight mobility. Specific objectives were to (1) evaluate the level of detail in Virginia practices compared with best practices with respect to accommodating truck parking needs, (2) assess how these practices influence undesignated parking, and (3) identify locations where the greatest amount of undesignated truck parking occurs. The scope of the project entailed reviewing best practices in other states and reviewing policy and data at the local level as they relate to land use, truck parking, and freight mobility. The following conclusions were drawn from the research findings: (1) best practices with respect to local reviews of industrial developments include a detailed review process with expectations for the traffic impacts, parking, routing, and amenities and a set of supporting local ordinances for each of these areas; (2) the expansion of e-commerce-driven industrial developments and distribution centers has amplified the need for localities to update zoning ordinances; (3) the Virginia review of ordinances indicates that localities exhibit uneven treatment of freight-related land use ordinances; (4) the moderate correlation of locality ordinance quality in Virginia and industrial site presence suggests that more industrialized localities are more likely to adopt detailed freight provisions in their zoning ordinances; (5) insufficient onsite parking at industrial facilities leads directly to undesignated parking on shoulders, ramps, and local streets, creating safety hazards and infrastructure damage; (6) undesignated parking in Virginia is not uniformly distributed and clusters around three roadway contexts—industrial queue, interchanges, and rest areas; and (7) the priority scoring cluster analysis adapted for Virginia use identifies interchange locations as the highest need based on the components of safety and undesignated parking instances and durations. Guidance was developed based on findings from the research tasks, with a focus on ordinance language that the Virginia Department of Transportation (VDOT) can share with localities. States identified in the literature review were the source of the initial template. Then, based on the review of Virginia ordinances and the parking analysis along major freight corridors, suggested language was provided across four key areas: applicant narrative, truck routing, parking (on and off site, with explicit consideration of staging), and amenities. The research recommends that VDOT's Transportation Mobility Planning Division (1) create a task group to review the guidance in the Appendix of this report, revise where appropriate, and share with localities as recommended ordinance amendment language and (2) apply the method provided in this report of using truck parking clusters to prioritize truck parking needs. Supplemental materials can be found at https://library.vdot.virginia.gov/vtrc/supplements.			
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ABSTRACT

Undesignated truck parking is one of the consequences of the growth in industrial freight activity. Truck drivers frequently park on roadway shoulders, off-ramps, vacant lots, and local streets near industrial and commercial facilities because truck stops are full, onsite staging is prohibited, and long delays at the facilities consume available hours-of-service time. Although Virginia legislation has encouraged jurisdictions to identify freight corridors in their comprehensive plans, knowledge of proactive policies for industrial developments is limited at the local level. The purpose of this research was to develop guidance for local reviews of industrial developments that will enable localities to support VTrans' goals in the areas of industrial land use, truck parking, and freight mobility. Specific objectives were to (1) evaluate the level of detail in Virginia practices compared with best practices with respect to accommodating truck parking needs, (2) assess how these practices influence undesignated parking, and (3) identify locations where the greatest amount of undesignated truck parking occurs. The scope of the project entailed reviewing best practices in other states and reviewing policy and data at the local level as they relate to land use, truck parking, and freight mobility.

The following conclusions were drawn from the research findings: (1) best practices with respect to local reviews of industrial developments include a detailed review process with expectations for the traffic impacts, parking, routing, and amenities and a set of supporting local ordinances for each of these areas; (2) the expansion of e-commerce-driven industrial developments and distribution centers has amplified the need for localities to update zoning ordinances; (3) the Virginia review of ordinances indicates that localities exhibit uneven treatment of freight-related land use ordinances; (4) the moderate correlation of locality ordinance quality in Virginia and industrial site presence suggests that more industrialized localities are more likely to adopt detailed freight provisions in their zoning ordinances; (5) insufficient onsite parking at industrial facilities leads directly to undesignated parking on shoulders, ramps, and local streets, creating safety hazards and infrastructure damage; (6) undesignated parking in Virginia is not uniformly distributed and clusters around three roadway contexts—industrial queue, interchanges, and rest areas; and (7) the priority scoring cluster analysis adapted for Virginia use identifies interchange locations as the highest need based on the components of safety and undesignated parking instances and durations.

Guidance was developed based on findings from the research tasks, with a focus on ordinance language that the Virginia Department of Transportation (VDOT) can share with localities. States identified in the literature review were the source of the initial template. Then, based on the review of Virginia ordinances and the parking analysis along major freight corridors, suggested language was provided across four key areas: applicant narrative, truck routing, parking (on and off site, with explicit consideration of staging), and amenities. The research recommends that VDOT's Transportation Mobility Planning Division (1) create a task group to review the guidance in the Appendix of this report, revise where appropriate, and share with localities as recommended ordinance amendment language and (2) apply the method provided in this report of using truck parking clusters to prioritize truck parking needs.

Supplemental materials can be found at <https://library.vdot.virginia.gov/vtrc/supplements>.

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INTRODUCTION

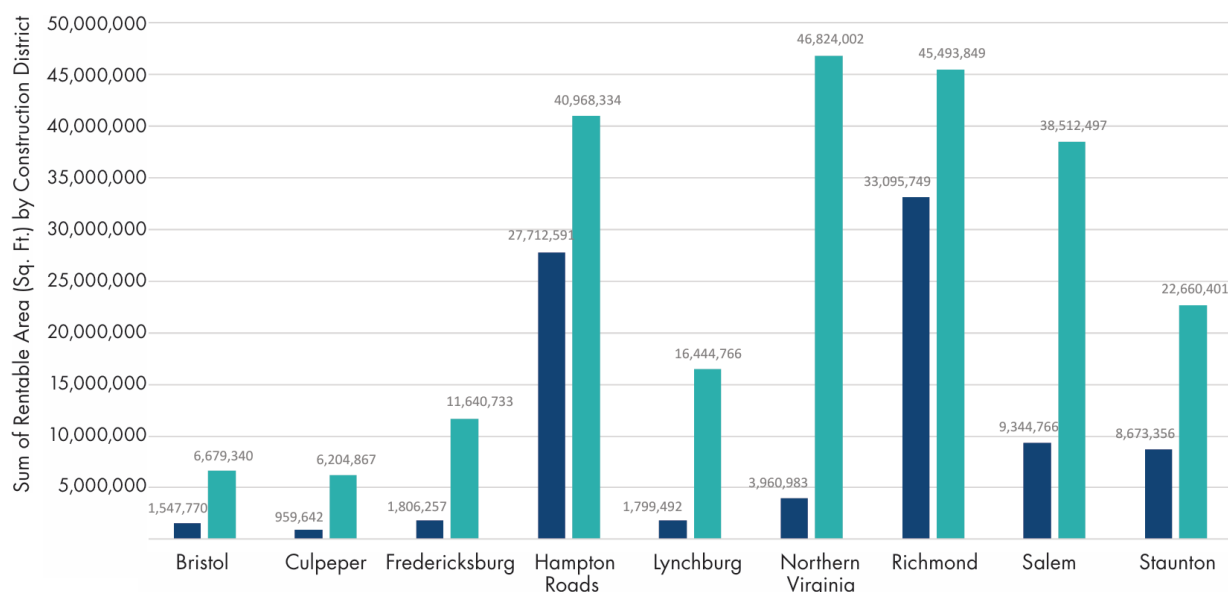
A 2016 U.S. Department of Transportation (DOT) report provided a discouraging view of how the United States has failed to adequately plan for and fund its transportation infrastructure (Fox, 2017). Significant shifts in transportation and growth patterns have occurred due to several factors, all which affect how land use and transportation planning are performed—increased urbanization, an aging population, and, the focus of this study, substantial increases in freight volumes (Sampson, 2015).

Increased Demand for Truck Freight in Virginia

Freight demand continues to grow alongside population and economic growth, and trucking plays a critical role in the supply chain and economy. In 2022, trucks carried more than 19 billion tons of freight valued at more than \$18 trillion annually in the United States, representing 67% of all the freight moved in the United States by weight and 73% by value (Dowell et al., 2022). With trucks moving most freight goods and the recent growth of e-commerce, industrial and residential developments are generating more truck trips and parking demand than local infrastructure can handle (Hayes, 2022).

E-commerce sales in the United States hit a record high of \$1.19 trillion in 2025, a 300.67% increase from \$297 billion in 2014. Experts predict that by the end of 2027, e-commerce sales will reach \$1.72 trillion and account for 22.6% of total U.S. retail sales (SellersCommerce, 2026), thus highlighting the need for additional warehouse and distribution space. As of 2024, the United States had an estimated 19 billion square feet of industrial space; most of it (11.1 billion square feet) was warehouse and distribution facility space (Bluerock, 2024). To meet customer delivery expectations, e-commerce warehouses and distribution facilities are moving closer to more densely populated urban areas (KSS Architects, 2021). As demand strengthens and consumers increasingly move online, Guirguis and Harris (2025) note that the United States is expected to need approximately 345.9 million square feet of additional warehousing space in 2026.

The effective and efficient movement of goods is vital to Virginia’s economy and is significantly influenced by how localities plan for developments that generate high volumes of truck traffic. A key goal of the Virginia Department of Transportation (VDOT) is to enhance both freight velocity and freight system resiliency, and according to 2023 data, Virginia moved approximately 1.2 billion tons of freight valued at \$300 billion (Bureau of Transportation Statistics, 2023). Virginia’s long-range transportation plan, VTrans, incorporates freight planning detailing mid- and long-term strategies, strategic investment actions, freight performance metrics, and the designation of critical freight corridors (Office of Intermodal Planning and Investment [OIPI], 2022). Truck trip generation and truck volumes tend to be more concentrated in or around warehousing and distribution center facilities; however, with the rise of e-commerce, the growth in the number of facilities during the past few decades is predominantly in distribution center space rather than warehousing, which is recognized in VTrans as a macrotrend with significant implications for the future of Virginia’s transportation system (OIPI, 2022). As Figure 1 shows, warehouse and distribution centers affect the transportation system of every VDOT district, with the heaviest concentrations in the Northern Virginia, Richmond, Hampton Roads, and Salem Districts (OIPI, 2022).



Source: CoStar, 2021. Notes: For existing facilities only. Summary by construction districts may reflect partial data.

Figure 1. Rentable Area of Distribution Centers (Blue Bars) and Warehouse Facilities (Green Bars) Across VDOT Districts (reprinted with permission)

The Local Role

Modern warehouses and distribution centers have contributed to the expansion of freight movements, with estimates reaching up to 1,000 more truck trips per day within a warehouse’s surrounding region (Rubiano, 2022). Many industrial buildings are still not planned to include truck parking space, except for brief durations for loading and unloading. This demand-supply gap, as per Guerrero et al. (2022), leads truck drivers to find alternative areas to park, which oftentimes occurs at unauthorized, unsafe locations such as highway shoulders, highway exit ramps, or vacant lots. In communities where trucks frequently park in undesignated areas,

concerns are raised about increased air and noise pollution and damage to roads not built to withstand the weight of heavy-vehicle traffic. Over time, this volume degrades infrastructure and leads to higher maintenance costs (Federal Highway Administration [FHWA], 2022). Parking at unauthorized or undesignated locations also raises safety concerns for both truck drivers and other motorists. A Texas DOT (2020a) study reported 2,315 crashes involving parked trucks from 2013 through 2017 resulting in 138 fatalities and 997 injuries. With the rise of industrial developments in urban corridors generating higher volumes of truck traffic and a lack of adequate truck parking, the implications of municipality zoning regulations are becoming increasingly more relevant.

Zoning regulations are policies and land use rules that prescribe the types and sizes of development permitted within different zones or areas. By dictating industrial locations, zoning laws can help shape the economic development of a region; however, balancing industrial activity with the public interest is essential. Important considerations include traffic impacts, pollution, and noise levels (Millman National Land Services, 2023), but zoning laws may not have been updated to include modern freight-based land uses, such as e-commerce-driven distribution and warehouse facilities. Therefore, it is important that municipalities review and update their zoning ordinances on a regular basis to effectively manage these new industrial uses (Lehigh Valley Planning Commission [LVPC], 2022).

In concurrence with VTrans' goals, VDOT commissioned a study to assess the supply and demand for truck parking in Virginia, identify truck parking needs, and develop solutions to address existing and future parking gaps and needs (Morgan et al., 2022). The study emphasized the importance of collaboration between VDOT, local communities, and private developers whereby each entity can work together to address current and future truck parking needs. The study recommended research that examines local land use and ownership patterns, which can be used to inform possibilities for facility expansion or new parking lots for trucks. A recent Virginia Transportation Research Council (VTRC) study noted that regional planners can support the coordination of local planning and truck freight planning (Miller et al., 2025).

Problem Statement

Undesignated truck parking is one of the consequences of the growth in industrial freight activity. Truck drivers frequently park on roadway shoulders, off-ramps, vacant lots, and local streets near industrial and commercial facilities because truck stops are full, onsite staging is prohibited, and long delays at the facilities consume available hours-of-service time. Although Virginia legislation has encouraged jurisdictions to identify freight corridors in their comprehensive plans, knowledge of proactive policies for industrial developments is limited at the local level. Researchers presented a need to examine local practices for industrial developments at the spring 2024 Transportation Planning Research Advisory Committee meeting that ranked second in prioritization scoring. This study was initiated in support of that research need.

PURPOSE AND SCOPE

The purpose of this research was to develop guidance for local reviews of industrial developments that will enable localities to support VTrans' goals in the areas of industrial land use, truck parking, and freight mobility. Specific objectives were to (1) evaluate the level of detail in Virginia practices compared with best practices with respect to accommodating truck parking needs, (2) assess how these practices influence undesignated parking, and (3) identify the locations where the greatest amount of undesignated truck parking occurs. The scope of the project entailed reviewing best practices in other states and reviewing policy and data at the local level as they relate to land use, truck parking, and freight mobility.

METHODS

The following tasks were performed to achieve the study objectives:

1. Conducting a literature review.
2. Conducting a review of Virginia locality ordinances.
3. Conducting a parking analysis.
4. Developing best practice guidance.

Literature Review

The focus of the literature review revolved around the topic of industrial development as it relates to (1) land use, (2) traffic impacts, (3) truck parking, and (4) mobility innovations. As Figure 2 shows, many subtopics fall under the umbrella of "industrial developments," and although not all inclusive, the topics and subtopics indicate the areas that were reviewed as part of this research.

Review of Ordinances

The purpose of this research is to develop guidance for local reviews of industrial developments, and the methodology entailed three major steps: (1) review the literature (to determine best practices); (2) review the state of the practice in Virginia to determine practices Virginia localities use; and (3) develop a guidance document by comparing best practices to what Virginia localities do. This section addresses the method for that second step.

A review of Virginia locality (city and county) ordinances was undertaken to examine the scope and breadth of clause language related to industrial and freight activity. Virginia localities likely to experience industrial traffic along major freight corridors (e.g., Interstates 95, 81, 64, 77, and 66) were prioritized for the review and are shown in Figure 3. Understanding that more stress would be placed on localities experiencing more frequent industrial traffic, focus was placed on localities, depicted in blue for counties and orange for cities, through which freight routes intersect most. To perform the ordinance review task, a comprehensive zoning code matrix was created to quantify the thoroughness of locality codes based on specific subject categories. From the literature review, the ordinance language of townships in Lehigh County, including Upper Macungie, and Northampton County, including Forks and Moore, in Pennsylvania was

particularly comprehensive in cataloguing industrial and freight policies regarding loading, congestion, storage, distribution, access, and parking (Township of Forks, 2025; Township of Moore, 2025; Township of Upper Macungie, 2026). The matrix framework to organize the policies of Virginia localities used these categories, defined as:

- **Loading:** Method and space availability when moving freight into or out of establishments via truck.
- **Congestion:** Mitigation efforts of traffic-causing delivery patterns.
- **Storage:** Existence of hubs or warehouses to be used for local distribution.
- **Distribution:** Movement of goods from manufacturing centers or warehouses to commercial centers.
- **Access:** Policy surrounding ease of accessing parking or loading amenities by trucks.
- **Parking:** Space provided by private firms or by the city to accommodate temporary or long-term truck parking.

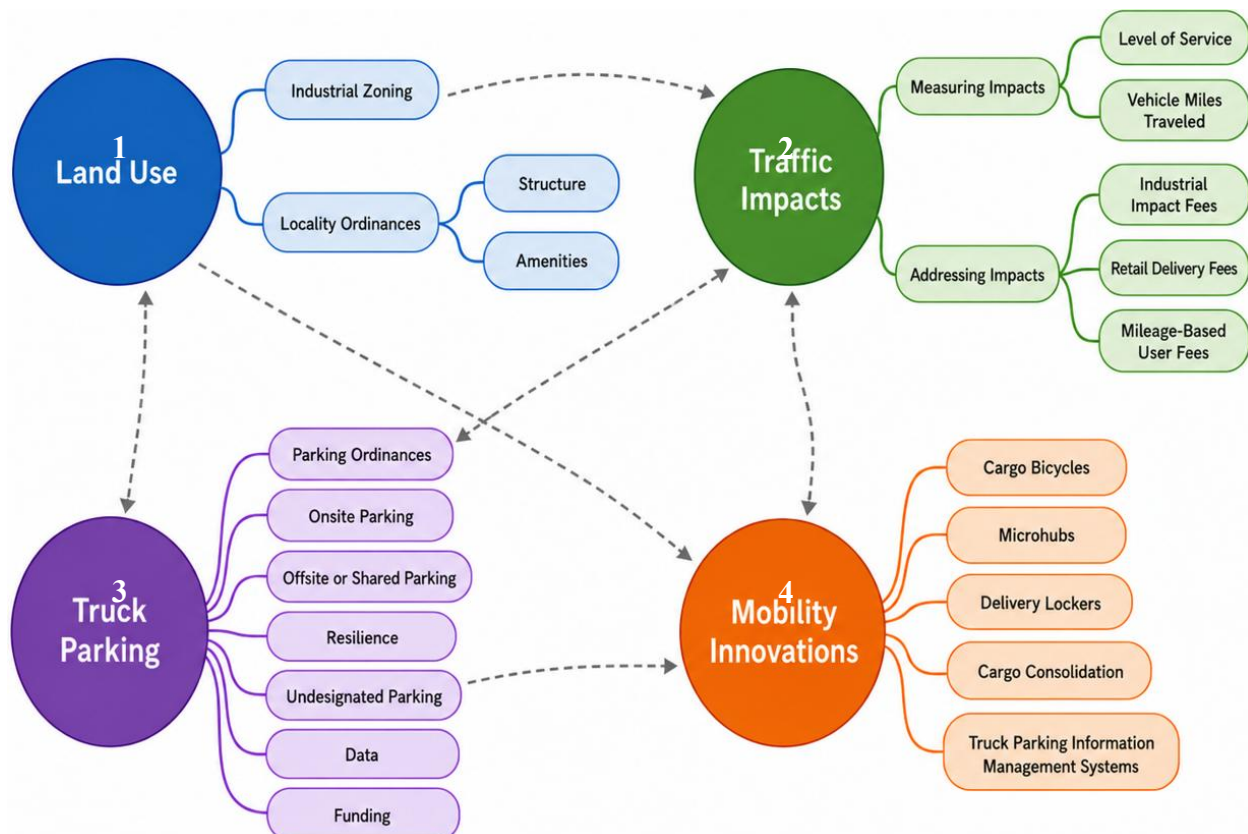


Figure 2. Topic Areas Covered in Literature Review

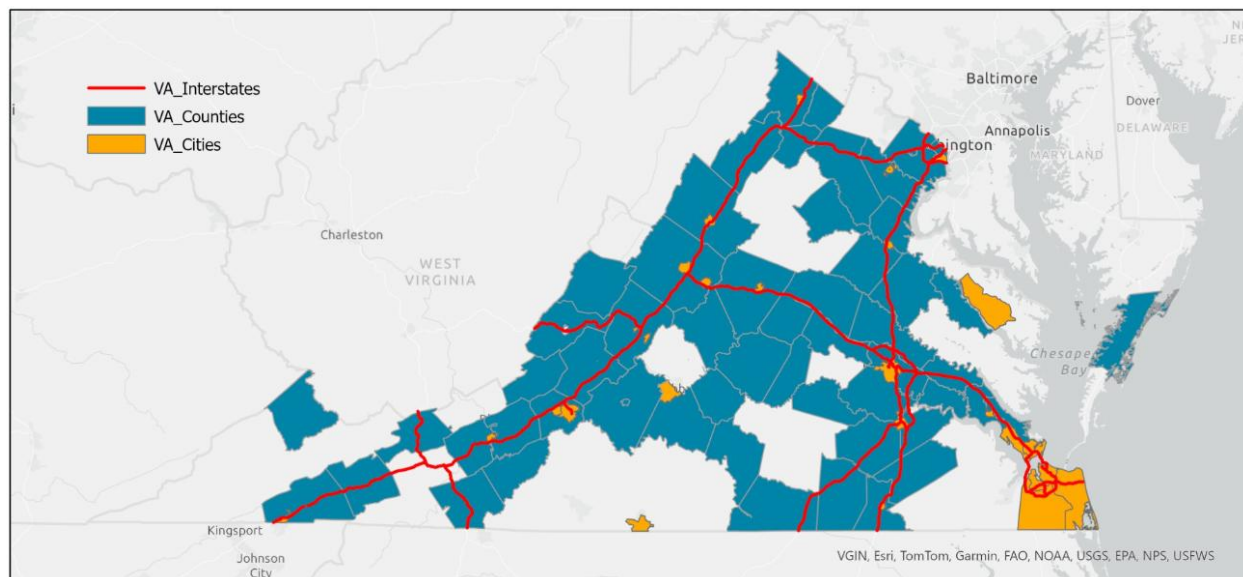


Figure 3. Counties and Cities Prioritized for Ordinance Review

Each of the locality's online codes was reviewed using a structured set of search terms (e.g., loading, freight, congestion, warehouse, delivery, truck access, parking, and so on) intended to capture relevant provisions despite differences in terminology across jurisdictions. Extracted code sections were included only when they contained explicit policy language beyond references, definitions, or statements of intent. A color-coded matrix system (coded green, yellow, orange, and red) was applied to visually quantify the depth of coverage within each category (e.g., loading, congestion, storage, distribution, access, and parking) for each locality reviewed. Using these categories, locality codes were then divided and ranked based on how thoroughly each category was covered (Table 1). Although color coding was at first used as the primary method by which to differentiate the quality of code within different topic areas, a score further distinguished each of the matrix colors to indicate quality numerically (green = 3, yellow = 2, orange = 1, and red = 0) for direct computation and comparison with other freight statistics.

Table 1. Structure of Evaluating Locality Code Extent

Code Extent	Extent Definition
Featured	Contains five or more codes regarding the handling of a specific category pertinent to industrial freight.
Mentioned +	Contains three or four codes regarding the handling of a specific category pertinent to industrial freight.
Mentioned -	Contains one or two codes regarding the handling of a specific category pertinent to industrial freight.
Not Found	Contains no code regarding the handling of a specific category pertinent to industrial freight.

Consistent Search Rules

To ensure that such large and varied quantities of information were being appraised with consistency, it was deemed pertinent that a list of search terms be used with the search function of each code's webpage to isolate sections that would likely include policies aligned with one of the established matrix categories. The search terms included *loading, freight, congestion, traffic, warehouse, storage, distribution, delivery, hub, access, parking, and truck*, all which could be

used in conjunction with one another to ensure that each county's code was thoroughly sorted. These search terms are other than category titles, which were used in conjunction with the ctrl+f function when searching online county codes. They were used to obtain clauses or excerpts that should be counted under the aforementioned category title but that may not be able to be found using the category title as a search term. Alternative search terms were used to overcome semantic differences between codes from different localities that may use a variety of separate words to refer to the same thing (e.g., tractor trailer, semi-truck, truck, and so on).

Alongside the list of search terms, a list of rules was created that determined which excerpts of the code could be used and which ones could not. The following rules served to identify what pretext is needed for a section to count toward a matrix score for a category:

- The mere mention of a relevant industrial policy being permitted does not qualify as having enough depth to be factored into a matrix score.
- Unless a section includes explicit policy pertaining to industrial freight code, definitions, references, and statements of intent do not count toward the number of codes featured in a matrix category.
- Freight codes that refer specifically to a single type of industry do not count toward the matrix score.
- Excerpts that would repeat throughout the county code are not counted as more than one instance contributing toward the matrix score. This narrowing is to prevent skewing from exceptionally redundant codes.
- Certain county sites were deemed uncooperative on account of unusual code layout. These counties required an excessive amount of scrutiny and were not factored into the matrix for this reason.

Whenever a useful section was found, it was copied into a document alongside its number and title within the code. This text was compiled alongside other sections from other zoning codes to form a comprehensive log (logs for both the counties and cities reviewed are in Supplements A and B, respectively, in the report's Supplemental Materials website). The policy categories that a section falls under are labeled in brackets preceding the excerpt. Any valid excerpt found in a locality's code contributed one point to its matrix scores in each relevant category.

Category Breakdown

Prior to reviewing locality ordinances, researchers reviewed the Code of Virginia (2026) to understand the general scope of clauses related to the aforementioned categories (a log for the Code of Virginia is in Supplement C of the report's Supplemental Materials website). Virginia is a Dillon Rule state, meaning that local governments have the powers explicitly granted to them by the state legislature. Virginia state code outlines language related to traffic impacts, but traffic impacts are not brought up elsewhere within the code in the context of a specific application. They are considered in the context of transportation planning more broadly or when making changes to comprehensive plans. In the case of loading areas, the state imposes certain requirements on what loading policy should seek to achieve. For example, the Code of Virginia (2026) section on the design and construction of facilities (9VAC20-170-90) states that, "Onsite queuing capacity shall be provided... so that...delivery vehicles do not back up onto the public

road.” This excerpt emphasizes the requirement for adequate queuing capacity for trucks but leaves the details of exactly how to do so up to individual localities. This example shows how Virginia state policy guides local policies in accordance with Dillon’s Rule, giving localities vague direction to facilitate independent policy implementation.

Loading

For the loading category of the matrix, clauses were sought within locality codes specifying loading space construction or design and limitations. Special focus was put on legal frameworks surrounding the treatment of freight immediately post-arrival or predeparture to or from a distribution center, factory, manufacturing center, or warehouse. To broaden the scope of the search to include all possible clauses pertaining to the category’s criteria, the search term “freight” was used in addition to “loading.” Table 2 shows parking and loading space requirements for Bedford County (2024) according to establishment square footage, including industrial use types. Similarly, Hanover County (2026) provides loading requirements, including those specifically for warehouses, based on gross floor area (Table 3). Table 4 shows other examples of language and justifications for using the specific code sections in the “loading” category.

Table 2. Bedford County Sec. 30-91-13—Modifications to Parking Space and Loading Space Requirements

Uses	Number of Loading Spaces
Offices, Commercial and Civic Use Types, Restaurants	Up to 15,000 sq. ft. = 1 space
	15,001 to 100,000 sq. ft. = 3 spaces
	100,001 to 1.0 million sq. ft. and more = 6 spaces
Industrial Use Types	Up to 40,000 sq. ft. = 1 space
	40,001 to 70,000 sq. ft. = 2 spaces
	70,001 to 110,000 sq. ft. = 3 spaces
	110,001 to 160,000 sq. ft. = 4 spaces
	160,001 to 240,000 sq. ft. = 5 spaces
	Each additional 100,000 sq. ft. = 1 additional space
Aviation Facilities, Hospitals	Up to 100,000 sq. ft. = 1 space

Table 3. Hanover County Sec. 26-259—Off-Street Loading Requirements

Use or Use Category	Size	Loading Spaces Required
Motel, hotel, office or office building, hospital or similar institutions, or auditorium	10,000 square feet of GFA or larger	One service space or one full-size loading space
Assisted living facility	25 beds or more	One service space or one full-size loading space
Restaurants, including those in outparcels but not those in shopping centers	2,500 square feet of GFA and larger	One service space or one full-size loading space
Retail stores (other than those in shopping centers) and commercial establishments or similar use	2,500–100,000 square feet of GFA	One service space or one full-size loading space
	More than 100,000 square feet of GFA	Two loading spaces, one of which shall be a full-size loading space
Shopping center	5,000 square feet of GFA	One service space or one full-size loading space

Use or Use Category	Size	Loading Spaces Required
	More than 100,000 square feet of GFA	Two loading spaces, one of which shall be a full-size loading space
Wholesale house, warehouse, manufacturing, industrial establishment or similar use	2,500–100,000 square feet of GFA	One service space or one full-size loading space
	More than 100,000 square feet of GFA	Two loading spaces, one of which shall be a full-size loading space

GFA = gross floor area.

Table 4. Textual Examples and Justification for the Loading Category

Textual Examples	Justification
Albemarle County (2026) <i>Sec. 4.12.18 Minimum Design Requirements and Improvements for Loading Areas:</i> - [Loading] d. Delineation of loading spaces. Loading spaces shall be delineated in a manner that identifies and preserves the required dimensions with paint striping, signage, or by other means approved by the zoning administrator. The zoning administrator may authorize that bumper blocks or posts be used to delineate loading spaces on surfaces that are not conducive to paint striping.	The codified delineation and construction requirements of loading spaces are specifications pertaining to loading space design.
Bland County (2025) <i>Sec. 62-283 Integrity of Required Open Space:</i> - [Loading] No part of a yard or other open space, or off-street parking or loading space required about or in connection with any building for the purpose of complying with this article, shall be included as part of a yard, open space, or off-street parking or loading space similarly required for any other building.	Restricting loading spaces from offering compliance satisfaction to more than one building is a form of loading space limitation.

Congestion

For the congestion category of the matrix, clauses were sought within locality codes outlining mitigation efforts for traffic-causing delivery patterns or proposing design accommodations for heavy industrial traffic. To broaden the scope of the search to include any and all possible clauses pertaining to the category’s criteria, the search terms “traffic,” “truck traffic,” and “trailer traffic” were used in addition to “congestion.” When proposing a development that may influence or would be influenced by the flow of traffic, locality codes may require a traffic impact analysis or traffic impact study at the behest of their zoning administrator. The Code of Virginia (2026) outlines certain criteria and direction for imposing traffic impact fees:

- *§ 15.2-2319 Authority to Assess and Impose Impact Fees:* Any applicable locality may, by ordinance pursuant to the procedures and requirements of this article, assess and impose impact fees on new development to pay all or a part of the cost of reasonable road improvements that benefit the new development.
- *§ 15.2-2320 Impact Fee Service Areas to Be Established:* The locality shall delineate one or more impact fee service areas within its comprehensive plan. Impact fees collected from new development within an impact fee service area shall be expended for road improvements benefiting that impact fee service area. An impact fee service area may encompass more than one road improvement project. A locality may exclude urban development areas designated pursuant to § 15.2-2223.1 from impact fee service areas.

- *§ 15.2-2321 Adoption of Road Improvement Program:* Prior to adopting a system of impact fees, the locality shall conduct an assessment of road improvement needs benefiting an impact fee service area and shall adopt a road improvement plan for the area showing the new roads proposed to be constructed and the existing roads to be improved or expanded and the schedule for undertaking such construction, improvement, or expansion.

Bedford County (2024) and Dinwiddie County (2026) acknowledge traffic impact analysis in their codes as part of an effort to guide freight traffic policy or manage congestion related to heavy freight. The following clauses are those featuring specific mentions of traffic impact analysis within the respective codes. Although the primary category is congestion, other categories overlap, which are shown in brackets:

- *Bedford County Sec. 30-63-6. Application Process:* [Congestion, Loading, Parking, and Access] A traffic circulation plan, including the location of access drives, parking and loading facilities, pedestrian walks, and the relationship to existing and proposed external streets and traffic patterns. General information on trip generation, vehicle classification, ownership, maintenance, and proposed construction standards for these facilities should be included. A traffic impact analysis may be required by the zoning administrator.
- *Dinwiddie County Sec. 22-234.3. Documents Required for Submission:* [Access and Congestion] A traffic impact study shall be prepared by an individual or firm qualified to conduct traffic engineering studies in a manner and form acceptable to the planning director. Such a study shall address projected traffic generation, internal and external traffic, turning movements and distribution at each access point, traffic distribution, capacity of surrounding roads, and road and access improvements.

Table 5 shows other examples that relate to the congestion category with respect to traffic, not specific to traffic impact analyses or studies. Table 5 shows example language and justifications for using the specific code sections in the congestion category.

Table 5. Textual Examples and Justification for the Congestion Category

Textual Examples	Justification
Prince George County (2026) <i>Sec. 90-862 Parking Construction Standards:</i> - [Congestion] (b) Bases must be well compacted and well drained and soft clay or heavy truck traffic necessitates a heavier base. Accepted bases for driveways are bank run gravel or stones up to inch in size, sandy gravel, crushed stone 1½ or 2½ inches in size slag or other inorganic porous materials as approved by the administrator.	The clause indicates driveway material preference based on anticipated heavy truck traffic, a proposed design accommodation.
Washington County (2025) <i>Comprehensive Plan Chapter 6—Transportation:</i> - [Congestion] The Board of Supervisors passed a resolution supporting “Steel Interstate” service along the I-81 corridor in 2009. This system includes a network of electrified railroad mainlines designed to provide maximum diversion of truck freight to rail and accommodate passenger and freight service on the same system.	The clause proposes a development in direct response to the need for truck freight diversion off the main Interstate 81 corridor.
Greensville County (2026) <i>Sec. 14-78 Through Trucks Prohibited:</i> - [Congestion] (a) It shall be unlawful for any person to operate any truck or tractor truck as defined by the Code of Virginia (2026), § 46.2-100, upon any	Road closures for through truck traffic is a measure taken explicitly to mitigate

Textual Examples	Justification
public road within Greenville County which, by ordinance, the board of supervisors has designated as closed to through truck traffic.	the effects of heavy industrial traffic.

Storage

For the storage category of the matrix, clauses were sought within locality codes dictating the management and construction of storage facilities pertinent to freight activity. To broaden the scope of the search to include any and all possible clauses pertaining to the category's criteria, the search terms "warehouse" and "hub" were used in addition to "storage." Table 6 shows textual examples and justification for the storage category.

Table 6. Textual Examples and Justification for the Storage Category

Textual Examples	Justification
York County (2026) <i>Sec. 24.1-484 Standards for Mini-Storage Warehouses:</i> - [Storage] (a) All storage for mini-storage warehouses shall be within a completely enclosed building, provided, however, that the outdoor accessory storage of recreational vehicles on the same site is acceptable if such storage is screened from view from adjacent streets and residential properties. However, no outdoor RV storage or parking shall be permitted in conjunction with any mini-warehouse facility located in a GB General Business zoning district.	Details are included within the clause stating management practices for mini-warehouse storage facilities.
Bath County (2024) <i>610.03 Conditional Uses:</i> - [Storage] 610.03-14 Wholesale business, storage or warehouse provided that any such use shall be distant at least fifty (50) feet from any Residential District.	The clause details construction proximity for storage facilities.
Brunswick County (2024) <i>19-11 Architectural and Development Standards:</i> - [Storage] 9. Outdoor storage shall be as permitted by the underlying zoning district, provided that all outdoor storage areas shall be visually screened from public rights-of-way, internal roadways, and adjacent properties. Screening shall consist of either a solid board fence, masonry wall, dense evergreen plants, or such other materials as may be approved by the board of supervisors with recommendation from the planning commission. All such screening shall be of sufficient height to screen storage areas from view and shall be appropriately landscaped in accordance with the standards set forth in section 19-11. Outdoor storage shall include the parking of all company-owned and -operated vehicles, with the exception of passenger vehicles.	Specific policy concerning the management of storage facilities and how they must be visually screened from the public right-of-way is outlined.

Distribution

For the distribution category of the matrix, clauses were sought within locality codes dictating the movement of goods directly from manufacturing centers or warehouses to commercial establishments. To broaden the scope of the search to include any and all possible clauses pertaining to the category's criteria, the search terms "delivery," "distribution center," and "hub" were used in addition to "distribution." Table 7 shows textual examples and justification for the distribution category.

Table 7. Textual Examples and Justification for the Distribution Category

Textual Examples	Justification
Appomattox County (2024) <i>Sec. 10-253 Exceptions:</i>	The clause lists an exception to solicitation policy, outlining certain privileges afforded to

Textual Examples	Justification
- [Distribution] (4) Route delivery persons who make deliveries at least once a week to regular customers and whose solicitation is only incidental to their regular deliveries.	individuals performing routine deliveries.
Buckingham County (2018) <i>District 11—Village Center District (VC-I)</i>: - [Distribution] Businesses allowed by right are those that; 1) do not have any outside storage or displays, 2) operate between the hours of 7 AM and 7 PM, 3) have no more than 60 trips/customers per day and 4) do not use delivery trucks with greater than 2 axles. Examples may include Antique/Gift Shop, Barber/Beauty Shop, and Day Care. All Business that does not fit within the parameters listed above must apply for a Special Use Permit.	The clause specifies that by-right uses must not use delivery trucks with more than two axles, a detail that explicitly limits the manner of goods distribution to such establishments.
Craig County (2025) <i>Sec. 54-175.1 Public Streets [Distribution] (h) Alleys</i>: - Alleys should be avoided unless they serve a useful and practical purpose. Dead-end alleys, if unavoidable, shall be provided with adequate turnaround facilities as determined by the state department of transportation. Alleys may be provided for delivery trucks, garbage pickup, and other service and maintenance type purposes.	Use of alleys for deliveries is a distribution method policy (by way of alleys).

Access

For the access category of the matrix, clauses were sought within locality codes facilitating ease of accessing parking, loading amenities, or roadways by trucks. This search included specifications for the construction and management of access-ways. To broaden the scope of the search to include any and all possible clauses pertaining to the category's criteria, the search terms "truck access," "trailer access," and "industrial access" were used in addition to "access." Table 8 shows textual examples and justification for the access category.

Table 8. Textual Examples and Justification for the Access Category

Textual Examples	Justification
Bland County (2025) <i>Sec. 62-291 General Off-Street Parking Requirements for Parking Lots</i>: - [Access] All commercial, industrial or public use parking shall be provided with space for turning or maneuvering which will not require backing into public street right-of-way.	This clause concerns ease of positioning for industrial parking, a key component of parking access.
Buchanan County (2026) <i>§ 73-65 Inspection and Sampling</i>: - [Access] D. Any temporary or permanent obstruction to safe and easy access to the industrial facility to be inspected and/or sampled shall be promptly removed by the industrial user at the written or verbal order of the Executive Director and shall not be replaced. The cost of clearing such access shall be borne by the industrial user.	Clear access to industrial facilities is emphasized in this clause, along with any ensuing repercussions of obstruction.
Prince George County (2026) <i>Sec 90-862 Parking Construction Standards</i>: - [Access] (a) All parking areas, access aisles and driveways shall be paved with a dust-free all-weather surface such as asphalt, concrete, or other hard surface, except as permitted by the administrator	Material construction of accessways is specified in this clause.

Parking

For the parking category of the matrix, clauses were sought within locality codes specifying temporary or long-term freight parking construction and design, limitations, or accommodations at distribution centers, factories, manufacturing centers, or warehouses. Clauses

detailing certain amenities to be provided by private firms or the city will also be included. To broaden the scope of the search to include any and all possible clauses pertaining to the category’s criteria, the search terms “truck parking” and “trailer parking” were used in addition to “parking.” Table 9 shows textual examples and justification for the parking category.

Table 9. Textual Examples and Justification for the Parking Category

Textual Examples	Justification
Roanoke County (2026) <i>Sec. 36.2-653 Maximum Parking:</i> - [Parking] (2) Spaces allocated to a fleet or accessory vehicles necessary for and directly associated with the operation of a business or service establishment shall not count toward any maximum parking standard. A fleet shall mean a group of motor vehicles, such as taxicabs, vans, or trucks, operated as a unit in association with a business or service establishment.	This clause delineates between fleet parking and maximum parking standards, offering allowances for parking related to industrial vehicles beyond the existing parking capacity.
Stafford County (2026) <i>Sec. 28-102 Off-Street Parking:</i> - [Parking] (12) Commercial vehicle parking. Commercial vehicle parking spaces shall be in addition to required parking for a specific use. Commercial vehicle parking may be permitted in agricultural, commercial and industrial zoning districts. Overnight commercial vehicle parking shall be limited to truck/freight terminals and truck stops, except for fleet parking and where permitted by this chapter.	Off-street parking time limits are laid out alongside where such limits do not apply (truck and freight terminals and truck stops).
Brunswick County (2024) <i>10-7 Requirements for Permitted Uses:</i> - [Parking] 10-7-4. Sufficient area shall be provided (a) to adequately screen permitted uses from adjacent business and residential districts and (b) for off-street parking of vehicles incidental to the industry, its employees and clients.	This section lays out off-street parking requirements for industry vehicles.

Multiple Category Satisfaction

Clauses exist within locality codes that may fulfill the criteria for multiple matrix categories opposed to only a singular category. The following are examples of clauses found in the review that fulfill multiple categories, as shown in brackets:

- Dinwiddie County (2026) *Sec. 22-230.3. Development Standards. Street Access* [Access and Congestion]:
 - The primary access to a planned manufacturing district shall be directly from either a major access road, major collector, major arterial, or minor arterial roadway as designated on the county thoroughfare plan. All streets within the industrial district that are not to be taken into the state system shall be built to a standard that will accommodate the weight load and volume of vehicles anticipated.
 - Justification—Accessways to major roads are addressed in this clause, along with explicit acknowledgment of accommodation for roads that are anticipated to experience high traffic volume, a display of policy melding access. and congestion concerns.
- Warren County (2026) *§ 155-46 Blocks* [Parking and Distribution]:
 - Blocks intended for business or industrial use shall be designed specifically for such purpose with adequate space set aside for off-street parking and delivery facilities.

- Justification—This clause addresses both the topic of parking amenities and designates business and industrial blocks as requiring design accommodation for delivery and distribution services.

Parking Analysis

On completing the ordinance review, the next task was to analyze truck parking near industrial developments and to examine the correlation between ordinance quality and the number of undesignated parking events. To perform this task, it was necessary to obtain data on truck parking near industrial clusters within localities along Virginia’s freight corridors. This section describes the process of obtaining truck parking data, the methods used to evaluate the data, and an undesignated parking cluster ranking process to prioritize improvements at locations using a method developed in Maryland (Maryland DOT, 2020).

Obtaining Truck Parking Data

A number of vendors process and package data on truck trips (origin to destination) via Global Positioning System (GPS) probe data, but few provide data specific to truck parking events lasting 30 minutes or longer. This lapse is because probe device identifiers in commercial trucks rotate after the vehicle has stopped for 10 minutes to provide anonymity. To evaluate parking data lasting longer than 10 minutes, it was necessary to seek a vendor that uses installed telemetry hardware in trucks. Telematic devices (i.e., electronic logging devices) are typically plugged directly into a truck cabin’s diagnostic port and provide GPS location, speed, braking, and specific engine diagnostics, such as idle and engine off event times. Based on a review of the Eastern Transportation Coalition’s prequalified vendors (of which VDOT is a member), Geotab is the only vendor in Eastern Transportation Coalition’s Transportation Data Marketplace that provides truck parking data using telematics. After discussions with Geotab staff on data needs, cost, and timeframes, truck parking data from Geotab’s Altitude platform were purchased through VDOT’s contract with the Eastern Transportation Coalition.

Geotab’s data are sourced from electronic logging devices in more than 50,000 unique fleet operations, which cover one out of eight commercially registered vehicles, resulting in a 20% penetration rate. Within Geotab’s Altitude platform is a Stop Analytics module that provides insights into truck parking events, including where the trucks stop and how long the vehicles remain parked. A *stop* is defined as the end of a trip, and it occurs when a vehicle has met any of the following conditions: idled for at least 200 seconds, shifted into park for at least 30 seconds, or the ignition has turned off. In some cases, engine-off events are not considered a stop, such as the following scenarios (Geotab, 2026):

- If the next stop is less than 5 meters from the start, it is assumed that this occurrence is the result of GPS drift or a quick car shuffle, and it is ignored as a stop.
- If less than 30 seconds occur between when the ignition turns on or off, it is assumed that the ignition signals are faulty and are ignored.
- If the distance and time between when an ignition turns on or off would result in a speed greater than 5 meters per second, it is assumed that the ignition signals are faulty and are ignored.

- When the ignition turns on or off with no movement in between, these actions are also ignored.

Privacy protection is built into Geotab’s Altitude platform architecture by aggregating data prior to it entering the system. The Stop Analytics module provides this aggregated stop data with granularity control for filtering by specific location, minimum and maximum stop durations, and trip durations and distances before and after stops. In addition, the platform provides data on fuel type, vehicle type, industry, and vocation. Figure 4 shows an example of location output from the Stop Analytics module for heavy-duty truck parking in Wythe, Virginia, near a Flying J truck stop (left image) and a Gatorade distribution center (right image). The data are aggregated by hexagon cells during the course of 3 months in 2025 (January–March), whereby the resolution can be adjusted to provide greater granularity on specific locations. The output shown in Figure 4 is the highest resolution capable in the module (H3 cell resolution: 12). The minimum aggregation is two parking events to comply with privacy rules. The module provides the ability to zoom into individual H3 cells to obtain specific aggregated parking data (e.g., pre- and post-trip travel distances and duration, idle duration, stop duration, fuel type, vocation and industry types, vehicle classification, and so on). The darker the hexagonal cell, the more instances of truck parking within that cell’s location.

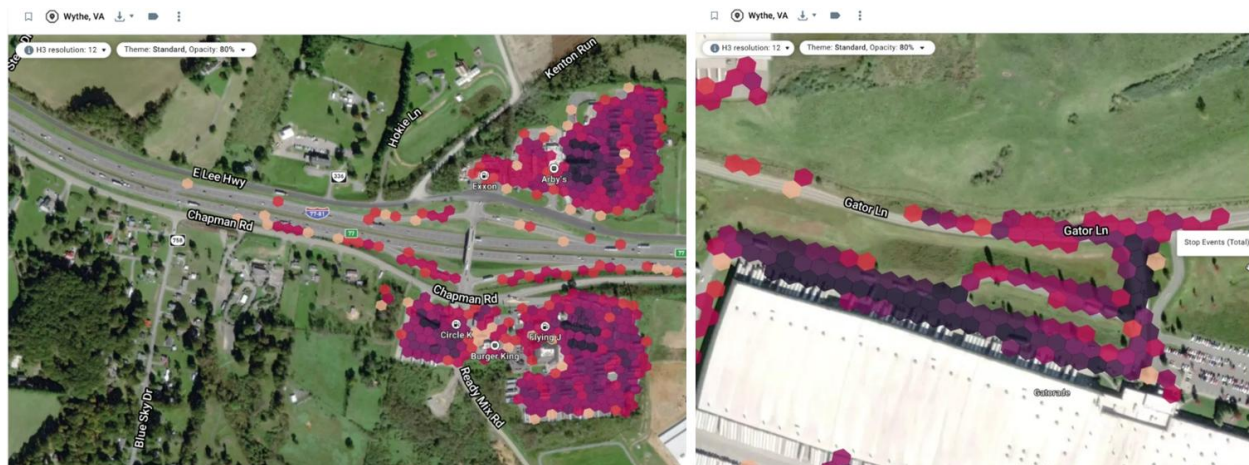


Figure 4. Aggregated Parking Events in 2025 at a Flying J Truck Stop and a Gatorade Distribution Center in Wythe, Virginia. The darker shading represents higher numbers of truck parking events.

Virginia Analysis

Historical stop analytics data were purchased from Geotab for 2 full months (April and October) in 2024 that included all stop events, as the previous section described, within the state boundaries of Virginia. These 2 months were chosen after consulting with Geotab staff on obtaining “typical” truck activity months during the spring and fall periods. Once given access to the platform, the researchers held onboarding primer meetings with Geotab to develop concepts and analytical methods.

Reviewed Localities

The first step was to develop a map of truck parking events that occurred throughout Virginia during the analysis period. To do so, a truck “parking” event had to be defined, which,

for the purposes of this project, is different than a truck “stopping” event, as described previously. The Altitude platform allows users to define specific parking time thresholds, and based on conversations with Geotab, it was decided that the most appropriate time threshold for a parking event should be at least 30 minutes to ensure that focus is kept on lengthy and deliberate parking instances rather than miscellaneous stops for reasons of emergency or convenience. Therefore, the analysis of stop duration was filtered to exclude any stops lasting less than 30 minutes.

Figure 5 shows a map of all truck parking events in Virginia from Geotab sources lasting 30 minutes or more during the 2-month evaluation period in 2024. The singular truck parking events are not shown because of privacy rules. One of the goals of the parking analysis is to build off the guiding freight codes for localities assessed in the Review of Ordinances section and to examine if correlations exist between the quality of ordinances and patterns of truck parking near industrial developments. Therefore, the parking event data in Figure 5 were then parsed based on the ordinance review of localities along the major freight corridors, which included all the counties shown in Figure 3 and the cities of Danville, Lynchburg, Richmond, Roanoke, and Salem. The port cities of Norfolk, Portsmouth, Newport News, and others were not included in the parking analysis because of the influence of the Port of Virginia, which can distort comparisons to inland freight hubs, especially with respect to truck parking activity and industrial developments. The data analyzed for each locality were (1) total truck parking count and (2) number of industrial sites. A Spearman’s Rank-Order Correlation was then used to assess the strength of the association between the numerical score of ordinance quality on both total truck parking counts and industrial site counts.

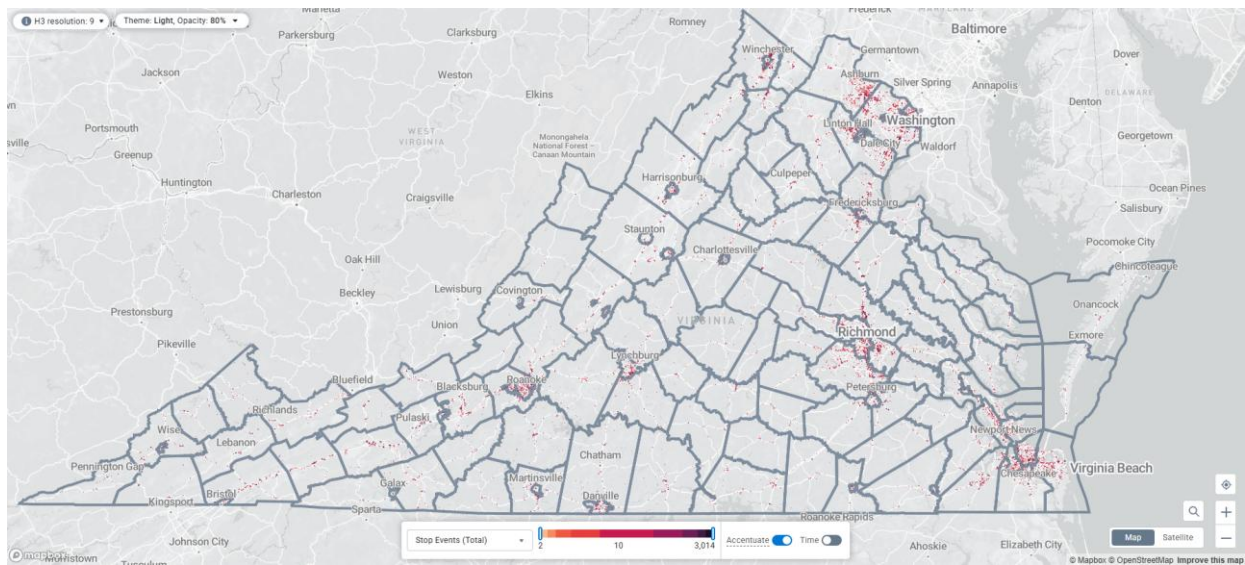


Figure 5. Geotab-Sourced Parking Events in Virginia Lasting 30 Minutes or More During the 2-Month Evaluation Period

Targeted Review of Localities

Specific counties and cities with substantial industrial activity and a range of quality of ordinance scores were then selected to undergo greater scrutiny to ascertain if a relationship exists between quality of ordinances and undesignated truck parking instances. Based on the

scoring methodology discussed in the Review of Ordinances section and in the interest of obtaining broad representation, two counties were selected with total points in the 14–17 range, three from the 11–13 range, three from the 8–10 range, three from the 4–7 range, and two from the 0–3 range. Figure 6 shows Henrico County’s high industrial activity that happened to score in the highest point range, and thus, Henrico County was chosen for further review. Table 10 shows the localities chosen for further review and their total scores. Supplement D in this report’s Supplemental Materials website provides examples of industrial activity within each of the selected localities.

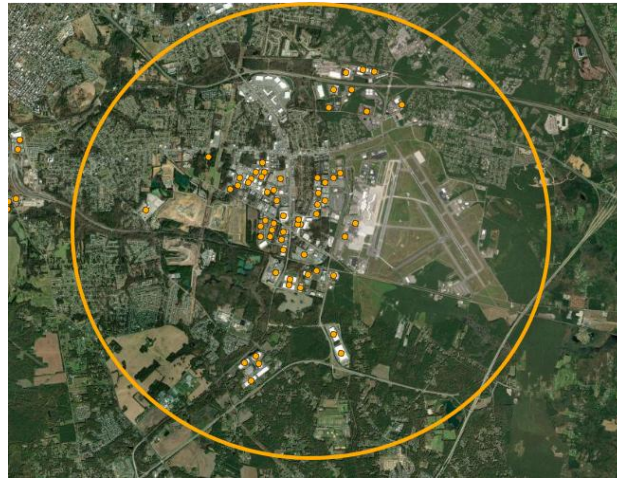


Figure 6. Heavy Industrial Cluster in Hanover County. Imagery Copyright of the Commonwealth of Virginia, Maxar Technologies, and Microsoft.

Table 10. Localities Selected for Further Review

Locality	Loading	Congestion	Storage	Distribution	Access	Parking	Code Score
Henrico	3	2	3	3	3	3	= 17
City of Lynchburg	3	3	1	3	2	3	= 15
Frederick	3	1	2	1	3	3	= 13
Spotsylvania	3	2	1	1	3	3	= 13
City of Salem	3	3	0	3	0	3	= 12
City of Roanoke	2	2	2	2	1	1	= 10
Augusta	3	1	1	1	1	3	= 10
Hanover	3	1	1	1	1	2	= 9
Warren	2	1	0	1	0	2	= 6
Pulaski	2	0	0	2	0	1	= 5
Campbell	0	2	0	0	2	0	= 4
Smyth	0	1	0	0	1	0	= 2
Chesterfield	1	0	0	0	0	0	= 1

Bold = localities along major freight corridors. Colored cells correspond with ordinance code quality, for which red = 0, orange = 1, yellow = 2, and green = 3.

Figure 7 shows a Geotab map of the 13 selected localities from Table 10. Similar to Figure 5, the red dots shown within each locality represent non-singular parking events lasting

30 minutes or longer during the 2-month evaluation period. Producing this map was an important first step, proof-of-concept, and led to more rigorous mapping and analysis on a smaller scale that identified clusters of truck parking activities within the 13 selected localities (Figure 8).

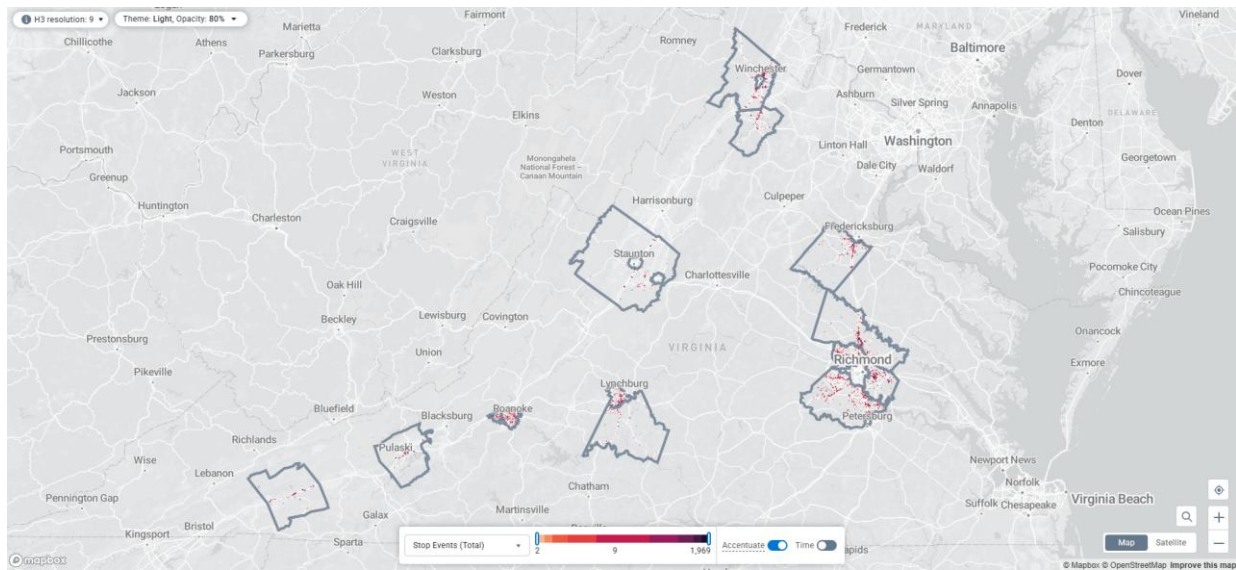


Figure 7. Geotab-Sourced Parking Events in Selected Localities

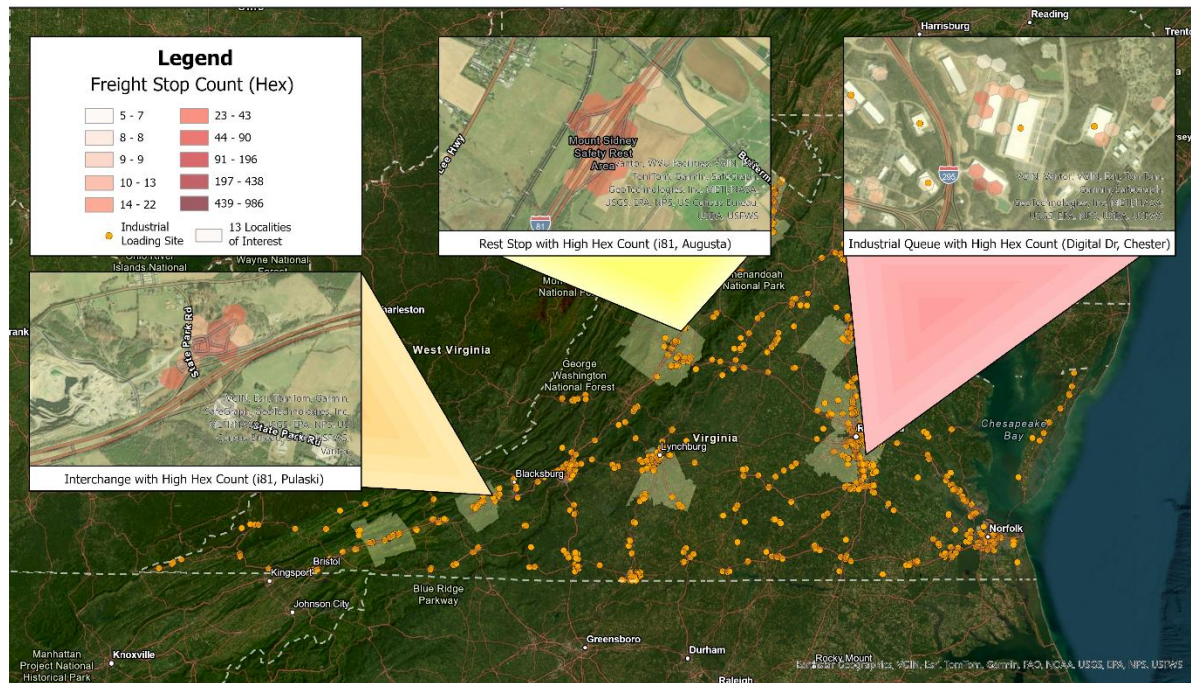


Figure 8. Example of Parking Clusters Within the Localities Selected for Further Review

Because of Geotab's data privacy rules, the hexagonal resolution (shown in the parking highlights of Figure 8) had to be adjusted. For example, larger encompassing hexes were used in the preliminary analysis to identify hotspots of parking activity but then fine-tuned to lower resolutions that would allow for more detailed locational scrutiny. However, because the Altitude platform refrains from singling out individual stop instances, the finer the resolution can lead to

data loss. Figure 9 shows an example of these phenomena at a location in Charlottesville, Virginia, for which Figures 9a through 9d show the lowest resolution coverage and high parking activity (Figure 9a) and fined-tuned to the highest resolution and low parking activity (Figure 9d). This loss of data is directly associated with privacy rules related to parking sample sizes.



Figure 9. Data Loss Related to Hexagonal Cell Resolution: (a) = more data, lower location precision through to (d) = less data, more location precision

To address this loss of both parking data and locational information using hexagonal cell data, custom zoning procedures were developed that allowed more flexibility. Custom zoning allows for the verification of the purported presence of truck parking along hex-identified roadways. For example, specifically shaped custom zones along a stretch of road can verify and give more locational specificity as to whether parking instances are taking place on the roadway shoulders opposed to at adjacent businesses or lots. Figure 10 shows an example of the same Charlottesville location depicted in Figure 9 but with a custom zone boundary created. After becoming more familiar with the methods to develop custom zones, a more in-depth trial analysis was conducted using a location in Wythe County to formulate a replicable set of instructions for creating and analyzing custom zones. This workflow is in Supplement E of the report's Supplemental Materials website. This workflow also includes instructions on how to migrate data in the Altitude platform to ArcGIS, which can allow for more analytical flexibility depending on need.



Figure 10. Custom Zoning Example

Roadway segments within the selected localities that exhibited high densities of truck parking based on hexagonal cell clusters were further explored. This task was accomplished by creating separate custom zones on the road segments (including ramps) similar to Figure 10 and filtering the data on vehicle class, vocation, and industry type based on the kinds of industries and freight being scrutinized within locality codes (i.e., industries such as solid waste management and municipal services were not included to prevent the skewing of results from their stops). Data filtering resulted in maintaining the following vehicle class, vocation, and industry in the dataset:

- Vehicle Class: Heavy-duty (> 26,000 lbs.).
- Vocation: Long distance, regional, local, hub, and spoke.
- Industry: Construction, manufacturing, retail trade, wholesale trade, transportation, and warehousing.

The filtered data were then used to identify (1) stop events, (2) median stop duration, and (3) median idle time for all clusters within each locality. On completing this step, the highest stop event location was then further scrutinized to obtain specific information on vocation; industry type; median, 15th, and 85th percentile pre- and post-stop trip distances; and median, 15th, and 85th percentile pre- and post-stop trip durations.

Cluster Priority Ranking

A cluster analysis was performed based on assessment criteria from the Maryland Statewide Truck Parking Study (Maryland DOT, 2020). This step was done to identify parking clusters of greatest concern using a scoring system to assign points to different types of undesirable parking behaviors. Table 11 shows the criteria used in the Maryland study, including components of safety (30 points), parking duration (50 points), and total parking count (20 points).

Table 11. Maryland Freight Parking Cluster Scoring Rubric (Source: Maryland DOT, 2020)

Safety	Points
Undesignated parking along last-mile connectors to freight generators	0
Undesignated parking at roadside facilities developed for emergency use (i.e., rest stops)	15
Undesignated parking along on- and off-ramps	30
Duration (Scaled based on number of stops to a <i>maximum of 50</i>)	
Parking events lasting 0.5 to 3 hours, scaled based on the number of stops	10
Parking events lasting 3 to 8 hours, scaled based on the number of stops	15
Parking events lasting more than 8 hours, scaled based on the number of stops	25
Total Number (Scaled based on number of stops to a <i>maximum of 20</i>)	
Total number of undesignated trucks parked.	20

Although scoring based on safety can be done using the fixed point-values provided by the Maryland DOT (2020) study, differentiating clusters based on the scoring criteria for duration and total number requires specialized scaling based on maximum stop count. Of the zones analyzed, the researchers found that the Interstate 81 (I-81)/Safety Rest Area intersection in Smyth County exhibited the highest stop count at 125. Likewise, duration scoring will differ from the Maryland study because no listed parking events lasted more than 8 hours, so the three categories were divided differently to account for this absence. Stop counts for other zones were then represented as a proportion of this maximum stop count to provide the recommended scaling factor. The score a cluster received was then multiplied by this scaling factor for the total number and duration sections. Table 12 shows the adjusted cluster scoring rubric used for this effort.

Table 12. Revised Freight Parking Cluster Scoring Rubric (adapted from Maryland DOT, 2020)

Safety	Points
Undesignated parking along last-mile connectors to freight generators	0
Undesignated parking at roadside facilities developed for emergency use (i.e., rest stops)	15
Undesignated parking along on- and off-ramps	30
Duration (Scaled based on proportion of max stop count)	
Parking events lasting 30 to 120 minutes, scaled based on the number of stops	10
Parking events lasting 120 to 240 minutes, Scaled based on the number of stops	25
Parking events lasting 240 to 360 hours, Scaled based on the number of stops	50
Total Number (Scaled based on proportion of maximum stop count)	
Total number of undesignated trucks parked	20

Best Practice Guidance

The researchers developed guidance based on findings from the previous tasks, with a focus on ordinance language that VDOT can share with localities. States identified in the literature review were the source of the initial template. Then, based on the review of Virginia ordinances and the parking analysis along major freight corridors, suggested language was provided across four key areas: applicant narrative, truck routing, parking (on and off site with explicit consideration of staging), and amenities. Care was taken to provide definitions that were compatible with existing ordinances used in Virginia. This guidance is in the Appendix and provided as a standalone document in Supplement F of the report's Supplemental Materials website.

RESULTS

Literature Review

Land Use

Land use planning is important for guiding where and how development occurs, ensuring that different land uses are compatible with each other and the surrounding environment. As Meyer and Miller (2001) postulate, trip-making patterns, volumes, and modal distributions are largely a function of the spatial distribution and use of land. Therefore, controlling the trip-generating characteristics of land use can result in making the demand consistent with existing infrastructure. Historically, industrial development was predominantly in rural areas, where affordable land and convenient highway access made economic and logistical sense (KSS Architects, 2021). These economic and logistical factors helped to keep the concentration of large freight users within specific zones typically outside urban core areas. However, as Holguín-Veras et al. (2020) point out, locating freight clusters far from the urban core can lead to longer travel distances for trucks during last-mile deliveries, thereby increasing vehicle miles traveled (VMT) and associated environmental impacts.

With the rapid growth of e-commerce in recent years, companies are increasingly locating warehouses and distribution centers closer to urban areas to better meet customer delivery expectations (Brogan, 2025). Distribution centers can employ hundreds, if not thousands, of workers, and proximity to the workforce is a contributing factor for locating closer to more densely populated areas (KSS Architects, 2021). Felix and Pollack (2021) note that the competition to add warehouse and distribution centers has resulted in a high demand for industrial real estate, particularly in urban areas, which require both substantial amounts of land and easy access to the regional highway network. As a result, urban freight-based land uses have increased dramatically in the past 10 years, both in terms of land consumption and traffic generation (LVPC, 2022). Data from subdivision and land development plans reviewed by LVPC indicate that more than 35 million square feet of warehousing and distribution center development has been proposed within the Lehigh Valley region since 2020 (LVPC, 2022).

With this growth, municipalities have an important role regarding the siting and operating of distribution and warehousing facilities, and their approaches should align with and advance transportation, economic, and sustainability goals for the region (Felix and Pollack, 2021). However, as Rephann (2022) notes, municipalities often lack due diligence when performing market feasibility analyses of industrial development need. As a result, industrial developments are often built in suboptimal locations with limited access to labor and other business resources or are built substantially larger in size than local market need would dictate. For example, in the Otay Mesa area of San Diego, where much of the land is zoned residential, the San Diego Association of Governments has witnessed a significant increase in industrial developments near residential neighborhoods that the agency has been unprepared to address (Maricopa Association of Governments [MAG], 2024). Addressing the intensity of the land use with zoning is important to minimize the negative effects with surrounding communities, and municipalities must balance their needs between matching building form and scale to transportation demands and appropriate infrastructure (LVPC, 2020).

Industrial Zoning

Zoning regulations are rules and guidelines that dictate how land can be used. They include regulations that limit the type and size of development allowed in certain areas (Tolj, 2024). Vasquez (2022) suggests that a tendency exists to associate industrial with nuisance activity, such as loud and pollution-generating trucks operating within and around industrial sites. This perception has caused many cities and towns to adopt industrial zoning, which allows only industrial activity to occur on properties with such zoning. However, each jurisdiction can have nuanced rules affecting how land can be used and what permits are required (Millman National Land Services, 2023), and as Vasquez (2022) notes, each municipality has its own zoning code and may define types of industrial zoning differently.

Rubiano (2022) points out that the United States is the only industrialized country without a national, standardized zoning code and, thus, no universal definition of what a modern warehouse or distribution center is, how hazardous it should be considered, and where it should be placed. Furthermore, many zoning codes are outdated in the sense that they separate warehouses and distribution centers from residential development, thus driving increased sprawl of these facilities. Rubiano (2022) describes that New York City's zoning code has remained unchanged, whereby last-mile facilities built today still fall under the 1961 definition of a warehouse, and building them activates no environmental requirements. To address this issue, New York City is considering developing an amended zoning code for e-commerce facilities that would define last-mile trucking facilities based on size and the number of vehicle trips per day, allowing regulators and communities to fully understand the effects.

Outdated zoning codes are not unique to New York City. With the evolving demands of e-commerce, communities across the country are finding the need to reconcile antiquated or inadequate zoning regulations (Rubiano, 2022). However, policy and ordinance changes are often difficult to implement because they require legal revisions that can take years to finalize. According to the Maricopa Association of Governments (2024), many peer regions have experimented with ordinances targeting noise, vehicle idling, and emissions, yet only a few have successfully implemented these policies on a broad scale. Holguín-Veras et al. (2020) suggest that public-sector decision-makers often lack detailed knowledge of industrial and freight operations and typically have not received formal training in freight transportation policy and management. Consequently, when confronted with freight-related challenges, public officials frequently revert to familiar regulatory strategies, pushing all types of distribution centers—even the “last-mile” centers—away from residential areas.

Local Ordinances

Industrial development is known to boost economic growth by providing jobs and tax revenue to localities (Virginia Economic Development Partnership [VEDP], 2023). A recent press release from the Virginia governor's office announced that Amazon is building its fourth Virginia robotics fulfillment center in Goochland County, creating more than 1,000 jobs that will bring significant economic opportunity to the region. Since 2010, Amazon has invested more than \$135 billion in Virginia, creating more than 42,000 direct jobs in the Commonwealth (VEDP, 2025). Promoting new employment activities in development areas is typically a goal in a county or municipality's comprehensive plan. For example, some of Albemarle County's

(2025) goals in its comprehensive plan are to promote new employment activities in development areas and encourage developers of industrial projects to incorporate the neighborhood model principles (e.g., move development away from a pattern of sprawl and toward compact, interconnected buildings and infrastructure). According to Lester et al. (2014), industrial zone designations are effective in supporting the growth of industrial space; however, local ordinances are often designed solely for large-scale traditional industrial sites common in the mid-20th century. Therefore, local governments should update their ordinances to adequately account for modern freight-based land uses (LVPC, 2022).

A study conducted by the North Jersey Transportation Planning Authority (NJTPA) on freight movement in Southern Middlesex County found that freight expansion in the area has contributed to increased traffic congestion and other associated conflicts between pedestrians, automobiles, and large trucks (NJTPA, 2023). The effects on local and county infrastructure and mobility have been well documented as congestion travel delays, and crashes have increased, resulting negatively on local communities, non-motorized travel, and the environment. Locality ordinances that regulate industrial activity, such as allowable uses, building heights, buffer zones, and traffic impacts can help alleviate some of the negative effects associated with freight generators; however, this regulation can be challenging (LVPC, 2020).

Ordinances Related to Parking. Dowell et al. (2022) discuss how land use policies have failed to keep pace with modern shipping practices and suggest that communities can benefit from reviewing land use and zoning policies to ensure they encourage adequate truck parking for new developments that generate truck traffic. Truck drivers need parking to rest, stage, and store their trucks to operate in the communities they serve. However, truck parking and staging often conflict with land use in densely populated areas often covered by local ordinances that may not reflect current parking and staging demand. Phelan et al. (2017) propose that in areas with heavy concentrations of terminals, distribution centers, and other industrial sites, truck parking capacity can be addressed through local zoning requirements or agreements with regional and local governments. Still, the American Transportation Research Institute (ATRI) points out that a number of factors at the local and regional levels make it challenging for the siting and expansion of private sector parking projects (ATRI, 2024). In some cases, regulatory burdens limit construction or expansion opportunities, such as the purchase of rights-of-way, maintenance costs, noise and abatement regulations, and limitations or bans on truck parking. Truck parking policies often vary between states and localities, and local ordinances that ban or limit truck parking may result in negative consequences for neighboring localities (Washington State Department of Transportation [WSDOT], 2022).

In cases with regulatory burdens, MAG (2024) suggests that truck parking should be viewed as a land issue, and modifications to zoning ordinances should be made to require provisions of truck parking as part of a required traffic impact analysis. Colorado DOT supports requirements related to warehouse dock door ratios, and LVPC has been continuously tweaking code requiring parking based on the number of bays a facility has (MAG, 2024). LVPC is also working with each of its municipalities to develop truck parking guidance for adoption in municipal comprehensive plans and zoning regulations (NJTPA, 2023). The *Regional Truck Parking Study* mentions that staging within and around industrial developments is a sizeable component of truck parking activity in most U.S. metropolitan areas (Capital Region Transportation Council [CRTC], 2023). The study estimated that 25% of trucks parked during

peak overnight periods are making their next stops within the capital region and surrounding counties. To address this parking need in the context of the development process, the study developed a set of recommendations that included formal guidance for incorporating truck parking and staging into industrial site approvals that include the following (CRTC, 2023):

- **Incorporate parking and staging studies for trucks in traffic impact assessments for industrial land uses.** This process would be comparable with a local parking study for a commercial or mixed-use development in a downtown area but would cover a larger region and include an assessment of capacity and demand at a variety of facilities, such as highway rest areas and private truck stops.
- **Implement zoning requirements for onsite or pooled truck parking spaces in industrial areas.** This task would be accomplished by using standard zoning metrics, such as spaces per 1,000 square feet of gross floor area or spaces per loading dock door. These parking requirements could be met either through onsite spaces or in a pooled parking facility in an industrial park that serves as a centralized parking and staging lot for multiple industrial sites.
- **Include requirements for onsite driving amenities in zoning code provision.** At a minimum, this provision would include access to bathroom facilities. Additional amenities could include a driver's lounge and vending machines, microwave ovens, and similar features.
- **Update zoning requirements for industrial properties to allow long-term parking for the Federal Motor Carrier Safety Administration hours-of-service regulations.** This measure will require effective collaboration between municipal officials, property owners, and the trucking industry to ensure that this parking can be done safely and in a non-intrusive manner.

Similar to the *Regional Truck Parking Study* (CRTC, 2023), the Pennsylvania Transportation Advisory Committee (PTAC) recommends addressing truck parking in county and local comprehensive plans, as well as updating land use regulations, such as zoning and subdivision and land development, to include truck parking (PTAC 2023). Specifically, the recommendations encompassed:

- Developing model ordinances requiring truck parking for new developments.
- Updating subdivision and land development ordinances.
- Updating zoning ordinances to ensure truck parking is allowed in compatible zones and restricted in incompatible zones.
- Enlisting the help of municipal authorities to develop truck parking solutions.
- Streamlining permits and approvals.
- Incorporating truck parking demand into the industrial development and evaluation processes facilitated by local and state economic development entities.
- Addressing truck parking in county and local comprehensive plans.

With respect to the subdivision and land development ordinance provisions, Pennsylvania further recommends a truck parking assessment of proposed industrial land as a component of a traffic impact study similar to MAG (2024) recommendations (PTAC, 2023). Counties, cities, and municipalities across the nation already develop traffic impact assessments and review site

plans for new development, but as Dowell et al. (2022) postulate, these processes do not always consider the specific transportation and truck parking needs generated by freight activity. By reviewing the traffic impact assessment processed, truck volumes at a site and the effects of staging near a site can be better anticipated. Pennsylvania's subdivision and land development ordinance provisions attempt to address truck parking supply and demand assessments by requiring documentation of (PTAC, 2023):

1. Truck parking conditions and operations at an active industrial site similar to the proposed development.
2. Existing truck parking spaces proximate to the proposed industrial site in nearby parking facilities.
3. The total number of truck parking spaces needed to meet demand.
4. The net number of additional parking spaces required.

Maryland conducted a statewide truck parking study on sites where priority clusters were developed (Maryland DOT, 2020). Some clusters in Western Maryland were identified as having opportunities to benefit from integrating truck parking into land use, zoning, and planning considerations. The density of freight traffic, parking demand, and instances of undesignated parking near warehousing and industrial developments were key factors for promoting ordinance considerations. As an example, undesignated parking was identified on roadways near warehousing and a Costco Distribution Center in Monrovia. The study suggested that in cases in which developments increase origin or destination truck trips, exploring solutions such as requiring developers to provide truck parking on site by way of ordinances would assist in addressing undesignated truck parking.

In North Carolina, because of zoning and subdivision regulations being controlled on a local level, wide variations across jurisdictions can exist in implementing parking strategies (Cambridge Systematics, Inc., 2020). A law enacted in 2021 enables a more unified zoning approach to truck parking and provides many clarifying amendments and consensus reforms that will need to be incorporated into local development regulations (North Carolina General Assembly, 2021). Texas DOT (2020b) recommended that the state create guidance to help localities evaluate the potential effect on local roads if increased parking demands from projects are not met. By identifying the truck parking needs before a project is built, projects can incorporate design changes or mitigation measures to address the potential effects and help meet truck parking needs. Texas DOT could play a lead role in developing guidance or sharing best practices with local communities.

Ordinances Related to Structures. With the growth of e-commerce warehouses and distribution facilities, municipalities are tasked with accommodating larger building footprints and building space. As Felix and Pollack (2021) note, e-commerce warehouse and distribution facilities require more loading docks, expanded parking areas, larger building footprints, and higher ceiling heights than traditional warehouses. In terms of revenue, a traditional warehouse would need approximately 400,000 square feet of building space to generate \$1 billion in revenue, whereas an e-commerce distribution facility would require 1.2 million square feet to generate that revenue. Given the footprint and freight generating demands of distribution facilities, sustainable design and planning practices become increasingly important. To help

alleviate the negative effects of freight-generating industrial sites, Holguín-Veras et al. (2020) offer the following recommendations:

- Enhance building codes that require new buildings or existing buildings that undergo massive renovations to provide the parking and loading areas required to conduct the freight and service activity the building generates.
- Upgrade parking and loading docks to accommodate the volume and geometric needs of current and future trucks with adequate setbacks from roadways and proper design of access and egress lanes to facilitate traffic maneuvers and minimize traffic impacts.
- Designate staging areas where larger freight vehicles can transfer cargo to smaller vehicles for last-mile delivery, thus reducing the effects of large-truck deliveries in urban areas on communities.

Form-based code is a land development regulation that focuses on the physical form of buildings and their relationship to surrounding land uses rather than solely on the types of uses allowed. Several municipalities have adopted this type of regulation for industrial developments to achieve more sustainable freight-based land uses. For example, the Wasatch Front Regional Council worked with its partners to develop form-based zoning code. As part of a study the Wasatch Front Regional Council commissioned (Brogan, 2025), a scan of practice revealed that some cities have incorporated freight considerations into their form-based codes, including Portland, Oregon; Miami, Florida; and Louisville, Kentucky. The freight components provide design standards for loading areas, buffer zones, and sustainable freight practices, such as off-peak deliveries, consolidated shipments, integration with transit stations, and use of low-emission vehicles.

With the growth of e-commerce and demand for warehouse space, adequate land for industrial development is becoming scarce, especially in urban and suburban locations. The building of high-cube warehouses is one approach to addressing the lack of suitable land. These types of warehouses can reach heights of up to 180 feet and are becoming more common; however, building ordinances for these types of structures must be amended to allow for these heights. For example, Upper Mount Bethel Township in Pennsylvania has proposed ordinance amendments approving building heights of up to 100 feet by right and up to 110 feet with conditional approval. Similarly, the Township of Upper Macungie has considered allowing building heights of up to 140 feet (LVPC, 2020). According to Best (2021), municipalities should develop appropriate strategies to address the effects of these types of warehouses through updated zoning ordinances and building codes.

Ordinances Related to Amenities. Essential facilities and comfort amenities for truck drivers are an important component both at onsite and offsite or shared facilities, and to address growing freight activity and its effect on transportation networks, municipalities should incorporate standards for driver amenities into subdivision and land development ordinances (LVPC, 2020). Leslie and Murray (2024) report on a Kay and Towey (2022) finding that an average of 44% of customer facilities do not allow drivers to use bathroom facilities of any kind while waiting to load or unload. This prohibition becomes a significant discomfort and raises potential medical issues, and it can be particularly troublesome for women drivers because of the higher likelihood of those drivers being required to wait beyond their scheduled appointment time to pick up or deliver freight.

Recent legislation passed in Washington State aimed to address this problem by requiring customer facilities to grant drivers access to employee or customer bathrooms when delivering freight (Fletcher, 2023b). Ideally, customers would allow drivers access to a lounge, break room, or waiting area to prevent these issues, but drivers reported that 78% of customer facilities on average do not provide any such space (Leslie and Murray, 2024). In Pennsylvania, PTAC (2023) developed provisions in the municipal zoning ordinance to require onsite driver amenities for drivers during loading and unloading, staging, and parking. At a minimum, the amenities should include restrooms and drinking water, whereas optional amenities may include a lounge area, vending machines, and Wi-Fi access. Onsite bathroom access has also been gaining support nationally through the Trucker Access Bathroom Act, which was initially introduced to the 118th U.S. Congress as H.R. Bill 3869 in 2023 (Library of Congress, 2023) and reintroduced in 2025 as H.R. Bill 2514 (Library of Congress, 2025). The bipartisan bill, which would ensure truckers have access to restroom facilities when they are picking up or delivering cargo, is receiving strong support from some industry members (Worthen, 2024).

Amenities should also be a consideration when developing new offsite truck parking facilities or improving existing parking lots to make them attractive for truck drivers. Restrooms and showers are critical factors in making truck parking more attractive to truck drivers (Maryland DOT, 2020). Pennsylvania’s recommendations include ordinances to address amenities at offsite parking locations or shared parking at larger planned industrial parks (PTAC, 2023). Potential amenities identified for these types of facilities include driver showers, laundry facilities, restaurants, fueling facilities, convenience stores, and other amenities at the developer’s discretion. In consideration of increased demand and need for electric vehicle charging for trucks, overnight parking facilities should provide electric vehicle charging in addition to diesel fuel (Texas DOT, 2020b). Municipal standards should require or incentivize electrical hookups within truck parking areas to mitigate the effects of diesel-run units on the neighboring area and regional air quality (Miami-Dade Metropolitan Planning Organization [MPO], 2012).

In Texas, a truck driver preference survey was conducted on preferences and priorities when it comes to choosing where to park (Texas DOT, 2020a). The study found that when drivers park their trucks, most expect to satisfy only their basic needs, which include food, fuel, restrooms, phones, and showers. For short-term parking, respondents identified toilets as the top priority, followed by (in order of priority) real-time parking information, enhanced food choices, Wi-Fi access, and showers. For long-term parking, respondents identified toilets as the top priority, followed by (in order of priority) real-time parking information, showers, Wi-Fi access, and enhanced food choices. A Miami-Dade County study developed a list of core, primary, and secondary truck parking amenities that should be considered for offsite or shared parking facilities (Miami-Dade MPO, 2012; Table 13).

Table 13. List of Core, Primary, and Secondary Truck Parking Amenities (Source: Miami-Dade MPO, 2012)

Core Amenities	Primary Amenities	Secondary Amenities
• Convenience store • Restrooms • Shower • Truck electrification • Safety and security	• Restaurant • Laundry facilities • Banking facilities (i.e., ATM) • Wireless internet access • Truck scales	• Lounge • Business center • Retail • Intelligent Transportation System

Core Amenities	Primary Amenities	Secondary Amenities
• Diesel fueling • Vehicle fueling • Maintenance facility • Truck wash • Leaky load containment • Cafe		

Traffic Impacts

Planners typically use data from the Institute of Transportation Engineers' (ITE) *Trip Generation Manual* (currently on the 12th edition) for estimates on trip generation rates from a wide variety of land uses and use this information to evaluate the traffic impacts of those land uses (ITE, 2025). For example, ITE land use code 150 is for warehousing, and calculations from the manual consider trip rates based on land use codes. Industrial developments typically require traffic impact studies because of the high volume of traffic generated from the sites.

Many communities have concerns about the truck traffic and changes to traffic patterns that accompany industrial developments. For this reason, LVPC strongly recommends that all proposals for new warehouses, including those requiring special exception or conditional use approvals be accompanied by a traffic impact study. Although these studies are typically required in a municipalities zoning ordinance, they are even more crucial now given that the traffic impacts of high-cubed and automated-warehousing facilities are still not fully understood. Therefore, municipalities are encouraged to adopt updated land use codes and to apply the most accurate and current traffic data available when reviewing warehouse development proposals (LVPC, 2020).

For high-cube facilities, the ITE (2025) manual has only recently been updated to include four distinct subtypes based on operational characteristics (ITE codes 154–157). One of those subtypes is a high-cube warehouse serving as a fulfillment facility, whereby ITE data from the 10th addition indicate traffic volumes up to seven times greater than those of traditional warehouses (Civiletti et al., 2023). Because high-cube warehouses are a relatively new land use, the amount of data on trip generation rates is limited (LVPC, 2020).

Despite the availability of this updated, albeit limited, data, some municipalities have yet to adopt the values provided in the ITE (2025) manual for high-cube warehouses when conducting development reviews. This noncompliance could be due to the lack of confidence in the accuracy of the data because of limited sample sizes, but Civiletti et al. (2023) describe the consequences of using outdated trip generation rates using a recent case in Riverhead, New York, as an example. In the town of Riverhead, a 641,000-square-foot Riverhead Logistics Center was proposed; however, the town assessed the traffic impacts of this development using the general warehouse code rather than the updated codes for high-cubed warehouses. The implications of this decision include increased truck volumes that induce more air pollution and stress on the local two-lane roads that were not designed for heavy truck use.

Outdated ordinances and incorrect use of land use codes that result in improper traffic impact studies have caused some municipalities to enact strict ordinances regarding distribution or fulfillment centers. Rubiano (2022) describes a case in the city of Morgan Hill, California,

where ordinances define a fulfillment center as a building with a minimum of 100,000 square feet and 24 feet in height. In 2021, the city council, in conjunction with members of the Morgan Hill Responsible Growth Coalition, developed new ordinances prohibiting buildings larger than 75,000 square feet, 34-foot-high ceilings covering more than 25% of the building, and more than one dock-high door per 25,000 square feet. These new ordinances have effectively banned distribution and fulfillment centers within the city.

Measuring Impacts

Traffic impacts are typically measured under a development proposal process, and then those impacts are addressed through traffic impact mitigations or fees, or both. This section focuses on two of the primary components of how traffic impacts are measured—level of service and VMT.

Level of Service. A traffic impact analysis or traffic impact study typically accompanies proposed industrial developments because of the expected traffic generated from these types of facilities. When conducting traffic impact analyses, traffic engineers and planners are accustomed to measuring the effects of development on the transportation system in terms of level of service. Level of service is a straightforward concept outlined in the *Highway Capacity Manual* (National Academies of Sciences, Engineering, and Medicine, 2022), in which free-flowing roads get a score of “A,” and roads that have reached their capacity get a score of “F.” For signalized intersections, it is based on the average delay at the intersection, for which a delay of more than 80 seconds is scored an F (McCahill, 2024). These level of service scores are generated based on trip generation rates developed within the scope of the traffic impact analysis. Generally, the required elements of a traffic impact analysis include the following (Code of Virginia, 2026):

- **Background of development:** Site location, existing road network, and programmed improvements.
- **Site trip generation:** Based on ITE rates (highest trip-generating use under proposed zoning).
- **Traffic distribution and assignment:** To document traffic internal capture and pass-by reductions based on logical regional patterns.
- **Level of service analysis:** To document delay based on existing traffic conditions, future traffic conditions without development, and future traffic conditions with development.
- **Recommended site and network improvements:** Location, nature, extent, and preliminary cost estimates.

In Virginia, industrial development or rezoning proposals must be submitted to VDOT if they substantially affect transportation on state-controlled highways. The threshold VDOT uses for determining whether a traffic impact analysis must accompany a proposal is if a development generates more than 5,000 vehicle trips per day at the site’s connection to a state highway. For jurisdictions maintaining their own roads, this measurement applies if the site is within 3,000 feet of a state highway and exceeds 5,000 vehicle trips per day (Code of Virginia, 2026). Other states have similar criteria, but trigger thresholds for traffic impact analysis can vary. Table 14 shows a comparison of Pennsylvania DOT (2017), Maryland State Highway Administration (2019), and VDOT (Code of Virginia, 2026) traffic impact analysis aspects relating to trigger thresholds,

study areas, trip generation, analysis years, level of service and mitigation, and industrial focal points.

Table 14. Traffic Impact Analysis Aspect Comparisons

Aspect	Pennsylvania Department of Transportation	Maryland State Highway Administration	VDOT
Trigger Threshold	≥ 3,000 daily trips or 1,500 vehicles/day; ≥ 100 trips/hour; significant safety and flow impact	> 50 peak-hour trips; size tiers of small = 50–100 trips, medium = 101–750 trips, and large > 750 trips	> 5,000 daily trips or ≥ 1,000 peak-hour trips; rezoning proposals with substantial impact
Study Area	Defined at scoping meeting; typically, adjacent intersections and corridors	Radius based on size of small = ¼ mile, medium = ½ mile, and large ≥ 1 mile	Based on trip volume of < 500 trips within 2,000 ft, 500–999 trips up to 2 miles, and ≥ 1,000 trips per VDOT
Trip Generation	Use ITE (2025) <i>Trip Generation Manual</i> ; local data allowed if justified; consider truck percentages	Prefer local rates; else ITE (2025) manual; regression or weighted average per ITE manual	Use ITE (2025) <i>Trip Generation Manual</i> unless VDOT approves alternative; internal capture and pass-by allowed
Analysis Years	Existing, opening year, and design horizon (5 years after opening)	Existing, background, and buildout year	Existing, background, buildout, and 6 years post-buildout
LOS and Mitigation	LOS drop > 10 seconds requires mitigation; options include turn lanes, signals, roundabouts, alternative transportation plans	Mitigate any movement below LOS level D; address queuing and storage issues	Mitigate LOS drops and queuing issues; may include travel demand management strategies (e.g., staggered shifts)
Industrial Focus	Truck access design critical; sight distance, driveway throat length, turning radii	Include truck percentages in counts; evaluate merge, diverge, and weaving impacts	Heavy vehicle factor in LOS analysis; evaluating geometrics vs. <i>Road Design Manual</i> (VDOT, 2026)

ITE = Institute of Transportation Engineers; LOS = level of service.

Maryland, Pennsylvania, and Virginia are generally Dillon Rule states (with some home rule exceptions), meaning local governments are considered an extension of the state, and power is distributed to those local governments according to the state constitution (Moore, 2020). Therefore, municipalities within each state must conform to the minimum state requirements for traffic impact analysis. As Table 15 shows, the cities of Roanoke (n.d.) and Charlottesville (n.d.) in Virginia have differing thresholds for triggering traffic impact analysis, but they do not exceed the thresholds set by VDOT.

Table 15. Thresholds for Triggering TIAs

City	Threshold for TIA	Scope of Analysis	Process
Roanoke	≥ 250 peak-hour trips or ≥ 2,500 daily trips; within 3,000 feet of state highway	Existing and future conditions, trip generation (ITE, 2025), distribution, LOS, and mitigation	Submit to VDOT; review 45–120 days; scoping meeting if ≥ 1,000 peak-hour trips
Charlottesville	≥ 50 trips per hour during adjacent street peak hour	Multimodal analysis (vehicles, bikes, pedestrians, transit), LOS, queuing, and mitigation	Report includes introduction, conditions, trip generation, and mitigation

LOS = level of service; TIA = traffic impact analysis.

Although traffic impact analyses are required to be submitted to the state, and the state is required to provide comments, no requirement explicitly dictates that the comments must be addressed.

Vehicle Miles Traveled. Resulting from the growing demand for e-commerce, just-in-time supply and expedited services, the frequency of delivery trips has increased. Many of the delivery vehicles that serve these demands still rely on internal combustion engines using fossil fuels, which cause environmental impacts related to greenhouse gas emissions and pollution. It is significant to note that last-mile deliveries account for 40% of urban freight systems' energy consumption and emissions (Jaller et al., 2024). Because of these effects, a push to abandon level of service and replace it with a measure of VMT is growing as the primary metric for measuring transportation impacts. California is currently the only state that uses VMT in place of level of service. The idea originated from California's SB 743 (State of California, 2026), which disqualified level of service as a measure of air quality impacts resulting from transportation.

Under the rule, the state recognized that efforts to improve level of service typically led to more driving, discouraged multimodal improvements, and made urban development more difficult. In contrast, VMT is meant to encourage transportation investments and land use patterns that facilitate less driving through shorter trips and greener modes. McCahill (2024) postulates that level of service may not be as ingrained in local planning practice as generally assumed and that most planners view VMT as an appropriate metric to measure environmental impacts resulting from transportation, both generally and in their own jurisdictions. However, outside environmental review, some jurisdictions will likely continue to use level of service to assess development impact fees.

An impact study conducted by Urban Crossroads (2022) for a yet-to-be-developed Riverside County property provided a good summary of details on the process and scope of using VMT as a criterion for approvals. The scope of development on the property included either a single 438,823-square-foot high-cube fulfillment warehouse, a smaller 304,376-square-foot high-cube fulfillment warehouse, or a separate 130,477-square-foot high-cube cold storage warehouse. California is a home rule state where municipalities can create their own laws or local policies largely independent of state law. As a case in point, Riverside County has its own specific screening criteria to determine if a presumption of a less-than-significant impact can be made without the need for a full project-level VMT analysis. The screening criteria include:

- Small project screening, estimating trips generated and greenhouse gas emissions.*
- High Quality Transit Area screening, including proximity to an existing transit stop or along a high-quality transit corridor.*
- Local serving retail.
- Affordable housing.
- Local essential services.
- Map-based screening, a threshold for VMT based on the traffic analysis zone and county guidelines.*

Those criteria noted with asterisks were selected for further review based on applicability to the project. County of Riverside (2020) transportation analysis guidance states that a land use

project needs to meet only one of the screening criteria to result in a less-than-significant impact. Because none of the screening criteria were met, the project noted previously required a full VMT analysis, which involved traffic forecasting modeling based on employment density factors and VMT per employee. It was found that work VMT per employee would exceed the county threshold by 3.8% and, thus, the project would result in a significant and unavoidable effect with respect to VMT. The study also noted that because the future tenants are not known, VMT reduction measures (carpooling; end-of-trip facilities such as bike parking and lockers; electric charging stations; increase in the amount of pedestrian infrastructure such as sidewalks, mixed-use paths, and trails; and so on) cannot be guaranteed or meaningfully quantified (Urban Crossroads, 2022).

Addressing Impacts

Addressing the effects of industrial development through traffic impact analysis can be accomplished in several ways. The three most common methods are local industrial impact fees, retail delivery fees, and mileage-based user fees.

Industrial Impact Fees. Local governments often impose one-time impact or development fees on new industrial or warehouse developments to cover the cost of infrastructure upgrades needed to handle increased truck traffic. These fees are used extensively in Florida (State of Florida, 2026), California (Southern California Association of Governments, 2026), and Colorado (Arapahoe County, n.d.) and are not only for building but for the added traffic associated with the type of industrial land use (e.g., light, warehouse, high-cube, and so on). These fees require a developer to pay a proportionate allocation of the infrastructure costs for the traffic generated and are levied on property taxes to address items such as road degradation and roadway capacity reductions from increased truck traffic. As an example, the city of Vernon, California, once imposed a 2,000% increase in property taxes on warehouses to address road degradation from truck traffic (Martin, 2000). In Virginia, starting on January 1, 2025, Spotsylvania County became the first Virginia jurisdiction to impose a transportation impact fee (Silverburg, 2024), but the impact fee was not limited to commercial development. The National Association of Home Builders (2026) points out that transportation impact fees (again, not specific to commercial development) in Virginia are allowed only in certain fast-growing areas.

Retail Delivery Fees. A new trend aimed at high-volume delivery traffic, such as Amazon warehouses, is the retail delivery fee. In 2022, Colorado became the first state to implement a fee on all retail deliveries by motor vehicles, and the fees help fund road, bridge, and transit projects (Colorado Department of Revenue, 2026). More recently, Minnesota and New York have enacted similar retail delivery fees (Minnesota Department of Revenue, 2026; Taxconnex, 2026). In Minnesota, the retail delivery fee applies to specific transactions involving retail deliveries, such as deliveries by third-party shippers, couriers, and company vehicles, unless exemptions apply. Such a delivery fee was considered in Virginia (Stilton, 2026).

Truck Parking

To support the purpose of this project, the researchers reviewed literature pertaining to truck parking as it relates to industrial activities within and around communities. A major

concern for communities is that truck parking has not kept up with the proliferation of freight-intensive uses (NJTPA, 2023), which can be attributed to a shift in land use where distribution centers are moving closer to the consumer. Colorado DOT pointed out that Amazon distribution facilities have taken over smaller retail stores and, thus, become a source of truck parking issues (MAG, 2024). The San Diego Association of Governments has heard from many stakeholders that communities want to accommodate truck parking and understand truck parking needs but have concerns regarding noise, damage to roads, and safety (MAG, 2024). Road damage and safety hazards due to truck parking have been documented along county and local roads in New Jersey (NJTPA, 2023), where truck drivers are often unable to access delivery sites early and are forced to wait elsewhere.

ATRI (2024) conducted a study that examined critical issues in the trucking industry. The study found that the lack of available truck parking was the second highest-ranked issue revealed by a survey of industry stakeholders. To address parking needs associated with industrial development, some jurisdictions and municipalities have modified zoning ordinances to require provisions for truck parking. For example, Lehigh Valley in Pennsylvania has developed ordinances requiring private industries to provide parking in an amount similar to the number of bays each facility has. Similarly, the Denver Regional Council of Governments in Colorado is considering recommending the creation of a truck parking zoning ordinance for freight routing and freight cluster areas in the next plan update (MAG, 2024).

The literature reviewed on the topic of parking has many subtopics, as Figure 1 shows. Those deemed most relevant to the research topic of industrial development included literature documenting the undesignated parking problem and solutions, including onsite parking, offsite parking, and emergency parking, as related to resilience planning. Other topic areas examined included parking facility funding mechanisms and analytical tools to evaluate truck parking.

The Undesignated Parking Problem

Many commercial and industrial establishments forbid truck parking at their facilities beyond the loading and unloading of cargo, which can generate excessive parking demand and result in undesignated parking in surrounding areas. As Guerrero et al. (2022) suggest, undesignated parking locations can be unsafe, disrupt traffic, and cause a nuisance to the community. Dowell et al. (2022) state that communities often express concerns about the effect of truck-intensive development on community livability, which includes increased maintenance costs for repairing roadway shoulders, ramps, and private property not designated for heavy vehicle parking.

The *Regional Truck Parking Study* found that the most problematic locations for shoulder parking were not on limited-access highways but on secondary roads situated in areas where they are close to existing truck stops that are filled beyond their capacity or are access routes to major industrial areas, or both (CRTC, 2023). Maryland DOT (2020) concurred that undesignated truck parking is often found along the roadway shoulders to industrial land uses, such as warehouses and distribution centers. In Texas, some districts reported that undesignated parking on shoulders have prompted the need to do shoulder reinforcements and repairs on a regular basis costing in the hundreds of thousands of dollars annually—money that is taking away from the needs in other areas (Texas DOT, 2020b). Further analysis of sample areas in Texas shows that

approximately 1% of all stopped trucks on average are parked on roadway shoulders or streets in residential areas, and approximately 3.5% of all stopped trucks are parked on roadway shoulders in industrial areas (Texas DOT, 2020a). This amount equates to roughly 8 million undesignated truck parking events in residential and industrial locations during the course of a year.

The Washington State truck parking assessment concluded that a truck driver is likely staging for a shipper-receiver appointment when parked in undesignated locations near a freight generator and often on last-mile roads (WSDOT, 2022). The assessment found that most undesignated stops on last-mile roads at or near the Port of Longview lasted less than 3 hours; however, one-third of the stops exceeded 8 hours.

Morgan et al. (2022) found that many undesignated truck parking events occur on off-ramps near commercial and industrial properties in Virginia (Figure 11). Additional data revealed frequent undesignated parking at vacant commercial or industrial sites. These locations often have large surface lots originally designed for cars, conveniently situated near loading and unloading points, making them attractive for staging and short-term parking compared with roadside shoulders. However, these properties are privately owned, not designed for truck parking, and typically lack essential safety features, driver amenities (such as restrooms), and maintenance needed to support truck operations.



Figure 11. Undesignated Truck Parking Observed at the I-95 Off-Ramp at Maury Street to Access the Industrial Area South of the James River in Richmond, Virginia (Source: Morgan et al., 2022)

Leslie and Murray (2024) note that delays within customer facilities often lead to truck staging outside the premises, which increases the likelihood of undesignated parking nearby. This delay—commonly referred to as driver detention—occurs when a driver must wait beyond their scheduled appointment time to pick up or deliver freight. Detention can result from various customer inefficiencies, including scheduling issues, insufficient parking or dock space, inadequate staffing, or upstream production delays. Closely associated with customer inefficiencies is the anecdotal finding that shippers are not increasing labor and dock capacity to reflect increased freight movement and truck activity (Speltz and Murray, 2019). ATRI's (2024) latest detention research found that the industry lost 135.9 million hours of driver productivity in

2023, resulting in more than \$11 billion of lost revenue for the industry. Detention also poses a safety risk. The same ATRI (2024) study found that detained drivers drove 14.6% faster than drivers who were not detained.

In a survey of motor carriers, about 70% of respondents reported that delays at customer facilities were often or always the primary factor affecting hours-of-service compliance, and 52% ran out of available hours-of-service on-duty time at a customer facility because of detention (Leslie and Murray, 2024). In addition, 57.8% of truck drivers experienced at least one instance in 2023 in which they were late or had to cancel a pick-up or delivery because of detention at a previous customer's facility. In Texas, one company stated that it stopped serving certain customers because of excessive waiting times and the lack of onsite staging or nearby parking (Texas DOT, 2020a). Drivers and carriers consistently expressed frustration over the absence of staging options at these facilities.

Onsite Parking

A common theme in the literature is that truck parking should be integrated with development projects, and this process can be accomplished through modifying local land use regulations. The benefits of requiring basic staging areas (a dedicated lot for trucks queued up to make deliveries to that facility) or larger truck parking facilities include the following (PTAC, 2023):

- More efficient operations for local industry and trucking companies.
- Improved safety for professional drivers and the general public.
- Reduced congestion, miles traveled, and associated emissions.
- Encouraging freight generators to bear more of the burden of their operations.

Pennsylvania recommends that required parking spaces be scaled to the operational capacity of the proposed facility, such as one truck parking space per two loading bays or one truck parking space per 100,000 square feet of floor area (PTAC, 2023). For long-term parking, Pennsylvania proposes ordinance provisions that will allow long-term onsite parking per the Federal Motor Carrier Safety Administration hours-of-service regulations as a permitted-by-right use. Facilities with long-term parking would be accommodated with amenities such as driver's lounges, restrooms, and so on.

Proactively integrating truck parking needs in the planning process, as Dowell et al. (2022) suggest, will help meet the parking demand while also helping to spread the costs of providing truck parking. Requiring provisions of onsite truck parking in zoning ordinances is analogous to the employee and customer parking requirements already included in many zoning ordinances. Table 6 shows the benefits and barriers of implementing onsite parking per Dowell et al. (2022).

Table 16. Benefits and Potential Barriers to Implementing Onsite Parking (Source: Dowell et al., 2022)

Benefits	Potential Barriers to Implementation
• It concentrates parking supply at the point of staging demand. • It improves driver conditions and favorability of the customer.	• It is not commonly required today. • It may be limited to new developments or major redevelopments.

Benefits	Potential Barriers to Implementation
• Site already generates truck traffic, and new externalities are minimized.	• State and local zoning powers vary throughout the nation. • Regulations related to impervious cover and stormwater runoff may deter development of additional parking space.

Maryland DOT (2020) and Phelan et al. (2017) discussed examples of successful cases in which onsite truck parking is provided at Meijer and Unilever distribution centers for drivers serving those facilities. Unilever developed a pilot program with the intention of making its facilities easy for truck drivers to service, as well as increase the ability to become a “shipper of choice” for carriers when the trucking market is “tight.” The pilot program has since matured to implementation at all Unilever’s North American distribution centers and manufacturing plants, demonstrating the benefits of shipper and receiver collaboration on truck parking solutions.

North Carolina describes examples of successful onsite truck parking with the New Belgium Brewery distribution center and the Mount Olive Pickle Company plant. The Mount Olive Pickle Company built a staging area that can handle up to 60 trucks at a time and includes weight scales, restrooms, and refrigeration hookups on site. The company believes the staging area and amenities will increase efficiency, be attractive to trucking companies, and promote the building of goodwill to the citizens of the town. In Asheville, the New Belgium Brewing Company distribution center built onsite parking with access to a break room, bathrooms, and free food. The facility allows off-hour parking, which enables staging on site (Cambridge Systematics, Inc., 2020).

Texas DOT (2020b) developed action items related to truck parking, including onsite parking. One action item is to encourage commercial and industrial property owners to provide truck parking on unused portions of property. The supporting agencies to implement this action item would include local municipalities and industry. The supporting agencies to implement this action item would involve local municipalities and industrial property owners, with resource support from Texas DOT. No regulatory hurdles would be included with this action item, and timing for implementation is considered short using the following three steps (Texas 2020b):

1. Meeting with local municipalities and industrial property owners to evaluate the opportunities and constraints of the policy.
2. Developing guidelines to assist interested local municipalities in deploying the policy.
3. Developing an outreach campaign to industrial property owners that local municipalities could use or that Texas DOT could integrate into its public education campaign.

Another innovative Texas DOT (2020b) action item is to support the development of a mobile application that connects property owners desiring to rent space to truck drivers needing parking. No regulatory adjustments would be needed, and in addition to local municipalities, technology companies would be utilized to support the initiative. Researching and sharing related industry best practices would be the first step toward implementation, and to integrate it into policy (second step), commercial and industrial property owners need to be encouraged to provide truck parking on unused portions of the property.

Washington has also developed action plans for shippers and receivers to provide parking and basic amenities (WSDOT, 2022). The plans include developing guidance for permitting agencies to require onsite truck parking at new developments, providing tax incentives for shippers and receivers to provide onsite truck parking, and requiring shippers and receivers to provide onsite truck parking at new developments. In addition, the state could mandate restroom access for truck drivers at businesses where they are picking up or delivering.

Offsite or Shared Parking

The cost of land, availability of land, development fees, and liability are impediments to shippers and receivers providing onsite parking. In many cases, the development cost for onsite parking is prohibitive for the private retail establishment owner, and the added truck parking spaces do not generate sufficient additional sales revenue to justify the substantial capital cost (Maryland DOT, 2020). These capacity and cost constraints are typical in urban and suburban geographies. In such cases, developing offsite parking facilities near the origins and destinations of major freight generators and near major corridors is a viable alternative to onsite parking. As many states seek to address their truck parking shortages, Dowell et al. (2022) suggest that offsite or shared parking facilities provide an opportunity to leverage partnerships to meet truck parking demand, whereby partnerships can exist between private entities, between public entities, and between public and private entities. As provided by Dowell et al. (2022), Table 17 shows the benefits of and barriers to shared parking.

Table 17. Benefits of and Barriers to Implementing Shared Parking (Source: Dowell et al., 2022)

Benefits	Potential Barriers to Implementation
• It increases efficiency of parking provision in a concentrated area. • Sites can be near existing centers of truck and industrial activity. • Security, waste management, wayfinding, and maintenance costs are consolidated.	• Property owners may have liability concerns. • Security policies at land, air, and water ports may limit parking hours or duration. • Suitable publicly owned sites often serve an existing purpose (e.g., park-and-ride lots). • Local ordinances may prohibit overnight parking.

By developing shared parking facilities, municipalities can capitalize on underutilized space to provide both short- and longer-term (overnight) parking, which can help to discourage unsafe parking in undesignated spots, such as roadway shoulders, while making an area more appealing to freight-dependent businesses (NJTPA, 2023). In areas of intensive industrial development activity, shared lots may be a feasible way to address truck parking and staging needs for multiple industrial sites by developing adjacent parking within or near the industrial cluster (PTAC, 2023).

The *Southern Middlesex County Freight Movement Study* addressed collaboration between large freight operators, municipalities, and landowners to offer both short-term and overnight parking facilities (NJTPA, 2023). Some state DOTs have begun conversations on this model, in which the DOT will provide the infrastructure necessary to support truck parking in return for the business allowing access to the lot or land. A Washington study action plan suggests local jurisdictions consider promoting truck parking to property owners with existing lots already zoned for commercial or industrial use and permitted for truck activity (WSDOT, 2022). The action plan also recommends that WSDOT pilot a Truck Parking Partnership Program

at underutilized infrastructure, such as car and truck (e.g., large retail and industrial) parking lots, during overnight hours when not in use.

By utilizing existing parking infrastructure, such as at park and rides, schools, distribution centers, and large parks, short-term overnight parking can be accommodated. DOTs can partner with businesses in their regions, such as Walmart, to use their large parking lots for overnight truck parking or coordinate with owners of large parking facilities (fairgrounds, stadiums, racetracks, and other large event venues) to allow both short- and longer-term parking when the lots are not in use (Texas DOT, 2020b). A Miami-Dade County study recommends providing short-term shared parking facilities at commercial centers (malls, truck stops, and big-box retail), institutional properties (schools and park-and-ride lots), and car parking lots in public rest areas (Miami-Dade MPO, 2012). However, to do so, it is important to determine the times of day and days of week when parking is most needed. For overnight parking options, Yuan et al. (2024) recommend that public agencies partner with businesses to utilize existing large parking lots after hours.

Phelan et al. (2017) support the redevelopment of brownfield sites to provide truck parking and staging capacity near centers of freight activity. To identify potential offsite or shared parking locations, developing and employing location screening criteria is important, and brownfield sites are one of the potential criteria a Pennsylvania study mentions to evaluate offsite truck parking sites (PTAC, 2023). Table 18 shows the criteria and descriptions.

Table 18. Potential Truck Parking Site Evaluation Criteria (Source: PTAC, 2023)

Evaluation Criteria	Description
Parcel Size	10 acres or more (acreage)
Designated Networks	5 miles or less from a prioritized highway corridor
Compatible Zoning	Zoned industrial or commercial
Industrial Park	Located in an existing or planned industrial park
Existing Truck Parking Facilities	Located adjacent to an existing truck parking facility, expansion of existing facility, or a facility under construction
Brownfield	Brownfield redevelopment opportunity
Community Impact	Located in proximity to local schools, daycare, neighborhoods, or environmental justice communities
Access via CUFC/CRFC	Location is accessible to NHFN and NHS via CUFC and CRFC
Property Ownership	Public and private

CRFC = critical regional freight corridor; CUFC = critical urban freight corridor; NHFN = National Highway Freight Network; NHS = National Highway System.

The Miami-Dade County study evaluated offsite truck parking locations and developed an indepth screening process for sites identified for further examination (Miami-Dade MPO, 2012). The criteria include the following:

- **Neighborhood impacts:** This category relates to the types of land uses in the immediate area of the site. Sites near residential land uses and communities are not preferred because of the compatibility concerns with truck parking facilities.

- **Distance to freeway:** For a truck parking facility to be useful, it needs to be in close proximity to the freeway system because most long-haul truck commerce occurs on these facilities.
- **Site visibility from freeway:** The site needs to be visible so that truck drivers not familiar with the area will be able to see the truck parking facility from the freeway.
- **Freeway truck percentages:** Truck parking facilities should be near freeways that serve a significant amount of truck traffic.
- **In proximity to terminal or major hub and industrial or commercial truck generators:** Two factors were considered for this criterion. The proximity to truck terminals and major hubs and the proximity to industrial and commercial facilities that generate truck traffic.
- **Site accessibility:** Ease of access to truck parking facilities is an important parameter due to the requirements of trucks, which need larger radii for turning maneuvers and have slower acceleration and deceleration rates than passenger vehicles. Accessibility was classified in three groups: preferred, average, and poor, based on roadway geometry, roadway width, pavement condition, and signalized intersection control.
- **Future 2030 truck volumes:** Development could change future truck patterns.
- **Land cost feasibility threshold:** If a site is too expensive, developing a truck parking facility may not be feasible.

The literature also provides several examples of “next-generation” type parking facilities. In Washington, one of the action plans envisions a hub-and-spoke strategy in which a remote parking facility serves as a staging lot, connected via information systems to the truck drivers’ customers and to other short-term staging lots nearby (WSDOT, 2022). Using this model, drivers would “check in” with their customers and wait at the remote lot, with access to amenities, until their customers were ready to receive them. A Texas DOT (2020b) study supported developing guidelines to create logistics parks that include integrated and full-service truck parking and staging facilities near customers and recommended making these guidelines available to local governments, economic development agencies, and developers. More recently, the New York City (NYC) DOT (2025a) launched an overnight truck parking pilot in select industrial business zones in an effort to improve parking compliance and minimize overnight truck parking in residential areas. These pilot parking zones offer metered parking to commercial vehicles, including tractor trailers.

Emergency Parking

Stronger, more frequent storms and natural disasters cause major disruptions in freight operations and add significant costs to the maintenance of the infrastructure on which these goods move (Mason and McCoy, 2022). During the past decade, the number of major disaster events rose significantly as shown in Figure 12. Costs also rose, whereas 14 separate billion-dollar weather and climate events occurred across the United States in 2019 totaling \$45 billion (U.S. DOT, 2020), Mason and McCoy (2022) report that 20 separate billion-dollar weather and climate-related disasters occurred in 2021 costing \$145 billion.

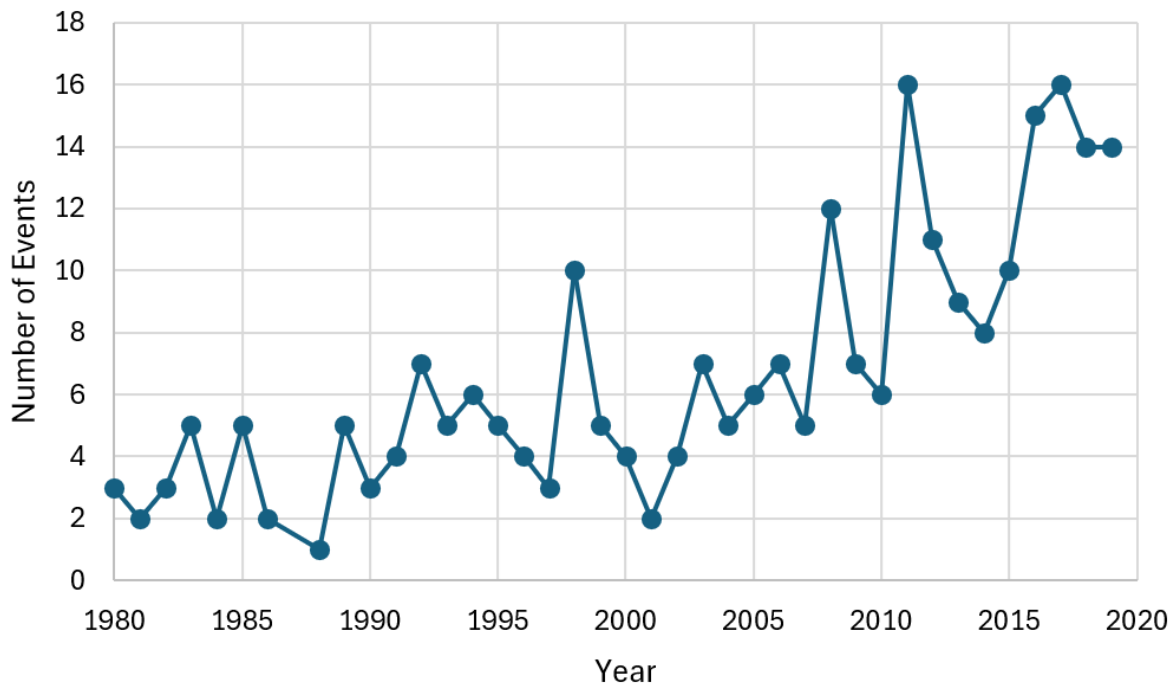


Figure 12. U.S. Billion-Dollar Disaster Events from 1980 to 2019 (Redrawn using data from U.S. DOT, 2020)

A resilient freight transportation system can provide services when it encounters small disruptions and can return to service quickly after large disruptions. Table 19 shows examples of extreme weather disruptions to the U.S. freight transportation network in the past decade. In 2021, the Infrastructure Investment and Jobs Act explicitly required state freight plans to incorporate development strategies to improve the resilience of the freight transportation system, including strategies to decrease the severity of the effects of extreme weather and natural disasters on freight mobility (Mason and McCoy, 2022).

Table 19. Extreme Weather Disruptions to the U.S. Freight Transportation Network in Past Decade

Event	Description
Hurricane Maria	September 2017. This category 5 hurricane in Puerto Rico led to infrastructure damage, causing emergency relief supplies to be stuck in containers at the Port of San Juan for weeks.
Texas Deep Freeze	February 2021. An electrical grid failure caused grocery stores across Texas to have severe food shortages.
Glenwood Canyon Wildfire and Mudslides	July 2021. Wildfires created burn scars, which resulted in subsequent mudslides after heavy rains. Commercial vehicles had to take a 250-mile detour delaying delivery of fuel, food, and supplies to the Western Slope communities of Colorado.
Delta Wildfires	September 2018. Rapid wildfire overtook a section of Interstate 5 in Northern California, causing a complete road closure for several days. Seventeen commercial truck drivers were forced to abandon their vehicles, and several rigs melted to the roadway surface.
Missouri River Flooding	In 2011 and 2019. The Missouri River flooded because of heavy snowfall in the Rocky Mountains, followed by heavy spring rain. Three thousand miles of state highways were washed away or closed, cutting off access to communities. In Iowa, a section of Interstate 29 that included several bridges was closed for more than 100 days, disrupting the flow of freight and people.

During extreme events, ensuring adequate and reliable truck parking strengthens network resilience by reducing unsafe road stops, leading to supply chain bottlenecks. A U.S. DOT policy goal is to address supply chain bottlenecks by supporting state DOTs and the private sector in developing and implementing strategies that expand truck parking availability consistent with local land use considerations (U.S. DOT, 2022). To manage disruptions, collaboration between public and private sector stakeholders is important for developing strategies such as truck detour routes from road closures and temporary emergency parking at non-traditional locations. In New York, CRTC (2023) recommends (1) analyzing where heavy surges of truck parking demand occur during emergencies and weather-related disruptions and (2) developing plans for truck parking in locations that accommodate large numbers of trucks in emergencies. These locations could include the following:

- Sports venues.
- Shopping malls.
- Park-and-ride lots.
- Surplus municipal or county properties.
- Military facilities with available space outside security checkpoints.

Phelan et al. (2017) recommend that state DOTs work with property owners and other public agencies to study the feasibility of using stadiums and convention centers for parking capacity during highway closures, weather events, and other similar disruptions. For the purpose of reducing the number of undesignated parking events during emergencies, Maryland currently provides spaces for emergency truck parking at commuter parking lots and park-and-ride facilities (Maryland DOT, 2020), and truck drivers can access information about the availability of these parking locations through Maryland's Emergency Truck Parking Portal (Maryland DOT, 2026). In addition, Maryland has identified other locations, including school parking lots, colleges and universities, racetracks, state parks, and interstate transportation management sites. Pennsylvania recommends developing agreements with municipalities to use municipal-owned space for emergency parking, considering ways to reward private facilities for providing emergency parking, and developing an emergency truck parking map similar to Maryland's (PTAC, 2023; Figure 13).

In North Carolina, incidents or uncommon events are a common contributor to undesignated truck parking, particularly when full road closures are required and truck drivers need a place to stop while incidents clear (Cambridge Systematics, Inc., 2020). North Carolina DOT developed a concept of operations for providing emergency event parking along two highway corridors: I-26 and the western portion of I-40 in western North Carolina, where rockslides are a concern, and the eastern portion of I-40 between Wilmington and I-95, where flooding due to hurricanes or tropical storms creates issues. The study found that commuter park-and-ride lots on I-26 and I-40 were too small to accommodate truck parking; however, some areas of the state, especially on the outskirts of urban areas, have larger lots that are more suitable for truck parking during emergencies. Data from ATRI were used to identify how trucks operated during past events, including:

- A rockslide along the western portion of I-40 in February 2019. Major slides close lanes roughly once a decade. In 2019, both highway directions were closed for approximately a

week between Exit 20 and the Tennessee state line. Westbound lanes remained closed for more than a month, with traffic using one of the eastbound lanes during that time. Data showed a heavy effect on truck traffic initially after the rockslide event.

- Hurricane Florence in 2018. The 2018 storm flooded sections of I-40 and I-95 for days, and it was evident from the data that trucking companies had time to prepare and avoid the area. While the storm made landfall, very few trucks were in operation in the region.
- A statewide snowstorm in December 2018. Large snowfalls contribute directly to roadway closures and delays, with additional impacts from associated vehicle crashes. In some areas, the 2018 snowstorm dropped more than a foot of snow, with Mount Mitchell (northeast of Asheville) receiving nearly 3 feet of snow.

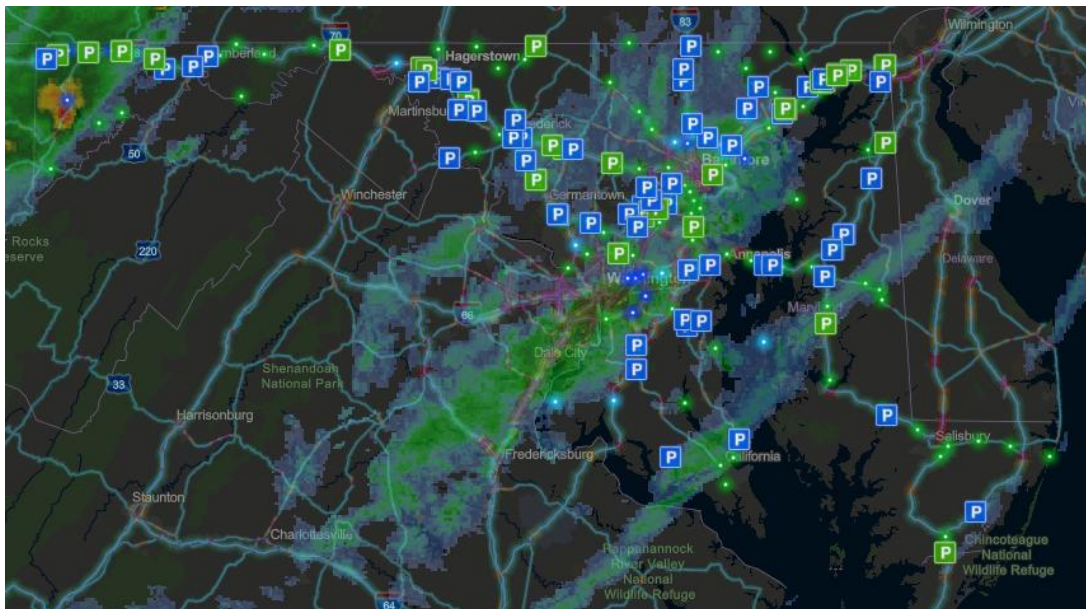


Figure 13. Maryland Emergency Truck Parking Locations: green = regular parking; blue = park-and-ride lots (Source: Maryland DOT, 2026; reprinted with permission)

In Texas, road closure data were collected for the interstate highways, U.S. highways, and state highway networks to evaluate the potential effect of road closures on truck parking throughout the state (Texas DOT, 2020a). Data were used to identify corridors with a high frequency of long-term road closures, combined with high truck volumes, significant truck parking demand, little or no truck parking near the corridor, and limited or no alternate routes. Key findings and observations included the following:

- More than 38,250 road closures occurred in Texas between March 2017 and December 2018. Flooding was the main contributing factor to road closures that lasted more than 10 hours. These longer closures have the greatest disruption to travel patterns and potential demand for truck parking.
- The top five corridors with closures include I-27 and U.S. 87 between Midland and Amarillo, I-35 between Laredo and San Antonio, State Highways 73 and 87 between Winnie and Orange, U.S. 281 between Brownsville and Rancho Alegre, and U.S. 59 between Victoria and Rosenberg.

- These five segments had 61 closures lasting 395 days during the period analyzed, and 31 of those closures lasted longer than 24 hours.
- All routes have nearby alternatives, limiting the effect of any single road closure on the system as a whole.

To reduce unforeseen losses for freight users, effective communication is essential to warn truck drivers of impending or occurring disruptive events and to notify systems that provide accurate predictive information about road closures or weight restrictions. Patnala et al. (2024) suggest developing appropriate impact analyses of diverse types of network disruptions, which will enable managing organizations to make more informed decisions and devise effective strategies to bolster resilience. In Virginia, a severe snowstorm in 2022 left hundreds of drivers stranded as VDOT shut down I-95 near Fredericksburg at 5:30 p.m. on January 3rd and did not reopen it until 7 p.m. the following day. A post-event report stated that multiple agencies mishandled the event and that communications failed during the storm to clearly state the need to avoid travel on I-95 and provided inaccurate information in some cases (Commonwealth of Virginia, 2022). The recommendations included:

- Establishing protocols for a more assertive “do not travel” message to the public.
- Placing an emphasis on situational awareness beyond the immediate tasks at hand.
- Obtaining lessons learned from other state DOTs for severe winter events.
- Ensuring effective communication through event verification and staying current on changing conditions.
- Ensuring a protocol is in place to communicate potential worse-case scenarios early and assertively to the public, motorists, and affected governments through multiple media sources.

Funding

As Pennsylvania notes, the development cost for increasing onsite or shared truck parking can be prohibitive for private business owners because the added truck spaces may not generate sufficient sales revenue to justify the substantial capital cost (PTAC, 2023). In cases when additional truck parking is needed, a collaborative effort should be sought between the establishment owners and public agencies that have access to federal funding opportunities. Pennsylvania recommends promoting federal funds for truck parking projects and pursuing collaboration with neighboring states on innovative grant applications for regional solutions.

A number of discretionary grant programs can be leveraged to assist with truck parking initiatives, and several states already receive grant awards. North Carolina notes that the Florida DOT received \$1 million from the Accelerated Innovation Deployment Demonstration program for deploying its Truck Parking Availability System and an additional \$10.8 million the following year for the system through the INFRA Grant Program, formerly FASTLANE (Cambridge Systematics, Inc., 2020). BUILD Grants (formerly TIGER) awarded Wyoming \$25 million for the Regional Truck Parking Information Management System and truck parking on I-80. In Texas, the I-10 Corridor Coalition received \$6.8 million for its truck parking availability system through the Advanced Transportation and Congestion Management Technologies Deployment grant program. In addition to competitive discretionary grant programs, federal

formula funds can also be utilized for truck parking initiatives. Table 20 shows some of the discretionary and federal formula programs by type and eligible activities.

Table 20. Federal Formula and Discretionary Grant Funds for Truck Parking Initiatives

Program	Type	Eligible Activities	Funding Notes
Surface Transportation Block Grant	Formula	Truck parking facilities (Jason's Law)	State allocation
National Highway Freight Program (NHFP)	Formula	Truck parking, real-time traffic information	Must benefit NHFP or the Primary Freight System
Highway Safety Improvement Program	Formula	Truck parking if consistent with the Strategic Highway Safety Plan	Safety focused
National Highway Performance Program	Formula	Safety improvements on NHS, including truck parking	Supports national performance goals
Congestion Mitigation and Air Quality	Formula	Truck stop electrification (not parking construction)	Requires Environmental Protection Agency consultation
INFRA Grant (formerly FASTLANE)	Discretionary	Freight and highway projects on NHFP/NHS	Up to 60% of project cost
BUILD (formerly TIGER)	Discretionary	Multimodal, innovative projects, including truck parking	100% rural / 80% urban
Accelerated Innovation Deployment	Discretionary	Innovation in highway transportation	~\$10M in fiscal years 2016–20
Diesel Emissions Reduction Act	Discretionary	Clean diesel projects, truck stop electrification	~\$40M competitive grants
Advanced Transportation and Congestion Management Technologies Deployment	Discretionary	Advanced transportation technology, including the Truck Parking Availability System	Up to \$60M (50/50 match)

NHS = National Highway System.

Another example of where federal funds can be used pertains specifically to the Appalachian region (Figure 14). Appalachian Development Highway System funds are dedicated to developing highways in the Appalachian region with federal shares up to 100%. Although federally funded, state DOTs manage the projects. Congress funds Appalachian Regional Commission grants to support economic and community development. Although these grants are federally funded, the application process begins at the state government level and aligns with local needs. Although both programs are primarily federally funded, they often require or leverage non-federal, state, or local matching funds for certain projects. The *Appalachian Regional Truck Parking Study* developed two recommendations for the Appalachian Regional Commission relating to truck parking funding opportunities: (1) utilize existing Appalachian Development Highway System funding and Appalachian Regional Commission grant funding to support the improvement of truck parking in the Appalachian region and (2) assist communities in identifying and capitalizing on federal and state grant opportunities to fund truck parking projects (Yuan et al., 2024).



Figure 14. Operational Boundaries of the Appalachian Regional Commission (Source: Boettner and Herzenberg, 2021; reprinted with permission)

In addition to federal funding opportunities, various studies have proposed several types of innovative funding concepts. For example, the *Southern Middlesex County Freight Movement Study* recommends creating a regional freight district where trucking companies are charged using geofencing for each new property access point (NJTPA, 2023). The fees charged are modified based on the number of trips that enter and access the property according to the regional model. The goal of such an initiative is to enable municipalities to mitigate negative truck impacts through infrastructure and resource improvements that complement county and state roadway initiatives. It is recognized that user charging systems are complex and require stakeholder buy-in.

Tax incentives are another means of funding. This funding could include tax incentives for communities near new public and private truck parking facilities and for businesses that provide new truck parking facilities (Maryland DOT, 2020). Phelan et al. (2017) suggest that special industrial tax districts could be established in conjunction with local zoning regulations in areas with heavy truck traffic generators, such as manufacturing facilities and distribution centers. In these tax districts, a portion of the local taxes paid by property owners and users of these areas could be dedicated to funding offsite improvements, such as truck parking and staging areas. At workshops in North Carolina, stakeholder participants suggested that onsite truck parking and staging space be a requirement for industrial parks and developments (Cambridge Systematics, Inc., 2020). Zoning and land use or development incentives, such as tax breaks or relaxation of other requirements, might create new truck parking and staging space at facilities.

Public-private partnerships are highly recommended when both public and private interests are shared when developing, operating, and maintaining infrastructure. Dowell et al. (2022) suggest that truck parking is an appropriate public-private partnership candidate because “it sits at the nexus of public interests and private industry operations—when truck parking is

adequate, safety and mobility are improved, as is the economic competitiveness of private industry.” The *Appalachian Regional Truck Parking Study* provides three examples of appropriate public-private partnership truck parking models (Yuan et al., 2024):

- **A DOT buys land adjacent to an existing private truck parking site.** If vacant land is available adjacent to an existing truck parking site, the DOT can buy the land and develop truck parking on it, giving drivers access to the amenities provided by the private operator next door. Alternatively, the DOT can lease or give the land to the private truck stop operator and establish which party will be responsible for maintenance and upkeep. The operator then expands truck parking at the site.
- **Asset-lite business utilizes an existing lot, and DOT helps offset costs for drivers.** Asset-lite businesses can utilize existing lots and set up secure parking facilities that drivers pay to access. To help drivers access these sites, DOTs can partner with the asset-lite business to help offset the costs of a driver parking there overnight or for staging purposes.
- **Partnering with businesses to utilize existing large parking lots after hours.** DOTs can partner with businesses in their regions, such as Walmart, as Texas DOT (2020b) also suggested, to use their large parking lots for overnight truck parking. Some DOTs have begun conversations on this model, in which the DOT will build the facilities and infrastructure necessary to support truck parking in return for the business allowing access to the lot or land.

With regard to resilience and parking opportunities during major disruptive events, a number of grant opportunities can be explored through federal agencies such as the Federal Emergency Management Agency, U.S. Department of Commerce’s Economic Development Administration, U.S. Department of Housing and Urban Development, National Oceanic and Atmospheric Administration, and the Centers for Disease Control and Prevention. Table 21 shows a list of grants that may have applicability related to funding truck parking facilities under the umbrella of resilience.

Table 21. Grants with Potential Applicability Resilience and Truck Parking

Source	Grant Name	Description
1	Emergency Management Performance Grant (EMPG)	EMPG provides state, local, Tribal, and territorial emergency management agencies with the resources required for implementing the National Preparedness System and works toward the National Preparedness Goal of a secure and resilient nation.
1	Homeland Security Grant Program (HSGP)	HSGP includes a suite of risk-based grants to assist state, local, Tribal, and territorial efforts in preventing, protecting against, mitigating, responding to, and recovering from acts of terrorism and other threats. This grant provides grantees with the resources required for implementing the National Preparedness System and working toward the National Preparedness Goal of a secure and resilient nation.
1	Regional Catastrophic Preparedness Grant Program (RCPGP)	RCPGP plays an important role in the implementation of the National Preparedness System. RCPGP supports the building of core capabilities essential to achieving the National Preparedness Goal of a secure and resilient nation by providing resources to close known capability gaps in housing and logistics and supply chain management, encouraging innovative regional solutions to issues related to catastrophic incidents, and building on existing regional efforts.

Source	Grant Name	Description
1	Building Resilient Infrastructure and Communities (BRIC)	BRIC supports states, local communities, Tribes, and territories as they undertake hazard mitigation projects, reducing the risks they face from disasters and natural hazards. The program's guiding principles are supporting communities through capability- and capacity-building, encouraging and enabling innovation, promoting partnerships, enabling large projects, maintaining flexibility, and providing consistency.
1	Flood Mitigation Assistance (FMA)	FMA is a competitive grant program that provides funding to states, local communities, federally recognized Tribes, and territories. Funds can be used for projects that reduce or eliminate the risk of repetitive flood damage to buildings insured by the National Flood Insurance Program.
1	National Earthquake Hazards Reduction Program (NEHRP)	NEHRP is the federal government's coordinated approach to addressing earthquake risks. NEHRP's premise is that, although earthquakes may be inevitable, earthquake disasters are not. The Federal Emergency Management Agency (FEMA) is responsible for most of NEHRP's general implementation activities. In this role, FEMA translates the results of research and technology development into effective earthquake risk reduction plans and activities.
1	Pre-Disaster Mitigation (PDM)	PDM makes federal funds available to state, local, Tribal, and territorial governments to plan for and implement sustainable, cost-effective measures designed to reduce the risk to individuals and property from future natural hazards, while also reducing reliance on federal funding for future disasters.
1	Safeguarding Tomorrow Revolving Loan Fund (RLF)	The Safeguarding Tomorrow RLF program complements and supplements FEMA's Hazard Mitigation Assistance grant portfolio to support mitigation projects at the local government level and increase the nation's resilience to natural hazards. These low-interest loans allow jurisdictions to reduce vulnerability to natural disasters, foster greater community resilience, and reduce disaster suffering.
2	Disaster Supplemental Funding	The Economic Development Administration's (EDA) mission is to promote innovation and competitiveness to prepare American regions for growth and success. Between fiscal years 2018 and 2019, EDA received \$1.2 billion in supplemental disaster appropriations (\$600 million each year) from the U.S. Congress to help regions recover from the economic harm and distress resulting from natural disasters during 2017 to 2019. With the support of these funds, American regions and communities hit hard by major disasters rebuild stronger, more resilient economies.
3	Community Development Block Grant Mitigation (CDBG-MIT) Program	CDBG-MIT is a unique and significant opportunity for eligible grantees to use this assistance in areas affected by recent disasters to carry out strategic and high-impact activities to mitigate disaster risks and reduce future losses.
3	Community Development Block Grant (CDBG) State Program	Under the CDBG State Program, states award grants to smaller units of general local government that develop and preserve decent, affordable housing, to provide services to the most vulnerable in communities, and to create and retain jobs. Annually, each state develops funding priorities and criteria for selecting projects.
4	Climate Adaptation Partnerships (CAP) Program	CAP supports research projects that address climate-sensitive issues of concern to decision-makers and policy planners at a regional level. Eleven CAP teams exist across the country.
5	Climate-Ready States and Cities Initiative (CRSCI), formerly the Regional Integrated	CRSCI helps grant recipients from 11 jurisdictions use the five-step Building Resilience Against Climate Effects (BRACE) framework to identify likely climate impacts in their communities, potential health effects associated with these impacts, and their most at-risk populations and locations. The BRACE framework then helps grant recipients develop and

Source	Grant Name	Description
	Sciences and Assessments	implement health adaptation plans and address gaps in critical public health functions and services.

1 = Federal Emergency Management Agency (2025); 2 = U.S. Economic Development Administration (n.d.); 3 = U.S. Department of Housing and Urban Development (2026); 4 = National Oceanic and Atmospheric Administration (n.d.); 5 = Centers for Disease Control (2024).

Data

Two common types of freight data include origin-destination and parking data. Several different methods and tools are available to obtain these data. Origin-destination data are typically used to evaluate commodity flows and freight trip generation. Parking data can be used to develop demand estimates, understand need (i.e., overcapacity locations), and identify problem areas (i.e., undesignated parking). The sources to obtain freight data include surveys, crowdsourcing, GPS, aerial imagery, and inventories. For example, Holguín-Veras et al. (2016) used commodity flow survey data to estimate trip generation rates and peak parking demand; the MAG (2024) truck parking study used GPS data to estimate parking activity rates by land use; the Winston-Salem MPO developed truck trip generation equations based on the number of truck bays at facilities (FHWA, 2016); the Texas A&M Transportation Institute used GPS data to examine the nuances of truck trips such as origin-destination, length and duration of trips, and bottlenecks (Katsikides and Kong, 2021). A number of studies have analyzed truck parking data at undesignated locations, which is of relevance to this research effort. The following is an overview of each study.

The *Appalachian Regional Truck Parking Study* used multiple data sources to assess truck trip activity (Yuan et al., 2024). This activity included incorporating U.S. DOT’s Jason’s Law survey data to provide a baseline inventory of truck parking facilities, GPS data for insights into truck movement and parking patterns, crowdsourcing data to capture real-time truck parking utilization trends, and truck parking inventory data from state DOTs. Within the Appalachian Regional Commission’s operational boundaries (Figure 14), study results showed the following:

- There are 802 truck parking sites, with 36,411 spaces.
- Of the sites, 87.5% are private (i.e., commercial truck stops), and 12.5% are public (i.e., rest areas and weight stations).
- All interstate corridors within the region are forecast to see increased truck traffic by 2050, driven by new warehouses and intermodal hubs.
- There are 65 clusters of undesignated parking locations concentrated in southern Appalachia (Birmingham, Atlanta, Knoxville, and Charleston).
- Undesignated truck parking resulted in 1,146 crashes during a 4-year span (2018—2022).

In New York, the *Regional Truck Parking Study* analyzed parking at 32 truck parking facilities, including rest areas, service areas, private truck stops, gas stations, and undesignated locations (CRTC, 2023). The primary focus of the undesignated parking locations was on high-demand corridors and secondary roads near truck stops and industrial facilities. For the designated parking facilities, utilization rates and overflow parking patterns were analyzed through observations, aerial photography, and GPS data from ATRI. Parking occupancies were categorized in 15-minute intervals, from 30 minutes to 10 or more hours. Next-stop geographic

profiles (i.e., local versus long-haul trips) were also obtained from the ATRI data. The results showed that the region, as a whole, meets current truck parking demand; however, localized shortages exist. In addition, overflow from truck parking facilities resulted in undesignated parking along shoulders in high-demand corridors (I-90, I-97, and the I-88 and I-90 interchange). Undesignated shoulder parking on New York State Route 7 was attributed to staging for the Rotterdam Industrial Park.

The Texas truck parking study also utilized ATRI data to analyze truck parking data (Texas DOT, 2020a). The research team collected more than 1.6 billion records of truck movements during 8 weeks in 2018, of which 11 million stops were identified with a stop-time threshold of 15 or more minutes. One aspect of the study was to evaluate the supply and demand of truck parking at both public and private locations, instances of undesignated parking, and instances of crashes with trucks parked at undesignated locations. The results of the study showed that more than 140,000 trucks need parking daily statewide. In all major metropolitan areas, the parking demand exceeds the capacity, resulting in undesignated truck parking, whereby 63% of drivers park in undesignated locations weekly. Crash data from 2013 to 2017 revealed that 2,315 crashes involved trucks parked in undesignated locations, resulting in 138 fatalities.

One aspect of the Washington study was the identification of high-density undesignated parking clusters (WSDOT, 2022). To accomplish this task, INRIX GPS data were obtained for 4 months in 2021, whereby truck stops were identified (non-moving waypoints for 30 minutes or more), and undesignated parking was classified based on location (shoulders, ramps, and non-truck spaces at rest areas). The study found 42 clusters of undesignated parking with the highest concentrations in urban areas (the Seattle, Tacoma, and Everett area; Spokane; the Tri-Cities area; and Yakima) and along key corridors of I-5, I-90, and I-82. The four specific locations along these key corridors where undesignated parking was most prevalent include (1) rest area shoulders and non-truck spaces, (2) on- and off-ramps and corridor shoulders, (3) last-mile roads near freight facilities, and (4) near truck stops that are at capacity. Similar to the Texas DOT (2020a) study, the Washington study found that truck parking demand typically exceeds supply, especially for overnight and staging needs, and that safety and operational issues arise from undesignated parking.

Maryland used a combination of qualitative and quantitative approaches to both evaluate and make recommendations relating to truck parking in the state. Internal and external stakeholder focus groups were formed, and workshops were held to discuss the truck parking problem. Material presented to these focus groups included designated and undesignated truck parking events using GPS data obtained from INRIX, aerial imagery to identify truck parking facilities, and crowdsourced data from Trucker Path to determine parking availability at public and private facilities. The findings revealed that the peak shortage of truck parking occurs during the overnight period between 1 a.m. and 5 a.m., when the likelihood of finding parking is 22 to 25% statewide. This shortage of parking has led to an estimated 190 undesignated truck parking events per day. High-density clusters of these undesignated parking events are found near the I-95 Welcome Centers in Laurel, the I-70 South Mountain Welcome Center, Baltimore industrial areas, and along US 301 in Stevensville and US 50 in Salisbury.

Based on stakeholder insights on the truck parking problem in Maryland, a major concern is that freight efficiency is being affected because truck drivers are avoiding Maryland because of parking scarcity (Maryland DOT, 2020). This scarcity is due to lack of capacity throughout public and private locations in the state, and this lack has contributed to undesignated parking, thus creating safety concerns. In addition, stakeholders identified the cost of adding capacity and land use conflicts as major issues. To prioritize parking investments that would add capacity, an approach was developed to rank clusters of undesignated truck parking. The methodology included categorizing undesignated stop events into two types based on proximity to the National Highway System: (1) clusters on heavy-use corridors within 75 feet of the National Highway System and (2) clusters on last-mile connectors (more than 75 feet from the National Highway System). Clusters were then prioritized using three key criteria: safety, duration of parking, and total number of trucks parked. Each criterion was weighted as follows:

- **Safety (30 Points).** The safety criterion assessed the potential safety impact of the undesignated truck parking. Clusters were allocated points based on the location of the undesignated truck parking in relation to nearby roadways, specifically:
 - Clusters of undesignated truck parking primarily along last-mile connectors to freight generators—0 points.
 - Clusters of undesignated truck parking that encompass substantial parking on heavy-use corridors—10 points.
 - Clusters of undesignated truck parking using roadside facilities developed for emergency use—15 points.
 - Clusters of parking using on- and off-ramps—30 points.
- **Duration Parked (50 Points).** The duration parked criterion differentiates the number of trucks in a cluster of undesignated truck parking by the duration of the stops. More points were assigned to clusters with a greater number of long, undesignated stop events. The following categories were used to allocate the 50 points assigned to this criterion:
 - Number of short truck parking events (0.5 to 3 hours)—Scaled value based on the number of undesignated stop events between 30 minutes and 3 hours, a maximum of 10 points.
 - Number of medium-duration stops (3 to 8 hours)—Scaled value based on the number of undesignated stop events between 3 and 8 hours, a maximum of 15 points.
 - Number of long-duration stops (more than 8 hours)—Scaled value based on the number of undesignated stop events during 8 hours, a maximum of 25 points.
- **Total Number of Trucks Parked (20 Points).**
 - This criterion assigns a maximum of 20 points that are scaled based on the total number of undesignated stop events occurring in an undesignated cluster.

Mobility Innovations

Mobility innovations in freight delivery are rapidly transforming logistics, with a strong focus on efficiency to reduce emissions and optimize last-mile, middle-mile, and long-haul transportation. Examples of some innovations that address rising delivery demands and more efficient urban mobility include cargo bicycles, microhubs, delivery lockers, cargo consolidation, and truck parking information management or availability systems. These innovations are listed

here because some of them may inform local reviews of industrial developments, especially if considered alongside updates to zoning ordinances.

Cargo Bicycles

The change in the distribution model has also driven a change in the transportation that serves it. With the need for more rapid delivery directly to consumers, the need for smaller delivery vehicles has increased because large delivery trucks can present safety risks to pedestrians, cyclists, and other road users (KSS Architects, 2021); are less environmentally friendly; and often double-park on busy roadways or on sidewalks. In 2019, NYC DOT (2024) piloted a commercial cargo bike program designed to make deliveries safer and more sustainable by reducing the number of large delivery trucks on New York City streets. In 2022, the cargo bikes made more than 130,000 trips, delivering more than 5 million packages. This labor demonstrated their effectiveness for making deliveries and resulted in the reduction of more than 650,000 metric tons of carbon dioxide emissions, the equivalent of emissions generated by 1.6 billion miles driven by an average gas-powered passenger vehicle. With the intent of lowering truck emissions, easing congestion, and increasing freight efficiency, Fletcher (2023a) reported that the city of Miami and seven other U.S. cities will soon take part in an 18-month study on “freight bicycles” that are able to carry 500 pounds. Data will be collected on traffic flows, truck reductions, the number of vehicles needed for deliveries, and emissions avoided.

Microhubs

Another innovative solution to delivery frameworks is microhubs established near the outskirts of a specific urban area. Long-haul drivers with goods destined for an urban area can arrive at a hub, thereby bypassing regional distribution centers and cross-dock facilities. Their haul is then left at the hub for a local delivery partner to take over for final-mile transport. Calabrese (2024) notes that a system based on urban delivery hubs can reduce urban traffic and the wear-and-tear on the road, as well as emissions in the urban environment. NYC DOT is working to install delivery microhubs where trucks can safely offload to smaller, greener alternatives like cargo bikes.

Delivery Lockers

A delivery or parcel locker is a form of a microhub where the parcel is delivered to a central delivery locker rather than directly to the consumer. Ranjbari et al. (2023) mentions that this type of delivery system allows couriers to deliver multiple packages to one location rather than multiple locations (e.g., instead of going to multiple destinations in a neighborhood, a courier can deliver all packages to a locker in a nearby parking lot). The World Economic Forum (2020) indicates that by 2030, parcel lockers could reduce global delivery costs by 2 to 12% and emissions by 5 to 18%. A study in Amsterdam found that instead of having 1,475 stops for the whole delivery of 1,770 parcels, this alternative delivery model has 430 stops for the normal delivery route and only 47 stops for the parcel locker route (Van Duin et al., 2020). The related daily delivery costs were €2,704.85 per day, instead of €3,210.49 per day. On a yearly basis, this difference could save up to €121,356 for the area of De Pijp (population of 35,000). In April 2024, New York City launched LockerNYC (NYC DOT, 2025b), a free pilot program that utilizes lockers installed on public sidewalks to allow New Yorkers to receive secure package

deliveries. The program is designed to cut down on thefts by providing a secure place to send and receive packages while also reducing delivery truck trips by consolidating more deliveries at central locations.

Cargo Consolidation

According to Monsreal et al. (2024), an estimated 20% of the trucks on the road are traveling empty. This reduced efficiency causes traffic congestion, a hike in shipping prices, and greenhouse gas emissions. Cargo consolidation, or truck sharing, is one way to attain better efficiency in cargo transportation, which in turn helps avoid traffic congestion (Liu and Zhao, 2019). However, planning, coordination, and carriers' willingness to haul consolidated shipments can present challenges. Monsreal et al. (2024) found from a survey that most respondents in the private sector felt that it is very or moderately beneficial to implement cargo consolidation strategies for alleviating traffic congestion; however, a public agency survey revealed that although most public-sector respondents consider cargo consolidation moderately beneficial for reducing traffic congestion, they (the public agencies) are not willing to collaborate on the implementation of cargo consolidation strategies. Monsreal et al. (2024) suggest future research that improves optimization models.

Truck Parking Information Management Systems

As Hayes (2026) recognizes, emerging technologies influence truck parking compliance (e.g., truck electric charging station needs, intelligent transportation systems, truck parking information management systems, connected and automated vehicles, and truck platooning). Maryland cites that truck drivers are increasingly using their smartphones or other smart devices to locate and even reserve available truck parking (Maryland DOT, 2020), and major truck stop companies offer applications specifically designed to direct truck drivers to their nearest facility and provide information about the availability of truck parking at the facility in some cases. Phelan et al. (2017) recommend that agencies (1) develop interoperable tools to disseminate real-time information about parking availability at highway rest areas and private truck stops, (2) incorporate truck parking technology into trip planning and reservation services using existing fleet and vehicle management software, and (3) build parking availability and reservation capabilities into connected vehicle and vehicle-to-infrastructure technology. Texas DOT (2020b) found that one of truck drivers' top needs is accurate, real-time information about the availability of truck parking spaces. Based on this finding, it was recommended that the state invest in a truck parking availability system.

Potential Local Practices for Virginia

A synthesis of the foregoing literature suggests several practices that may be adapted to be applicable in Virginia. For instance, considering the material described in the Data section, some agencies directly related undesigned parking to truck crashes (Texas DOT, 2020a; Yuan et al., 2024), other agencies showed how to identify such undesigned clusters (CRTD, 2023; WSDOT, 2022), and one agency showed how to use these clusters to prioritize parking investments (Maryland DOT, 2020). Adaptation of these ideas to Virginia could mean that localities use such clusters of undesigned parking to apply for funds to invest in truck parking facilities. The advantage of such an approach is that one could use this parking to reduce

potential crash risks. The challenge of this approach is twofold: (1) by not relying on crash data, one does not have as firm evidence of a safety problem as one would have if patterns of truck crashes were available and (2) the cost of providing such parking.

The left column of Table 22 identifies 13 potential practices, within the area of local review of industrial developments, that Virginia localities may consider. The right column identifies potential challenges in implementing these practices. These practices generally require or would benefit from some state-level support, either in the form of technical assistance or funding.

Table 22. Potential Practices Regarding Local Reviews of Industrial Developments

No.	Potential Practice (Location or Source)	Potential Challenge
1	Localities may use large clusters of undesignated truck parking to identify locations for needed truck parking spots, with the justification of the investment being an improvement in safety.	- The use of large clusters of undesignated truck parking is not as compelling as observations of truck crashes. - Providing parking has an associated cost.
2	Use form-based zoning (Louisville, Wasatch Front Regional Council, and Portland, Oregon).	At the time of a land development review, the specific land use (e.g., warehouse versus high cube) may not necessarily be known.
3	Update local zoning ordinances to recognize that not all “industrial sites” are similar—e.g., last-mile facilities should be allowed to be closer to population centers (LVPC, 2022), and consideration could be given to innovative strategies such as microhubs (Calabrese, 2024).	- Modifications to local ordinances require both time and costs for the localities. - Good examples of such modifications may not be readily available. - Some of the “innovative strategies” may only be feasible in urban locations.
4	Require businesses to provide waiting areas for non-company drivers making or picking up deliveries (WSDOT, 2022).	Cost and security concerns will increase for businesses providing waiting areas.
5	Require amenities and shared parking at larger industrial parks (PTAC, 2023).	The business park will incur increased cost.
6	Use updated Institute of Transportation Engineers trip generation rates (Civiletti et al., 2023).	- Localities may need evidence that updated rates are applicable for local areas. - Large trip rates may lead to certain facilities, such as distribution centers, being banned from localities.
7	Incorporate adequacy of parking and amenities into state-level reviews of traffic impact analyses (MAG, 2024).	- Adding items to consider increases review time for TIAs. - Localities are not required to implement state DOT comments.
8	Use VMT impacts in TIAs to encourage placement of local distribution centers closer to population centers (County of Riverside, 2020).	Localities (and VDOT) do not have extensive experience with the use of VMT in TIAs.
9	Use industrial impact fees (Colorado Department of Revenue, 2026).	Only one Virginia locality has experience with these fees.
10	Use retail delivery fees (Minnesota Department of Revenue, 2026).	Proposed but not yet allowed in Virginia.
11	Have the DOT provide infrastructure to support truck parking in return for a business allowing parking on the land (WSDOT, 2022; Yuan et al., 2024).	- Cost to the state. - Agreements would need to be negotiated.

No.	Potential Practice (Location or Source)	Potential Challenge
12	Conduct (via MPO or state) an evaluation of candidate offsite parking locations (Miami-Dade MPO, 2012).	Locality, not the MPO or state, ultimately decides if those locations are allowed to be used for offsite parking.
13	Formalize agreements between states, localities, and private owners of infrequently used large parking lots (e.g., stadiums and racetracks) to use such lots for emergency truck parking.	This arrangement requires time and effort to develop these lease agreements and funds to use of these lots.

DOT = department of transportation; MPO = Metropolitan Planning Organization; TIAs = traffic impact analyses; VMT = vehicle miles traveled.

Review of Virginia Ordinances

Counties

Table 23 shows the color-coded matrix system (coded green, yellow, orange, and red) that was developed to visually quantify the depth of coverage within each category (loading, congestion, storage, distribution, access, and parking) for each county reviewed. The counties are listed in alphabetical order, and those shown in bold are along Virginia's freight corridors. *Wythe County is not included in the review, even though it intersects I-81, because the analytical methods to evaluate its ordinances proved difficult because of its format.* Based on the consistent search rules applied as discussed in the Methods section, the categories were scored so that green equals 3 points, yellow equals 2 points, orange equals 1 point, and red equals 0 points. The scoring column on the right side of the table shows the cumulative score. The counties that ranked the highest in terms of code quality, or breadth and thoroughness, include Henrico and New Kent Counties, with 17 points each, followed by York County (15 points), and Albemarle County (14 points). The counties of Bedford, Frederick, Prince William, and Spotsylvania each scored 13 points. Ten counties had cumulative scores of 3 points or lower. The average score for all counties across all categories is 7.8.

Table 24 shows the cumulative numerical score across each of the color-coded matrix categories. For example, in the loading category, 28 counties scored the highest (3 points), 12 counties scored 2 points, 11 counties scored 1 point, and 4 counties had no points. The total cumulative score is shown in the rightmost column. Loading was the category with the highest overall score ($28 \times 3 + 12 \times 2 + 11 \times 1 + 4 \times 0 = 119$ points), followed by parking (93 points). The storage and distribution categories scored the lowest across all counties reviewed, with 48 and 47 points, respectively.

Table 23. Color-Coded Scoring Matrix of Counties Reviewed

County ^a	Loading	Congestion	Storage	Distribution	Access	Parking	Total Score
Accomack	Yellow	Yellow	Orange	Yellow	Yellow	Green	12
Albemarle	Green	Orange	Green	Yellow	Yellow	Green	14
Alleghany	Yellow	Yellow	Orange	Orange	Orange	Green	9
Amelia	Orange	Orange	Red	Orange	Red	Orange	4
Appomattox	Yellow	Yellow	Red	Orange	Red	Green	7
Arlington	Green	Orange	Red	Orange	Red	Orange	6
Augusta	Green	Orange	Orange	Orange	Orange	Green	10

County ^a	Loading	Congestion	Storage	Distribution	Access	Parking	Total Score
Bath							9
Bedford							13
Bland							5
Botetourt							11
Brunswick							5
Buchanan							2
Buckingham							10
Campbell							4
Caroline							0
Carroll							2
Charles City							11
Charlotte							3
Chesterfield							1
Clarke							2
Craig							8
Culpeper							11
Cumberland							7
Dinwiddie							12
Essex							5
Fairfax							5
Fauquier							2
Floyd							2
Fluvanna							11
Frederick							13
Goochland							10
Greensville							2
Hanover							9
Henrico							17
James City							8
Louisa							11
Mecklenburg							6
Montgomery							9
Nelson							8
New Kent							17
Prince George							10
Prince William							13
Pulaski							5
Roanoke							9
Rockbridge							2
Rockingham							8
Shenandoah							7
Smyth							2

County ^a	Loading	Congestion	Storage	Distribution	Access	Parking	Total Score
Spotsylvania							13
Stafford							10
Sussex							8
Warren							6
Washington							9
York							15

^a Counties in bold font are along Virginia's freight corridors. Colors indicate information in the zoning ordinances, ordered from green (highest) to yellow to orange to red (lowest): green = 3 points; yellow = 2 points; orange = 1 point; and red = 0 points.

Table 24. Cumulative Numerical Score Across Matrix for Counties

Category	Number of Counties				Total Points
Loading	28	12	11	4	119
Congestion	5	9	27	14	60
Storage	5	6	21	23	48
Distribution	2	5	31	17	47
Access	6	13	19	17	63
Parking	17	12	18	8	93

Colors indicate information in the zoning ordinances, ordered from green (highest) to yellow to orange to red (lowest).

Cities

Table 25 shows the color-coded matrix system that was developed for cities. The cities are in alphabetical order, and those in bold font are along Virginia's freight corridors. The cities that ranked the highest in terms of code quality, (or breadth and thoroughness, include Portsmouth with 16 points, followed by Emporia, Lynchburg, Richmond, Virginia Beach, and Williamsburg, each with 14 points. The cities of Chesapeake and Newport News both have 13 points. The average score for all cities across all categories is 10.5.

Table 25. Color-Coded Scoring Matrix of Cities Reviewed

City ^a	Loading	Congestion	Storage	Distribution	Access	Parking	Score
Alexandria							6
Bristol							9
Buena Vista							5
Charlottesville							7
Chesapeake							13
Colonial Heights							8
Danville							11
Emporia							14
Fairfax City							7
Fredericksburg							9
Hampton							8
Harrisonburg							6
Lexington							9

City ^a	Loading	Congestion	Storage	Distribution	Access	Parking	Score
Lynchburg							14
Manassas							11
Manassas Park							12
Newport News							13
Norfolk							9
Petersburg							12
Portsmouth							16
Radford							6
Richmond							14
Roanoke							10
Salem							12
Staunton							12
Virginia Beach							14
Waynesboro							12
Williamsburg							14
Winchester							12

^a Cities in bold font are along Virginia's freight corridors. Colors indicate information in the zoning ordinances, ordered from green (highest) to yellow to orange to red (lowest): green = 3 points; yellow = 2 points; orange = 1 point; and red = 0 points.

Table 26 shows cumulative numerical score across each of the color-coded matrix categories. For the loading category, 20 cities scored highest (3 points), 6 cities scored 2 points, 3 cities scored 1 point, and 0 cities had no points. The total cumulative score is shown in the rightmost column. Similar to the counties, loading was the category with the highest overall score ($20*3 + 6*2 + 3*1 + 0*0 = 75$ points). Parking and distribution scored 63 points each, and storage had the lowest cumulative score at 24 points.

Table 26. Cumulative Numerical Score Across Matrix for Cities

Category	Number of Cities				Total Points
Loading	20	6	3	0	75
Congestion	5	7	17	0	46
Storage	0	5	14	10	24
Distribution	14	7	7	1	63
Access	3	6	14	6	35
Parking	13	8	8	0	63

Colors indicate information in the zoning ordinances, ordered from green (highest) to yellow to orange to red (lowest).

Localities Combined

Figure 15 combines the results of Tables 24 and 26 and shows that of the six categories, the strongest for Virginia overall is loading, with a score of 194, and the weakest is storage, with a score of 72. However, the effect of the ordinances is best understood in the context of other transportation needs. For instance, a lack of congestion-related ordinances in a rural area may not be as critical as a lack of such ordinances in a congested area. Similarly, a lack of ordinances

related to storage, although not ideal, is most problematic in locations that have freight hubs and warehouses.

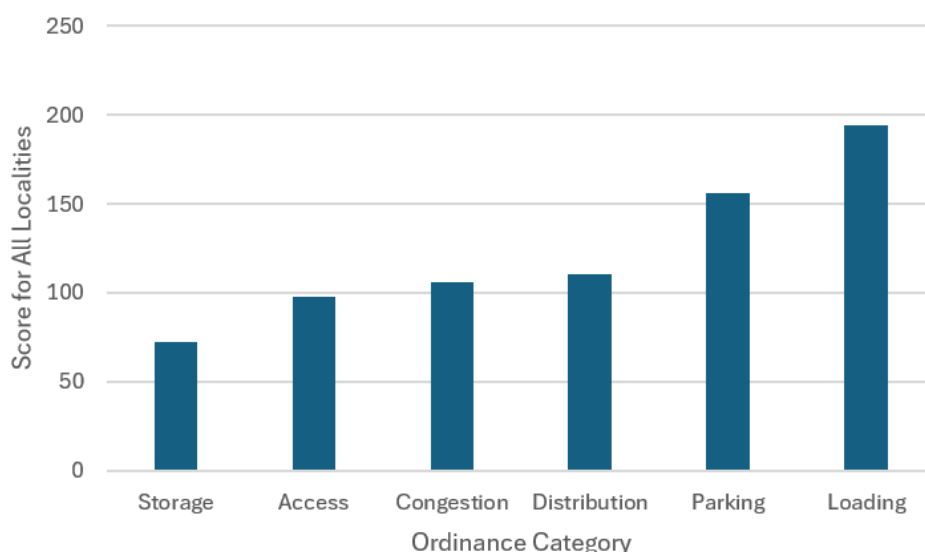


Figure 15. Ordinance Category Scores for All Virginia Localities

Accordingly, the cumulative results for each category were further organized into a map of the state (Figure 16), displaying each scrutinized locality in a different color to represent the quality of their codes (refer to the scoring columns in Tables 23 and 25 for counties and cities, respectively). This map was overlaid with an additional dataset outlining the locations of the freight-generating industrial locations throughout the state. Figure 16 shows the correspondence between the number of industrial sites and the county code quality score. For instance, Fauquier County has a low score and just a single industrial site, whereas adjacent Stafford County has a high score and a high number of industrial sites. However, Figure 16 also identifies counties whose ordinances merit attention: those that have a large number of industrial sites and a relatively low score. Furthermore, Figure 16 shows that some of these counties are clustered along one major corridor. Caroline, Chesterfield, and Greensville Counties all have lower scores and are along the I-95 corridor.

Although all six categories used to develop the color coding scheme in Figure 16 could be further investigated, two key categories—storage of trucks (especially for staging) and parking—demonstrate when local decisions have statewide consequences because both categories influence the demand for truck freight parking outside local boundaries. Accordingly, the next task focused on truck freight parking. Figure 16 served as an important tool for constructing the analytical platform of the parking analysis task.

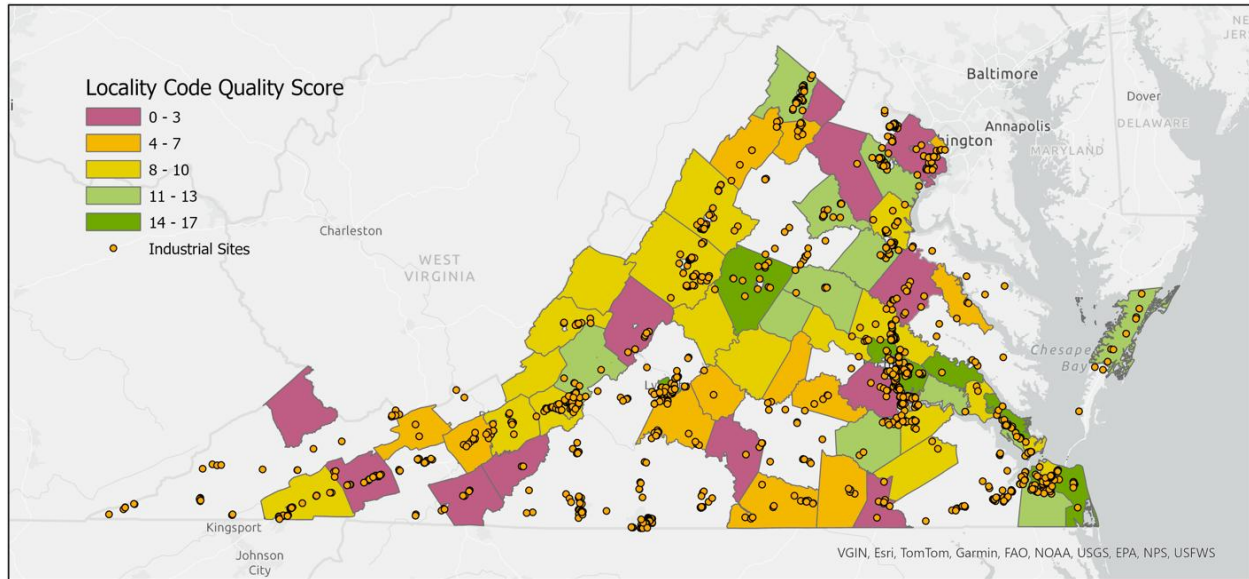


Figure 16. Map of Industrial Sites and Analyzed Virginia Counties and Cities by Code Quality

Parking Analysis

Ordinance Review of Localities

For the localities for which ordinances were reviewed, Table 27 shows the ordinance quality score, total truck parking counts within the locality (based on the sample data evaluated as described in the Methods section), and total number of industrial sites. These parking instances include all designated and undesignated parking in the Geotab dataset for the months of April and October 2024. The southeastern Virginia cities were excluded in the analysis because of the influence of the Port of Virginia. The top five localities with the highest number of truck parking events include the counties of Fairfax (22,944), Henrico (21,474), Chesterfield (19,563), Hanover (17,320), and Prince William (15,573). The city of Richmond had the highest count among the cities evaluated, with 11,050 parking instances.

Table 27. Locality Ordinance Score, Truck Parking Count, and Industrial Site Count

Locality ^a	Ordinance Quality Score	Total Truck Parking Count	Industrial Sites
Accomack	12	1,417	8
Albemarle	14	2,926	16
Alleghany	9	1,780	11
Amelia	4	525	4
Appomattox	7	554	1
Arlington	6	3,923	5
Augusta	10	9,428	29
Bath	9	243	0
Bedford	13	3,398	12
Bland	5	2,594	2
Botetourt	11	6,407	19
Brunswick	5	1,152	4

Locality ^a	Ordinance Quality Score	Total Truck Parking Count	Industrial Sites
Buchanan	2	1,276	0
Buckingham	10	436	0
Campbell	4	3,816	20
Caroline	0	7,776	13
Carroll	2	4,912	5
Charles City	11	411	1
Charlotte	3	870	6
Chesterfield	1	19,566	85
Clarke	2	461	0
Craig	8	290	0
Culpeper	11	2,806	19
Cumberland	7	176	2
City of Danville	11	5,624	27
Dinwiddie	12	3,050	12
Essex	5	636	2
Fairfax	5	22,944	34
Fauquier	2	2,295	1
Floyd	2	468	2
Fluvanna	11	1,143	0
Frederick	13	12,666	44
Goochland	10	2,180	7
Greensville	2	1,889	3
Hanover	9	17,303	50
Henrico	17	21,474	81
James City	8	5,343	7
Louisa	11	4,524	7
City of Lynchburg	15	8,392	58
Mecklenburg	6	3,649	16
Montgomery	9	6,341	12
Nelson	8	514	1
New Kent	17	2,201	1
Prince George	10	6,569	13
Prince William	13	15,573	33
Pulaski	5	4,044	9
City of Richmond	14	11,050	50
Roanoke	9	7,155	15
City of Roanoke	10	7,524	34
Rockbridge	2	8,405	2
Rockingham	8	6,735	34
City of Salem	12	2,567	19
Shenandoah	7	7,288	8
Smyth	2	3,944	26
Spotsylvania	13	8,738	18
Stafford	10	9,459	16

Locality ^a	Ordinance Quality Score	Total Truck Parking Count	Industrial Sites
Sussex	8	1,673	2
Warren	6	3,664	15
Washington	9	7,947	18
York	15	2,128	2

^a Localities in bold font are along freight corridors.

A Spearman statistical test was conducted that cross-compared industrial site concentration, numeric code score, and freight stop-count. The Spearman correlation coefficient (ρ) measures the strength and direction of the association (Table 28), and the p-value indicates whether the observed relationship is statistically significant at a 95% confidence level.

Table 28. Explanation of the Value of ρ Using the Spearman Ranking Analysis Standard

	Absolute Value of ρ	Interpretation
0.00–0.10	Negligible	Essentially no relationship
0.10–0.30	Weak	Very slight tendency
0.30–0.50	Moderate	Noticeable but not strong
0.50–0.70	Strong	Clear relationship
0.70–1.00	Very strong	Very tight relationship

Table 29 shows the results of the Spearman test, which found no statistically significant relationship between ordinance numerical score and total freight stop count. However, a modest positive relationship exists between ordinance numerical score and count of industrial sites, indicating that counties with higher ordinance scores tend to have more industrial sites. In addition, and as one might expect, the number of industrial sites was overall found to correlate with the total number of freight stops, as attested to by a strong linear correlation (Figure 17).

Table 29. Spearman Analysis Results

Analysis	Spearman ρ -Value	p-Value	Interpretation
Numerical Score vs Total Freight Stop Count	0.201	0.123	Weak positive relationship but not statistically significant ($p > 0.05$)
Numerical Score vs Industrial Sites	0.303	0.018	Moderate positive relationship, is statistically significant ($p < 0.05$)

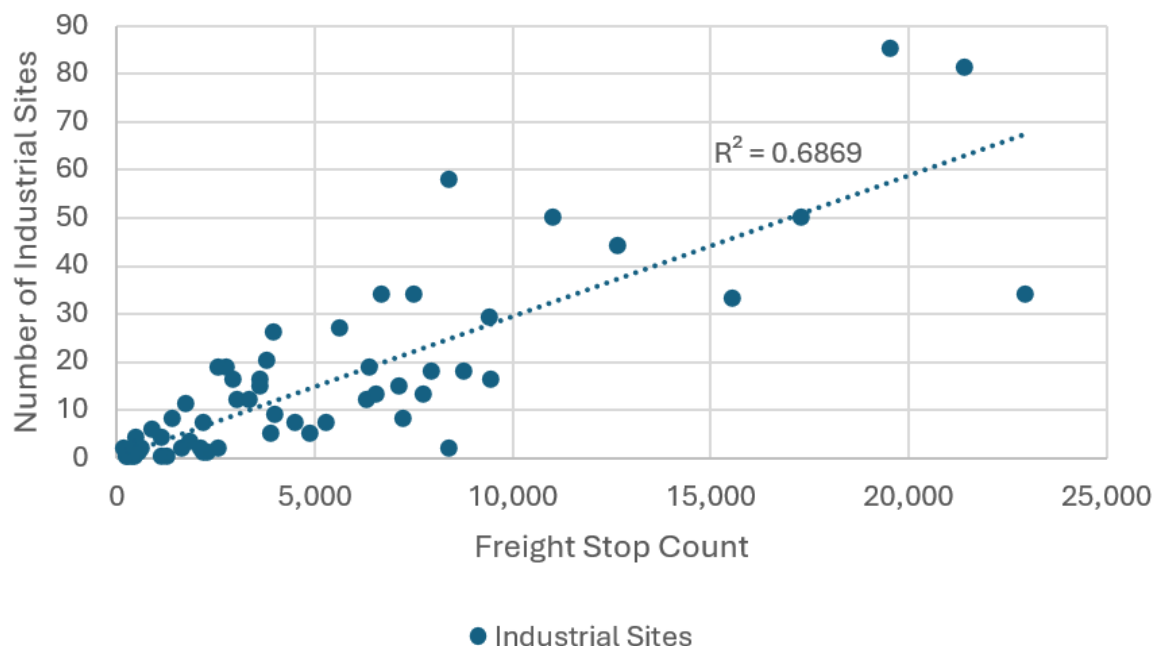


Figure 17. Industrial Sites Versus Total Number of Freight Stops (Both Designated and Undesignated Stops)

Targeted Review of Localities

A more detailed analysis was conducted on the localities and zones following the steps of the workflow developed for this project (the workflow is shown in Supplement E of the report's Supplemental Materials website). Of the 13 localities selected for review, 11 were found to have clusters of undesignated parking activity in and around rest stops, interchanges, and side roads. For each zone in Table 30, the number of undesignated parking events, median stop duration, and median idle times are given. Graphical representations of the zones for each locality are in Supplement G of the report's Supplemental Materials website. The five zones with the highest undesignated parking events include the I-81 Safety Rest Area in Smyth County (125 events), the I-66 Truck Park Area in Warren County (100 events), I-64 and Lee-Jackson Highway in Augusta County (75 stop events), the Mt. Sydney Rest Area in Augusta County (74 events), and the I-95 and I-295 interchange in Henrico County (72 events). The five zones with the highest median stop durations are I-95/England in Hanover County (355 minutes), the I-66 Truck Park Area in Warren County (319 minutes), Digital Drive in Chesterfield (173 minutes), the I-81 Welcome Center in Frederick County (157 minutes), and I-64/White Hill in Augusta County (141 minutes). Locations that did not exhibit undesignated parking events are included in Table 30, noted as "0" undesignated parking events, and visually in Supplement G of the report's Supplemental Materials website to show the areas analyzed. For those locations, hexagonal clusters were noted, but after creating custom zones, undesignated parking events were not found.

Table 30. Undesignated Parking Events and Durations for Select Localities and Analysis Zones

Locality	Analysis Zones	Undesignated Parking Events	Median Stop Duration (minutes)	Median Stop Idle Time (minutes)
Henrico	I-95/I-295	72	38	31
City of Lynchburg	US29/US501	0	N/A	N/A

Locality	Analysis Zones	Undesignated Parking Events	Median Stop Duration (minutes)	Median Stop Idle Time (minutes)
Frederick	I-81/Weigh Station	17	38	3
	I-81/Fairfax	6	62	31
	I-81/Welcome Center	55	157	31
	I-81/Hopewell	16	51	10
	I-81/Rest Church	12	93	32
	Zachery Anne	6	71	5
Spotsylvania	I-95/Mudd Tavern	45	94	4
	Mills/Hospital	0	N/A	N/A
City of Salem	I-81/Wildwood	19	39	34
Roanoke	I-581/Peters Creek	0	N/A	N/A
	Brandon Avenue	0	N/A	N/A
	Rte. 220	0	N/A	N/A
Augusta	Laurel Hill	0	N/A	N/A
	Mt. Sydney Rest Area	74	162	14
	I-64/Lee-Jackson Highway	75	98	32
	I-64/White Hill	38	141	18
Hanover	I-95/Lewistown	18	40	33
	I-95/England	20	355	1
	I-95/Kings Dominion	6	49	5
Warren	Rte. 522/Strasburg	0	N/A	N/A
	I-66/Truck Park Area	100	319	20
Pulaski	I-81/Cleburne	7	41	3
	I-81/State Park	23	59	31
	Lee/Cleburne	0	N/A	N/A
	James Hardie	0	N/A	N/A
Campbell	Dearing Ford/Clarion	0	N/A	N/A
	Clarion Road	23	72	1
Smyth	I-81/Nicks Creek	16	99	33
	I-81/Safety Rest Area	125	48	31
	I-81/Windsor	32	97	7
Chesterfield	Digital Drive	36	173	1
	E. Hundred Road	0	N/A	N/A
	Richmond-Petersburg Tpke	0	N/A	N/A
	Midlothian/Chippenham	0	N/A	N/A
	Midlothian Tpke	0	N/A	N/A

N/A = not applicable because no instances of undesignated parking were found.

Table 31 shows the localities identified as having undesignated parking clusters. In addition, Table 31 shows the locality code quality score, total stop count within the locality (both designated and undesignated), and the total number of undesignated parking totals from the clusters analyzed. When comparing undesignated parking as a percentage of total stop count, Smyth, Warren, and Augusta Counties exhibited the highest percentages at 4.4, 2.7, and 2.0%,

respectively. With some exceptions, as the ordinance score increases, the percentage of undesignated parking decreases (Figure 18).

Table 31. Localities Identified as Having Undesignated Parking Clusters ^a

Locality	Code Quality Score	Total County Truck Parking Count	Undesignated Parking Total	Undesignated Parking as a % of total Stop Count	Number of Clusters
Smyth	2	3944	173	4.386	3
Warren	6	3664	100	2.729	1
Augusta	10	9428	187	1.983	3
Frederick	13	12666	112	0.884	6
Pulaski	5	4044	30	0.742	2
City of Salem	12	2567	19	0.740	1
Campbell	4	3816	23	0.603	1
Spotsylvania	13	8738	45	0.515	1
Henrico	17	21474	72	0.335	1
Hanover	9	17303	44	0.254	3
Chesterfield	1	19566	36	0.184	1

^a Clusters are the number of analysis zones identified within each locality.

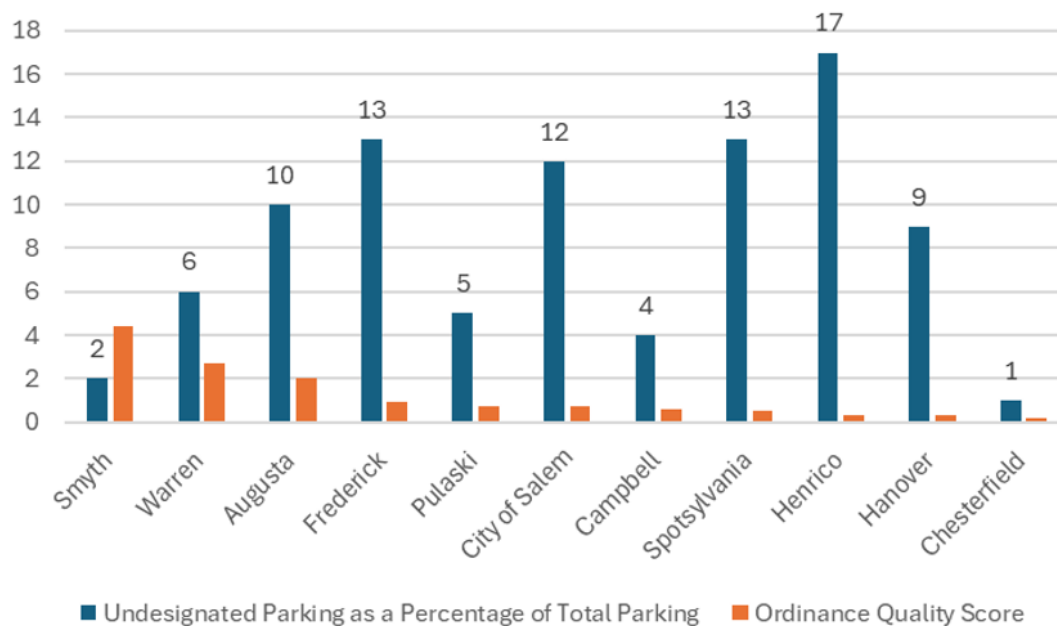


Figure 18. Locality Ordinance Scores Compared with Percentage of Undesignated Parking

Undesignated Parking as a Test of the Validity of the Code Quality Scores

For the subset of counties and cities shown in Table 31, the researchers regressed the percentage of total truck parking events that occurred in undesignated locations in each locality against the code quality score assigned to the ordinances in that same locality. The regression equation amounted to the following:

$$y_i = m \cdot x_i + b + e_i, \quad (\text{Equation 1})$$

Where:

y_i is the percentage of observed truck parking events that occurred in undesignated locations in county (or city) i .

x_i is the code quality score assigned to the ordinances in county (or city) i .

e_i is a random error term distributed $N(0,1)$.

m and b are fixed parameters.

The slope coefficient m of the estimated regression equation had a point estimate of -0.096% . In other words, a 1-unit increase in a county's code quality score was statistically associated with a decrease of 0.096 in the percentage of trucks that parked in an undesignated spot. The standard error of the slope estimate was 0.0786%. This result implies a P-statistic of 12.666%, whereas the likelihood that a slope estimate so far from zero would turn up if the true slope were zero is about one in eight. The R^2 of the regression was 0.14199. In other words, the code quality was able to explain a little more than 14% of the variation in the percentage of trucks that parked in undesignated spots.

The finding of a negative correlation between code quality and the percentage of trucks parking in undesignated spots provides some confirmation that the code quality score is a meaningful index of the features that promote the adequacy of truck parking facilities. The finding of a rather low R^2 provides an indication that other factors, besides the ordinances, also contribute to the adequacy of truck parking facilities.

Further Analysis of the Highest Cluster Stop Count

With the completion of the cluster analysis for the 13 analyzed localities, a deeper analysis was conducted for each locality for the cluster that saw the highest stop count. This analysis revealed insights into pre- and post-trip duration and distance (both median and at the 15th and 85th percentiles), as well as data on the type of vocation and industry. Figures 19 through 29 provide each of these details for each location. In addition, when analyzing these zones containing undesignated truck parking activity, three distinct kinds of parking locations were identified as the most prominent and are noted with each figure. These categories are industrial queue, interchange, and rest stop parking, each defined by its unique roadway geography. To assist with defining industrial queue parking, proximity to industrial developments and post-stop trip distances were ascertained. Although industrial queue parking at interchanges and rest areas certainly could occur, these types of parking instances were harder to identify based on vocation and post-parking trip distance data. Parking categories were defined as follows:

- **Industrial queue parking:** Undesignated parking identified in immediate last-mile proximity to some manufacturing plant or industrial center.
- **Interchange parking:** Undesignated parking identified very near to or on large highway interchanges. Instances of parking may manifest in approaching, departing from, or occupying the entrances or exits of the interchange.
- **Rest stop parking:** Undesignated parking identified around rest-stop establishments, specifically around the exits or entrances and on the approaching and departing roads. Does not include parking instances within the rest-stop facility.

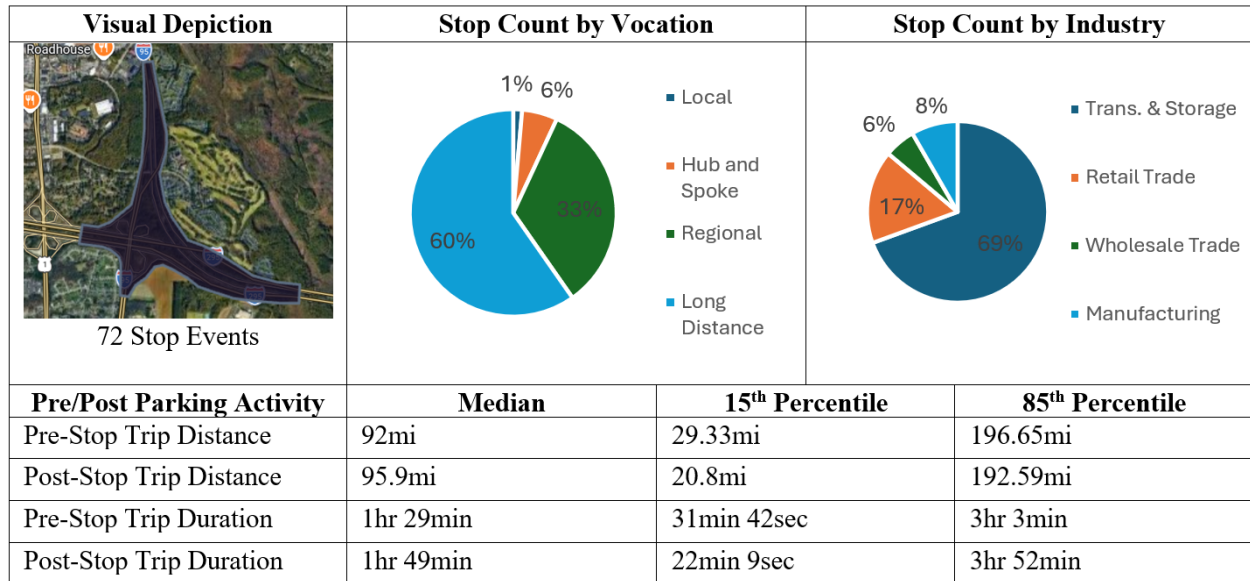


Figure 19. Henrico County Had the Highest Undesignated Parking Cluster at I-95 and I-295. Parking location type: interchange.

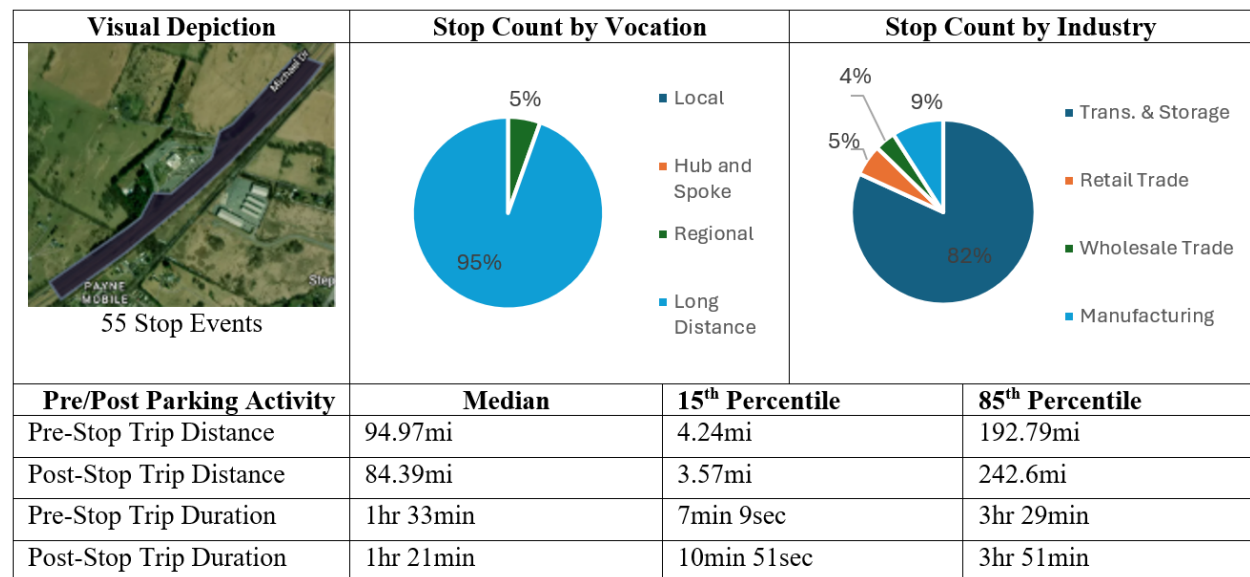


Figure 20. Frederick County Had the Highest Undesignated Parking Cluster at the I-81 Welcome Center. Parking location type: rest stop.

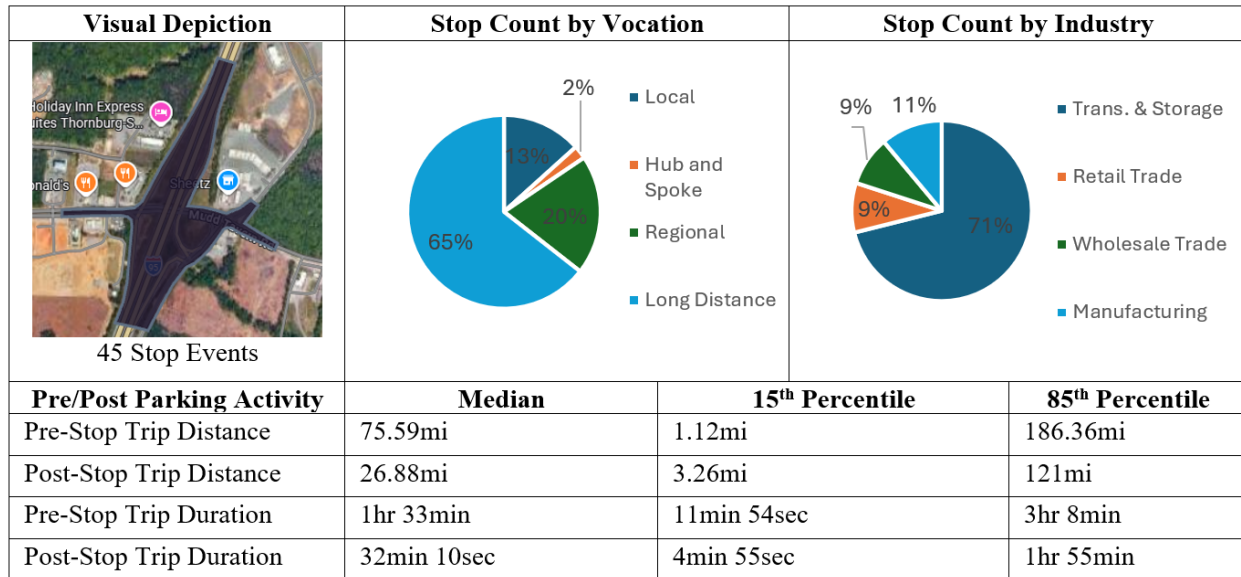


Figure 21. Spotsylvania County Had the Highest Undesignated Parking Cluster at I-95/Mudd Tavern. Parking location type: interchange.

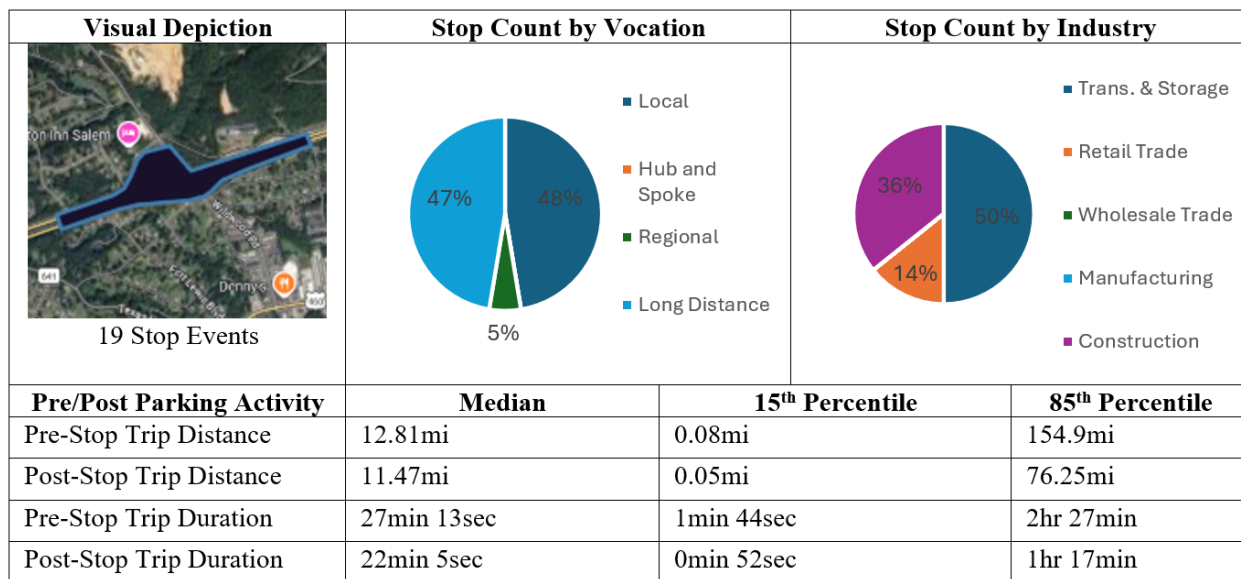


Figure 22. The City of Salem Had the Highest Undesignated Parking Cluster at I-81/Wildwood. Parking location type: interchange.

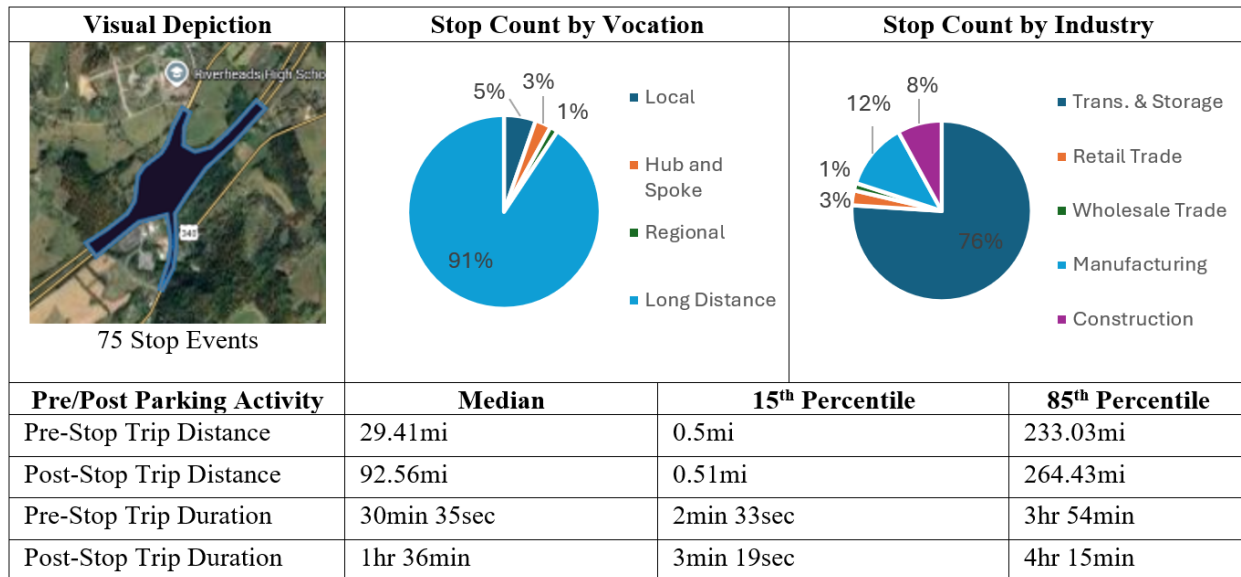


Figure 23. Augusta County Had the Highest Undesignated Parking Cluster at I-64 and Lee-Jackson Highway. Parking location type: rest stop and interchange.

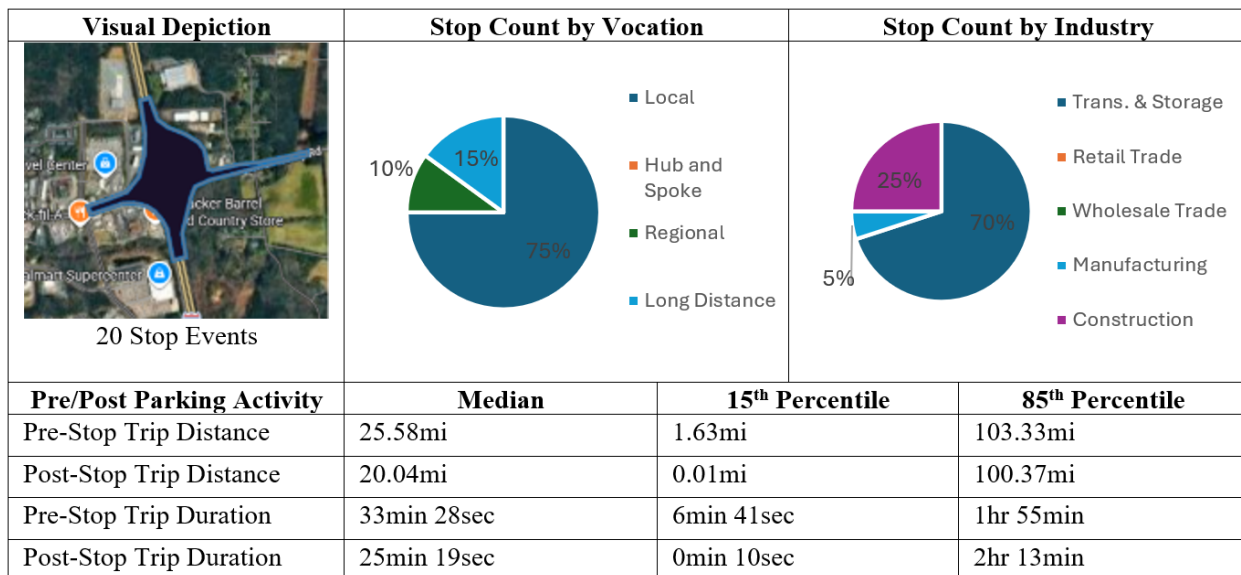


Figure 24. Hanover County Had the Highest Undesignated Parking Cluster at I-95/England. Parking location type: interchange.

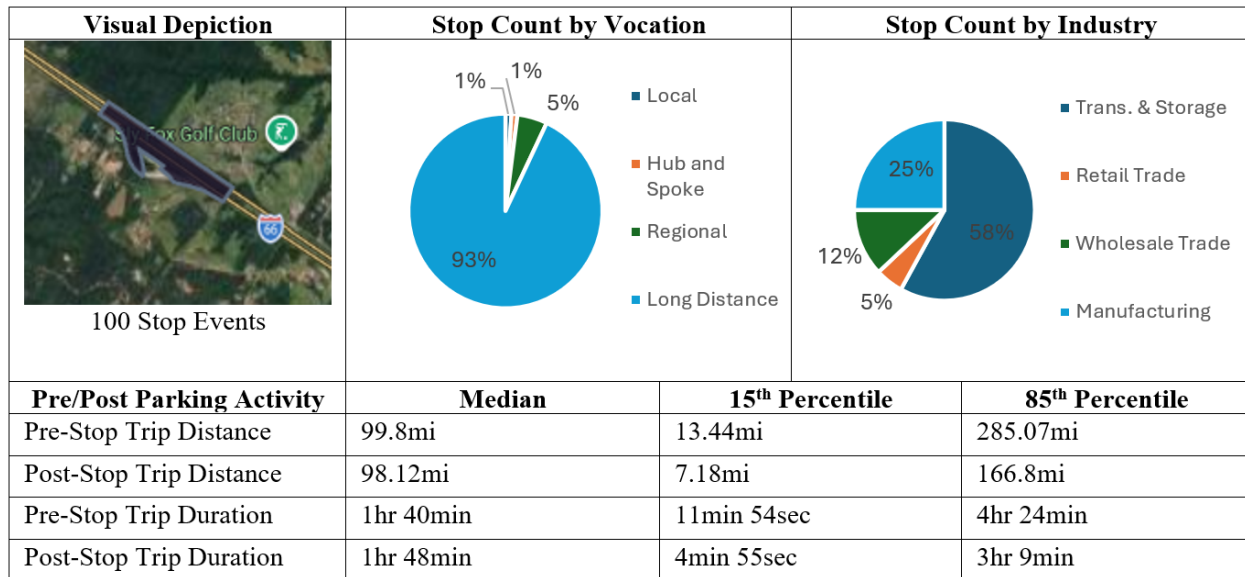


Figure 25. Warren County Had the Highest Undesignated Parking Cluster at the I-66 Truck Park Area. Parking location type: rest stop.

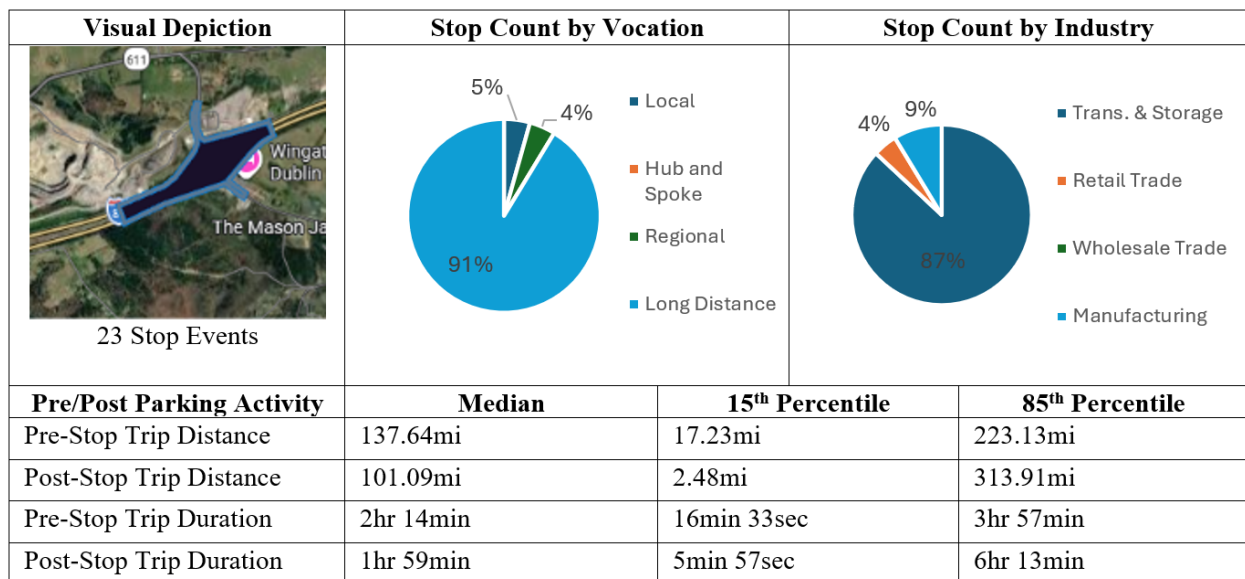
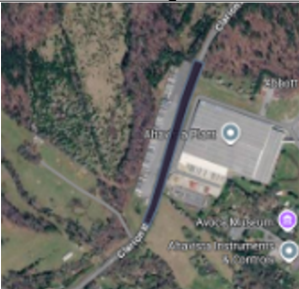


Figure 26. Pulaski County Had the Highest Undesignated Parking Cluster at I-81/State Park. Parking location type: interchange.

 23 Stop Events	5% 4% 91% Local Hub and Spoke Regional Long Distance		100% Trans. & Storage Retail Trade Wholesale Trade Manufacturing	
Pre/Post Parking Activity Pre-Stop Trip Distance Post-Stop Trip Distance Pre-Stop Trip Duration Post-Stop Trip Duration	Median 0.09mi 0.14mi 1min 40sec 2min 15sec	15th Percentile 17.23mi 2.48mi 0min 27sec 0min 32sec	85th Percentile 223.13mi 313.91mi 3min 40sec 44min 19sec	

 125 Stop Events	1% 99% Local Long Distance		1% 10% 89% Trans. & Storage Retail Trade Wholesale Trade Manufacturing	
Pre/Post Parking Activity	Median	15th Percentile	85th Percentile	
Pre-Stop Trip Distance	153.48mi	26.46mi	301.33mi	
Post-Stop Trip Distance	132.32mi	29.25mi	247.30mi	
Pre-Stop Trip Duration	2hr 25min	28min 4sec	5hr 8min	
Post-Stop Trip Duration	2hr 13min	30min 1sec	4hr 9min	

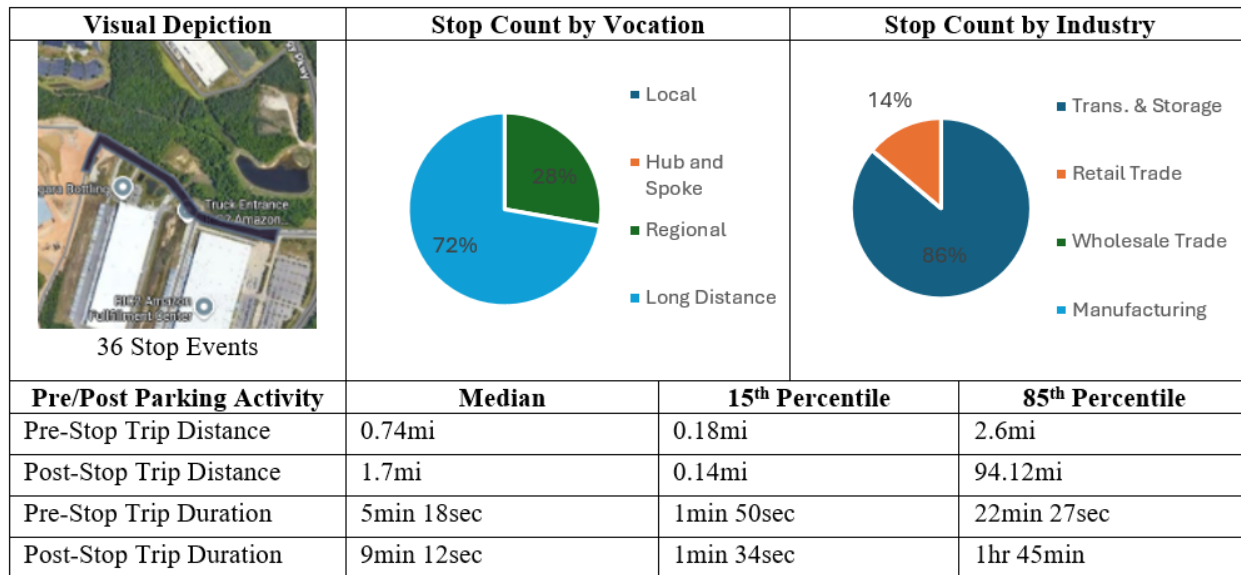


Figure 29. Chesterfield County Had the Highest Undesignated Parking Cluster at Digital Drive. Parking location type: industrial queue.

Cluster Priority Ranking

The 23 clusters within the 10 localities that were identified as undesignated parking events were evaluated for priority ranking based on safety, duration, and total parking counts. This type of analysis can help with prioritizing improvements. Table 32 shows the results of this ranking exercise and the associated county ordinance quality scores within each locality. The higher the total score in the right column, the higher the priority ranking, whereas the higher the ordinance score, the more thorough the ordinance language is relative to industrial developments. The Warren County I-66 Truck Parking location scored the highest, with 71 cumulative points, when considering safety (location), average dwell times of trucks parked, and total number of trucks parked in the cluster. Because of the scoring weights applied, industrial queue types of parking, as seen in Chesterfield (Digital Drive) and Campbell (Clarion Road) Counties, did not rank high because undesignated parking along last-mile connectors to freight generators scores 0 points. The weighting scheme for both safety and duration may help explain the lack of association between ordinance scores and the cluster priority scores (Figure 30).

Table 32. Cumulative Truck Parking Scores for Priority Ranking

Ordinance Quality Score ^a	Zone	Safety	Duration	Total Number	Total Score
6	Warren, I-66/Truck Park Area	15	40	16	71
10	Augusta, I-64/Lee-Jackson Highway	30	6	12	48
17	Henrico, I-95/I-295	30	6	12	47
2	Smyth, I-81/Safety Rest Area	15	10	20	45
10	Augusta, I-64/White Hill	30	8	6	44
10	Augusta, Mt. Sydney Rest Area	15	15	12	42
9	Hanover, I-95/England	30	8	3	41
13	Spotsylvania, I-95/Mudd Tavern	30	4	7	41
2	Smyth, I-81/Windsor	30	3	5	38

Ordinance Quality Score ^a	Zone	Safety	Duration	Total Number	Total Score
5	Pulaski, I-81/State Park	30	2	4	36
13	Frederick, I-81/Welcome Center	15	11	9	35
12	Salem, I-81/Wildwood	30	2	3	35
9	Hanover, I-95/Lewistown	30	1	3	34
13	Frederick, I-81/Hopewell	30	1	3	34
2	Smyth, I-81/Nicks Creek	30	1	3	34
13	Frederick, I-81/Rest Church	30	1	2	33
5	Pulaski, I-81/Cleburne	30	1	1	32
13	Frederick, I-81/Fairfax	30	0	1	31
9	Hanover, I-95/Kings Dominion	30	0	1	31
13	Frederick, I-81/Weigh Station	15	1	3	19
1	Chesterfield, Digital Drive	0	7	6	13
4	Campbell, Clarion Road	0	2	4	6
13	Frederick, Zachery Anne	0	0	1	1

^a Code Quality Score Colors: green = 14–17 points; light green = 11–13 points; yellow = 8–10 points; orange = 4–7 points; and red = 1–3 points

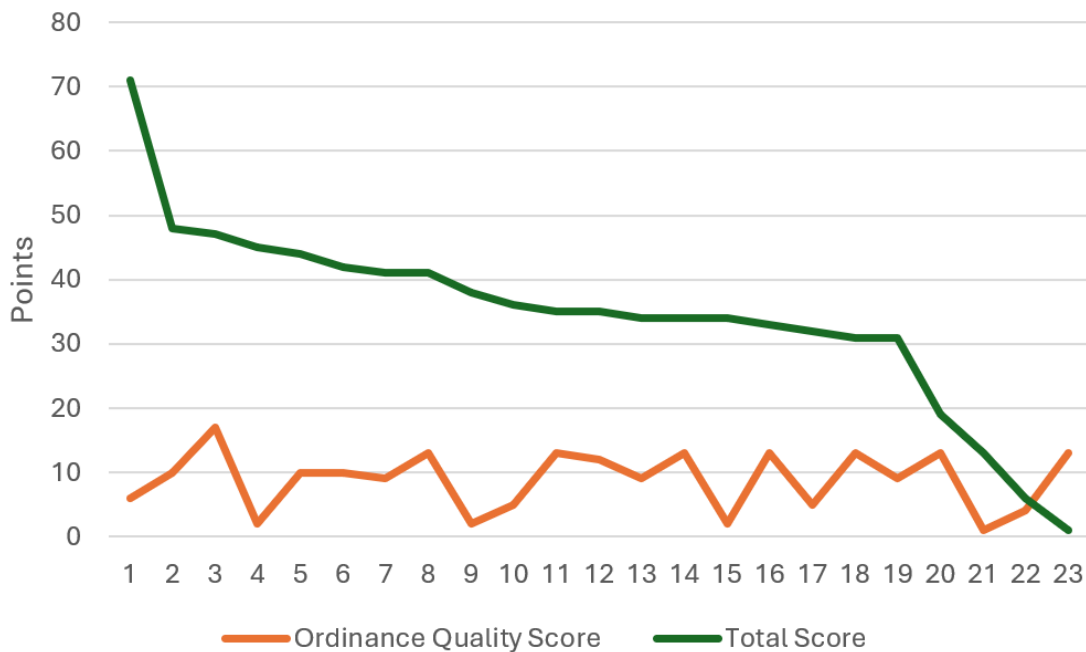


Figure 30. Plot of Ordinance Scores and Cluster Ranking Scores Across the 23 Locality Clusters of Undesignated Parking

For the cluster priority ranking analysis, 2 months of data were used. Datasets reflecting longer durations, such as 1 or 2 years, could be used in the future to supplement this analysis. Although additional data are certainly desirable, the methods here are applicable to both smaller and larger datasets.

CONCLUSIONS

- *Best practices with respect to local reviews of industrial developments include two main categories of elements.* The first category is a detailed review process with expectations for the traffic impacts, parking, routing, and amenities. The second category is a set of supporting local ordinances for each of these areas, such as proper turning radii (for traffic impacts), adequate staging space prior to delivery (for parking), compliance with a truck route plan (for routing), and lounge areas (for amenities).
- *The expansion of e-commerce-driven industrial developments and distribution centers has amplified the need for localities to update zoning ordinances.* The literature shows that industrial activity is encroaching on urban and suburban areas and that outdated zoning codes, which do not distinguish among different types of freight generators, and traffic impact methodologies contribute to negative impacts, including increased congestion, noise, and safety risks.
- *The Virginia review of ordinances indicates that localities exhibit uneven treatment of freight-related land use ordinances.* Although loading and parking are commonly addressed, most other categories show limited depth, particularly in the topics of storage, distribution, and congestion. Across appraised localities, 28 green, or highest scoring, results were observed in loading and 17 in parking but only 2 green results in distribution and 5 in storage. Congestion-related code elements were more often orange or red, lowest scoring, indicating limited guidance on mitigating industrial traffic impacts.
- *The moderate correlation of locality ordinance quality in Virginia and industrial site presence suggests that more industrialized localities are more likely to adopt detailed freight provisions in their zoning ordinances.* A Spearman ranking analysis showed a moderate positive correlation between locality code scores and the number of industrial sites within the locality.
- *Insufficient onsite parking at industrial facilities leads directly to undesignated parking on shoulders, ramps, and local streets, creating safety hazards and infrastructure damage.* Truck parking shortages continue to be an issue nationwide and have been intensified by the increase in distribution centers near urban areas. Best practices from multiple states show study recommendations requiring onsite or shared truck parking, driver amenities, and staging areas during the development review process for the purpose of reducing undesignated parking, improving efficiency, and increasing safety.
- *Undesignated parking in Virginia is not uniformly distributed and clusters around three roadway contexts: industrial queue, interchanges, and rest areas.* This pattern was identified using Geotab data and associated zone summaries (e.g., the I-66 Truck Park Area interchange in Warren County and the I-81 Safety Rest Area in Smyth County) and industrial queue contexts (e.g., Digital Drive in Chesterfield County and Clarion Road in Campbell County).
- *The priority scoring cluster analysis adapted for Virginia identifies interchange locations as the highest need based on the components of safety and undesignated parking instances and durations.* The highest scoring clusters include the I-66 Truck Park Area in Warren County

(total score of 71), I-64 and Lee-Jackson Highway in Augusta County (48), and the I-95 and I-295 interchange in Henrico County (47), all which are rest areas at interchanges and exhibit mid- to long dwell durations.

RECOMMENDATIONS

1. *VDOT's Transportation and Mobility Planning Division (TMPD) should create a task group to review the guidance in the Appendix of this report, revise where appropriate, and share with localities as recommended ordinance amendment language.* The findings of this research demonstrate the opportunity for localities to strengthen ordinance requirements and the review process for industrial developments.
2. *VDOT's TMPD should apply the method herein of using truck parking clusters to prioritize truck parking needs.* Ranking clusters can then be performed and prioritized for needs assessments and recommended improvements in SMART SCALE.

IMPLEMENTATION AND BENEFITS

The researcher and the technical review panel (listed in the Acknowledgments) for the project collaborate to craft a plan to implement the study recommendations and determine the benefits of doing so. This process is to ensure that the implementation plan is developed and approved with the participation and support of those involved with VDOT operations. The implementation plan and the accompanying benefits are provided here.

Implementation

Regarding Recommendation 1, TMPD will seek to form a task group to include appropriate locality, regional, and state agency representation and adopt with no changes or adapt with changes, in part or in whole, the guidelines as written within 1 year of publication of this report.

Regarding Recommendation 1, TMPD will share the guidelines with localities within 6 months of their adoption by the task group, either via a blanket share to all localities or a more directed share to those localities that had low ordinance quality scores (refer to Tables 23 and 25 in the Review of Virginia Ordinances section of this report).

Regarding Recommendation 2, by June 2027, TMPD will coordinate with the Office of Intermodal Planning and Investment (OIPI) to determine the feasibility of using truck parking needs to inform SMART SCALE scoring. This determination can be done by using the cluster analysis performed in this report, which produced a list of prioritized truck parking needs. If this effort is found to be feasible and has the necessary support, TMPD will coordinate with OIPI to incorporate truck parking needs into the SMART SCALE evaluation process.

Regarding Recommendation 2, another option, in addition to using the clusters evaluated for this study, is to expand the dataset. TMPD is currently working with an on-call consultant on

a task order to use the existing Stop Analytics data from Geotab to develop (1) a statewide truck parking inventory and (2) a parking demand analysis and needs assessment. If VTRC implementation funds are available, TMPD may request these funds to purchase data from Geotab for a longer period than what was used in this study to support the task order. With a longer evaluation period, sample sizes will increase, thus limiting the influence of privacy protections and improving data resolution.

Benefits

General

Projects that expand the availability of truck parking spaces generate benefits across multiple dimensions. The *Appalachian Regional Truck Parking Study* identifies five primary categories of benefits (Yuan et al., 2024):

- **Safety:** Fewer fatigue-related crashes and fewer crashes associated with undesignated or unsafe parking locations.
- **Environmental:** Reductions in emissions from avoided crashes and from improved driver productivity, including less circling or detouring in search of parking.
- **Mobility:** Reduced travel-time delays for the general public due to fewer crash-related disruptions, along with more efficient drive-time and rest-period management for truck drivers.
- **Vehicle operating cost savings:** Lower fuel consumption, reduced maintenance needs, and decreased asset depreciation resulting from fewer unnecessary miles driven.
- **State of good repair savings:** Reduced pavement wear and associated maintenance costs because of fewer miles traveled and less informal or shoulder parking.

Dowell et al. (2022) remark that, by making it easier for drivers to find safe, legal parking, these projects reduce both VMT (e.g., the distance traveled to reach a parking space) and the travel time (e.g., the time spent searching for a space). In addition to these direct benefits, Dowell et al. (2022) note that truck parking projects can also generate broader economic development impacts, including new jobs, increased income, and additional tax revenues, by:

- Lowering transportation and logistics costs that improve regional economic competitiveness.
- Attracting and retaining businesses that serve truck drivers near parking facilities, such as restaurants, repair shops, and retail establishments.
- Sustaining ongoing operations and maintenance activities associated with the parking facility.

Reduction in Crashes Due to Reduction in Undesignated Parking

The recommendations provided in this study translate directly to reducing undesignated parking by obtaining more concise parking data and developing recommendations for SMART SCALE applications (Recommendation 1) and by assisting localities with ordinance language to encourage onsite facility parking (Recommendation 2).

Quantitative Estimate of the Crash Cost Saving

One can make an argument that a better code, by leading to a reduction in the frequency of parking in undesignated spots, might lead to a reduction in parking-related crashes. An undesignated parking location—the shoulder of a last-mile connector to a freight generator in an origin-destination model, an undesignated spot at a roadside facility developed for emergency use (such as a rest stop), or an on- or off-ramp shoulder—is a place where a driver normally would not park. If one conceives of such a spot as a location where on-street parking is *prohibited*, then one may venture to model it as roughly equivalent to a location that is benefiting from the crash reduction factor (CRF) that a prohibition of on-street parking confers. Under this assumption, one may conceive of a certain percentage of trucks parking in the undesignated locations near a freight generator or a rest area as a certain percentage failure in compliance with the on-street parking prohibition and may postulate that this compliance failure “undoes” the same percentage of the benefits of the parking prohibition.

Three Numerical Examples

The first edition of the *Highway Safety Manual* assigns the countermeasure “Prohibition of On-Street Parking” a crash modification factor (CMF) of 0.72 (CRF of 28%) for all crash types of O severity and a CMF of 0.78 (CRF 22%) for all crash types of K, A, B, and C severity on the KABCO scale (KABCO = K - fatal injury, A - suspected serious injury, B - suspected minor injury, C - possible injury, O - no apparent injury) (American Association of State Highway Officials, 2010). The *Handbook of Road Safety Measures* assigns the countermeasure a CMF of 0.73 (CRF of 27%) for all crash types of O severity and a CMF of 0.80 (CRF of 20%) for all crash types of A, B, and C severity (Elvik et al., 2009). These CMFs and CRFs are based on crash counts from urban locations.

The modeling assumptions in the previous paragraph amount to a conjecture that the crash count at an undesignated location would be higher by a factor of $1/(1 - \text{CRF})$ if on-street parking were not prohibited and drivers parked at the location routinely.

Smyth County. By way of example, in the total sample of observations from Smyth County, 4.386% of truck parking occurred in undesignated locations (Table 31). One may conjecture that if motor vehicles *never* parked in undesignated spots, the crash counts at this location would reflect the full benefit of CRF equal to 20% or more (CRF associated with a prohibition of on-street parking, among the four CRFs cited previously). However, because 4.386% of the trucks in the neighborhood park in undesignated spots, 4.386% of the benefit of CRF is lost. In other words, the current crash count and the current crash cost are larger than they otherwise could be, by a factor of $(\text{Observed Crash Count}) / (100\% \text{ Compliance Crash Count}) = [1 - 20\% (1 - 4.386\%)] / [1 - 20\%]$. The additional benefit that might be realized if all trucks parked in designated spots would amount to $20\% \times (4.386\% / [1 - 20\% (1 - 4.386\%)]) = 1.085\%$ of the observed crash count and the observed crash cost at that location.

This study also examined in detail the parking patterns around three Smyth County intersections along I-81: Windsor, the Safety Rest Area, and the Nicks Creek Road intersection. During the 5-year period from 2021 to 2025, the vicinities of these intersections recorded 26 crashes involving trucks (on the KABCO scale, 1 K, 1 A, 2 Bs, and 22 Os). The updated crash

cost guidance from FHWA (2024) assigns these crashes a comprehensive cost of \$18,859,300—an average of \$3,771,860 per year. The benefit argument implies that if all trucks could be induced to park in designated spots at these locations, the crash cost savings would amount to 1.085% of these costs, or \$40,913.65 per year.

The benefit argument implies that if the Smyth County ordinances were revised according to the guidelines recommended in this report, to a sufficient extent to raise the county's code quality score by 1 point (that is, from 2 to 3), the percentage of trucks that park in undesignated spots would fall by 0.096%, from the 4.386% observed in this study to 4.290%. This small improvement in relevant sections of code would be predicted to capture a fraction $(0.096/4.386)$ of the crash cost savings previously estimated, or \$894.24 per year.

Pulaski County. In the total sample of observations from Smyth County, 0.742% of the truck parking occurred in undesignated locations. This study also examined in detail the parking patterns around two Pulaski County intersections along I-81: Cleburne and Claytor Lake State Park. During the 5-year period from 2021 to 2025, the vicinities of these intersections recorded 11 crashes involving trucks (on the KABCO scale, 1 A, 3 Bs, and 7 Os). The updated crash cost guidance from FHWA (2024) assigns these crashes a comprehensive cost of \$2,983,800—an average of \$596,760 per year. The benefit argument implies that if all trucks could be induced to park in designated spots at these locations, the crash cost savings would amount to $20\% \times (0.742\%) / [1 - 20\% (1 - 0.742\%)] = 0.185\%$ of these costs, or \$1,104.70 per year.

A 1-point improvement in the code quality score of Pulaski County's ordinances (from 5 to 6) would be predicted to reduce the percentage of trucks that park in undesignated spots from 0.742% to 0.646%. This small improvement would be predicted to capture a fraction $(0.096/0.742)$ of the crash cost savings previously estimated, or \$142.77 per year.

Henrico County. In the total sample of observations from Henrico County, 0.335% of the truck parking occurred in undesignated locations. This study also examined in detail the parking pattern around one Henrico County intersection, where I-95 and I-295 cross one another. During the 5-year period from 2021 to 2025, the vicinity of this intersection recorded 196 crashes involving trucks (on the KABCO scale, 2 Ks, 11 As, 28 Bs, 5 Cs, and 150 Os). The updated crash cost guidance from FHWA (2024) assigns these crashes a comprehensive cost of \$65,222,100—an average of \$13,044,420 per year. The benefit argument implies that if all trucks could be induced to park in designated spots at these locations, the crash cost savings would amount to $20\% \times (0.335\%) / [1 - 20\% (1 - 0.335\%)] = 0.08375\%$ of these costs, or \$10,942.70 per year.

A 1-point improvement in the code quality score of Henrico County's ordinances (from 17 to 18) would be predicted to reduce the percentage of trucks that park in undesignated spots from 0.335% to 0.239%. This small improvement would be predicted to capture a fraction $(0.096/0.335)$ of the crash cost savings previously estimated, or \$3,123.88 per year.

Summary

Smyth, Pulaski, and Henrico Counties were chosen as examples because these counties exhibited a range (high, medium, and low) of code quality scores, crashes, and percentages of

undesigned parking across the localities selected for further examination. Table 33 shows a summary of the benefit calculations for Smyth, Pulaski, and Henrico Counties. For the purposes of determining the estimated benefits of eliminating undesigned truck parking in localities throughout Virginia (with emphasis on those along the freight corridors) and based on assumptions and methodologies described previously, the total average yearly benefit per locality is estimated at \$17,654 for crashes (i.e., if all undesigned parking were moved to designated parking). Because a correlation exists between better local ordinance quality and less undesigned parking, Table 33 also shows a \$1,387 crash reduction benefit for each 1-unit increase in ordinance quality score.

Table 33. Summary of the Benefits for Smyth, Pulaski, and Henrico Counties

County	Crashes	Crash Type (count)					Average Annual Cost of Crashes	Average Yearly Benefits (per locality)	
		K	A	B	C	O		Eliminate all undesigned parking ^a	Eliminate some undesigned parking ^b
Smyth	26	1	1	2	-	22	\$3,771,860	\$40,914	\$894
Pulaski	11	-	1	3	-	7	\$596,760	\$1,105	\$143
Henrico	196	2	11	28	5	150	\$13,044,420	\$10,943	\$3,124
Total	233	3	13	33	5	179	\$17,413,040	\$52,962	\$4,161
Average	78	1	6	11	2	60	\$5,804,347	\$17,654	\$1,387

KABCO = (K) - fatal injury, (A) - suspected serious injury, (B) - suspected minor injury, (C) - possible injury, (O) - no apparent injury. ^a Assuming all undesigned parking moved to designated parking; ^b Assuming a 1-unit increase in total ordinance quality score, which will eliminate some, but not all, undesigned parking.

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APPENDIX

Best Practice Guidance for Local Reviews of Industrial Developments

The integration of warehouse and distribution centers into industrial-zoned properties requires deliberate design, mitigation, and management (Felix and Pollack, 2021). Localities should be diligent in examining both existing and neighboring land uses and those planned and zoned for the future use to avoid creating land use conflicts. High-intensity freight land uses, both in terms of trip generation numbers and square footage, can be appropriately located if they are planned for thoroughly. To avoid truck traffic spilling over into adjoining neighborhoods or trucks parking in undesignated locations, freight movement and access must be addressed in site plan reviews (LVPC, 2022). According to Felix and Pollack (2021), a comprehensive site plan review and approval process should address the adequacy of the following:

- Building design.
- Parking and loading facilities.
- Proposed number and type of parking spaces.
 - Parking demands by functional use.
- Traffic flow, circulation, and traffic impact.
 - Access points and routes to and from the site to adjoining streets.
 - Pedestrian and bicycle circulation systems to and from parking areas and structures.
- External lighting.
 - Type and amount to be provided.
- Landscaping and screening.
 - Type, quality, and quantity to promote an aesthetically pleasing environment and to properly screen the development from adjacent land uses.
- Stormwater.
 - Method of surface drainage.
- Utilities.
 - Methods of waste disposal (e.g., sewage and refuse) and water distribution.
- Snow removal and storage.
- Protection and enhancement of natural features.
- Compatibility of architecture with the surrounding rea.

The New Jersey Office of Planning Advocacy (NJOPA) developed draft detailed model ordinance language to help municipalities regulate more precisely the approval and construction of large warehouses (100,000 to 350,000 square feet) within their boundaries (NJOPA, 2024). Specifically, the sample language requires developers of large warehouses and distribution centers to apply for conditional use approval. According to NJOPA (2024), municipalities can use the guidance as written or tweak where necessary. Written in the preface of the model ordinance language:

This document is a tool to aid municipalities in amending their zoning and land use ordinances, and the language provided herein is intended to serve only as guidance to assist municipalities in drafting ordinances. Each municipality should consider these suggestions in light of its own unique planning needs and circumstances and in conjunction with other relevant sources. Any

ordinances designed to address large warehouses must also comply with all other municipal, county, State, and statutory restrictions and requirements related to land use and planning. All language should be reviewed carefully and in consultation with the municipality's legal counsel to ensure accuracy and consistency with each municipality's current code. All ordinance changes and updates should be in accordance with the Municipal Land Use Law N.J.S.A. 40:55D-1 et. seq.

The topics of ordinance requirements developed in New Jersey's model ordinance language are similar to those recommended by Felix and Pollack (2021) and the Townships of Moore (2025), Forks (2025), and Upper Macungie (2026) in Pennsylvania and can be adopted (and adapted where necessary) as guidance from VDOT to Virginia localities. The model ordinance language that New Jersey recommends as amendments to municipality ordinances contains three sections: (1) Definition of a Warehouse; (2) Warehouses as Permitted Uses; and (3) Warehouses as Permitted Conditional Uses (NJOPA, 2024).

Section I. Definition of a Warehouse

If the municipal code includes a definition of warehouse, this section should cite the current code and its section that lists the warehouse definition and state that it "shall be amended by deleting the definition of warehouse in its entirety and shall now read as follows," and then proceed with the language below.

If the municipal code does not currently include a definition of warehouse, this section should state that the code "shall be amended at" the appropriate section "to add the definition of warehouse" and proceed with the language below. If the municipal code does not include a definition of "sensitive receptors" this should be added in the Land Use definitions section "Sensitive receptors include, but are not limited to, hospitals, schools, daycare facilities, elderly housing, recreational playgrounds, athletic, and playing fields for children and convalescent facilities. These are areas where the occupants are more susceptible to accidents and the adverse effects of exposure to toxic emissions, pesticides, and other pollutants."

WAREHOUSE – A building or group of buildings/structures/centers/facilities primarily involved in the receipt of products and materials and their indoor storage, separation, processing, fabrication, transfer, or wholesale distribution, including order fulfillment, accessory transshipment facilitation, and related "last-mile" activities, but not including a truck terminal. The term warehouse shall include distribution facilities, fulfillment centers, logistics facilities and similar uses, including e-commerce activities.

Section II. Warehouses as Permitted Uses

This section should cite the current municipal code section that lists uses permitted by right in the Industrial (I) Zoning District and, using language that conforms with the current code, state that it shall be amended to restrict the maximum size of a warehouse as a permitted use to no more than 100,000 square feet.

Section III. Warehouses Permitted as Conditional Uses

This section should cite the current municipal code section that lists the conditional uses permitted in the Industrial (I) Zoning District and, using language that conforms with the current code, state that it shall be amended by adding a warehouse greater than 100,000 square feet and up to 350,000 square feet as a conditional use.

The following shows the structure of the Section III of New Jersey’s model ordinance language (NJOPA, 2024). As relevant to this research, specific topic areas on traffic, parking, routing, and amenities from Section III are provided herein, including an applicant narrative that provides details on application requirements. For official adoption of ordinance language, “Whereas Clauses” from New Jersey’s model ordinance language are provided at the end of the Appendix and can be referenced as model language for Virginia localities with adaptations where necessary (NJOPA, 2024). It is important to reiterate that the language given is considered a guide to aid localities when amending zoning and land use ordinances and tweaks may be made by any locality when deemed necessary.

1. Special area, height, and other bulk requirements.
 - a. Minimum lot area.
 - b. Lot width.
 - c. Lot frontage.
 - d. Lot depth.
 - e. Maximum building coverage.
 - f. Impervious coverage.
 - g. Land area ratio.
 - h. Floor area ratio.
 - i. Building height.
 - j. Minimum building setbacks (warehouse and industrial or residential).
 - k. Setback widths.
2. Measurement of buffer yards.
 - a. Footprint of principle structure: 100,000–250,000 square feet.
 - b. Footprint of principle structure: 250,000–350,000 square feet,
3. Buffer yard and landscaping requirements.
4. Berm requirements.
5. Circulation (site lines, access points, pedestrian accommodations, traffic control plans).
6. Traffic impact study
7. Truck route plan.
8. Off-street parking, loading, staging spaces, and loading docks.
9. Sustainability (electric vehicle charging, electric vehicles, sustainable infrastructure designs).
10. Stormwater management.
11. Miscellaneous (submission guidelines, dumpster enclosures, public safety requirements).
12. Narrative: nature and activities of site, hours of operation, general scale of operation, adequacy of parking, loading, and staging spaces.
13. Submission requirements.
 - a. Environmental impact statement.
 - b. Community impact statement.
 - c. Noise impact analysis.
14. Architectural design standards.
15. Facility amenities design standards.

Applicant Narrative

An applicant shall provide a written narrative and additional supporting information, documentation, studies, and reports as required that contain detailed descriptions of the proposed use, including type warehouse, and substantive evidence demonstrating consistency of the proposed use relative to each of the following topics:

1. The nature of all activities and operations to be conducted on the site, the types of materials to be stored, the duration of storage of materials, and the methods for disposal of any surplus or damaged materials. In addition, the applicant shall furnish evidence that the disposal of materials will be accomplished in a manner that complies with applicable state and federal regulations.
2. Hours of operation and the times and frequency of deliveries, distributions, and restocking.
3. The general scale of the operation in terms of its market area, specific floor space requirements for each activity, and the total number of employees on each shift.
4. Consistency of the proposed use, with each of the general standards for conditional use as set forth in Sections 1 through 11.
5. Consistency of the proposed use with site plan reviews and subdivision of land relative to any environmental or other effects (e.g., odor, noise, smoke, dust, litter, glare, vibration, electrical disturbance, wastewater, stormwater, solid waste, flood hazard areas, steep slopes, threatened and endangered species, and environmentally sensitive habitat) that are likely to result from the use and any specific measures to be employed to mitigate or eliminate any such negative effects.
6. Adequacy of the number, size, and location of loading and staging spaces provided for trucks to accommodate the expected demand generated by the use, including both pre- and post-loading activities.
7. Adequacy of off-street staging spaces available for tractor trailers arriving during non-business hours to prevent vehicles from parking on public streets while waiting to access the facility.
8. Adequacy of off-street staging spaces available at facility entrances to prevent vehicles from queueing on public streets while waiting to access the facility.

Traffic Impacts

Traffic Impact Studies

According to Felix and Pollack (2021), at a minimum, traffic impact studies should include projecting trips for all vehicular types (e.g., employee vehicles, vans, trucks, and flex drivers), site design (ingress, egress, and circulation), accommodations for pedestrians and bicyclists, and amount of parking. The results of the studies have a direct association with frequently expressed traffic concerns from residents regarding warehouses and distribution centers, including the following:

- Queuing, traffic, and idling on site and in the community.
- Trucks and vans using residential streets and trucks accessing bridges with low underpasses.

- Vehicles overwhelming gas stations when shifts begin or end.
- Illegal offsite parking.
- Vans pulled off to the sides of roads creating hazardous conditions for drivers to pass.
- Processions of trucks and vans causing traffic at key intersections

To better project trips for e-commerce type warehouse and distribution facilities, Felix and Pollack (2021) note that the Metropolitan Area Planning Council in Boston recommends the application of empirical trip data. This suggestion is because the Institute of Transportation Engineers (ITE) *Trip General Manual* does not include data for such land uses (ITE, 2025), and although the ITE Land Use Codes for Industrial Park (140), Warehousing (150), High-Cube Fulfillment Center Warehouse (155), and High-Cube Parcel Hub Warehouse (156) are related, they are not an exact match.

In the cases with traffic impact fee ordinances, Northampton’s guidance suggests that, before incurring the upfront costs of implementing a transportation impact fee ordinance, municipalities should consider several issues related to existing traffic conditions and projected land development activity to help determine whether the investment would indeed be worthwhile (LVPC, 2022). A municipality should conduct a feasibility or cost-benefit analysis of these issues before proceeding with the implementation of an impact fee ordinance. The analysis should focus on the following:

- Future land use projections.
- Review of proposed road improvements.
- Traffic volumes and roadway capacity.
- Potential revenue generation from impact fees.

Model Ordinance Language

New Jersey’s model ordinance language provides specific clauses related to traffic impact studies (NJOPA, 2024), as the following describes.

1. The applicant shall provide a traffic impact statement based on a traffic impact study at the time of the application submission.
2. The traffic impact study shall be prepared by a professional engineer, licensed in the State of XX, and it shall contain the requisite information as set forth in section XX of the XX code. In addition, the traffic impact study shall provide the following information:
 - a. A truck and automobile trip analysis that should include peak and off-peak hours.
 - b. An ingress and egress management plan to prevent queuing on adjacent roads in the event of restricted access (i.e., manned gate or swipe entry).
 - c. Identification of all on and offsite transportation impacts, including vehicle, truck, pedestrian, multimodal, and transit access.
 - d. Identification and quantification, including costs, of improvements necessary to address identified conflict points, diminished levels of service, and other related transportation capacity concerns along these routes.
3. Evaluation of the extent to which anticipated or planned truck routes will not be followed and provision of recommended strategies, with assistance and input from the locality,

transit agency, and department of transportation (DOT) as appropriate, to address and mitigate those possibilities where reasonably warranted.

4. Large format warehouses greater than 200,000 square feet that are anticipated or likely to have negative effects on adjacent or nearby communities shall include a narrative section outlining how and to what extent the proposed truck routes outside the hosting municipal boundaries will affect neighborhoods, downtowns, and sensitive receptors outside the localities boundaries and send a copy of this evaluation to the neighboring locality or localities, the locality Division of Planning, and DOT at least 30 days before the project is heard.
5. Where road widening or expansion is proposed, identification of environmental impacts (e.g., flooding, runoff, degradation of water, and other natural resources) and mitigation measures shall be provided.
6. The extent to which the configuration of the roads and the geometry of the existing turnarounds, ramps, circles, or exits allow for unimpeded movement of the additional traffic.
7. The extent to which the standards and road design of the secondary road network provide the proper turning radii and overpass clearances for the proposed traffic increase.
8. The extent to which the road design of the secondary route is constructed to handle the proposed increase in traffic loads.
9. The extent to which the standards and road design allow for compatibility with freight movements and a Complete Streets design, where appropriate.
10. The extent to which the condition and design of the road prevent structural damage to adjacent structures.

Parking

An ATRI (2024) study found that 50% of facilities on average do not allow drivers to park while waiting to load or unload. This policy leads to drivers having to park in undesignated or potentially unsafe areas elsewhere, as well as losing additional productivity traveling to and from the facility. To help address parking needs, New Jersey proposed the following model ordinance language as it relates to off-street parking, parking setbacks, staging, storage, and loading (NJOPA, 2024). Additional language from Dowell et al. (2022) on exceptions to parking requirements is also provided.

Off-Street Parking

1. Off-street parking shall be provided through driveways. Driveway widths for a warehouse may exceed the maximum requirement established by Article XX of the Locality's off-street parking schedule; however, no driveway width shall exceed 50 feet.
2. Parking areas shall be limited to a maximum of 25% at the front yard area.
3. This use shall reserve a minimum of 5% of the proposed total tractor trailer parking space for outbound trucks that are required to layover or rest because of hours-of-service regulations. Such spaces must be made available to tractor trailers during or after the facility's operating hours as necessary.
4. The facility's parking and driveway layout shall be designed to reduce mixing truck, car, bicycle, and pedestrian traffic, particularly in areas where cars and bicycles would have to maneuver around or through truck loading and unloading areas.

5. Driveways and internal drive aisles shall be designed with adequate widths and turning radii to allow tractor trailers to complete turning maneuvers while remaining within their designated travel lanes. Turning templates shall be provided for all anticipated vehicle types and routes.
6. Minimum off-street parking for distribution and warehouse facilities shall be provided in the amount of one (1) space per 2,000 square feet of gross floor area.
7. For warehouses where office space is accessory to the principal use at no more than 10% of the total floor area, the off-street parking requirements shall be inclusive of both uses. Where the amount of office space exceeds 10% of the total floor area, one (1) parking space shall be provided for each 300 square foot of office space floor area that exceeds 10% of the total floor area.
8. Understanding that advancements in technology will continue to shape development, such as through automation, e-commerce-based delivery applications, and the likely introduction of self-driving cars, it is entirely possible that the parking standards herein may exceed the realities of market demand. The approving board may grant a request by an applicant to bank up to 25% of the required spaces for potential future development should demand require.
9. Parking lots shall be landscaped to break down scale, provide user comfort, and to modulate microclimate.

Parking Setbacks

1. Parking for automobiles and light trucks shall be a minimum of 60 feet from external rights-of-way and property lines, unless the buffer requirement is greater than 60 feet. In all cases, the buffer requirement supersedes the parking setback requirement.
2. Parking for automobiles and light trucks may be reduced at the discretion of the planning board to a minimum of 25 feet from external rights-of-way, 25 feet from the rear yard property line, and 20 feet from any side yard property line when within densely developed urban areas that are classified as planning areas as defined by planning area boundaries.
3. Parking for semi-trailer trucks shall be a minimum of 150 feet from external rights-of-way and property lines except as all drive aisles, loading and unloading areas, and parking areas intended for use by tractor trailers, and outdoor storage areas shall be a minimum of 250 feet from any residential use, school, daycare, place of worship, overburdened community, park, or recreational facility.
4. No parking or loading areas shall be within 200 feet of any lot line shared with any existing residential property line or zone, school, daycare, hospital, place of worship, overburdened community, designated park, or open space.
5. Bicycle parking should be visible, accessible, easy to use, and convenient. Racks need to support the whole bike and enable the user to lock the frame and wheels of the bike with a cable or U-shaped lock. Preferably, bike parking would be covered, well lit, and in plain view without being in the way of pedestrians or motor vehicles.

Staging, Storage, and Loading

1. All staging and loading and unloading areas intended for tractor trailer use and outdoor storage shall be a minimum of 250 linear feet from an existing residential property line or

zone, school, daycare, place of worship, overburdened community, park, or recreational facility.

2. Staging spaces: Two (2) 12-ft. x 75-ft. truck staging spaces for each loading dock shall be required. A minimum of 5% of required truck staging spaces shall be reserved for outbound trucks required to layover or rest because of hours-of-service regulations. Such spaces must be accessible during and after the facility's operating hours as necessary.
3. Loading spaces: One (1) 12-ft. x 75-ft. truck loading space for each loading dock.
4. Loading docks: The minimum number of loading docks shall be determined using the following calculation:
 - a. The number of trucks per hour (at the peak hour of the use) multiplied by the turnaround time per truck (in hours) = the number of required docks.
 - b. The number of docks determined by the previous formula shall then be rounded up to the next whole number.
 - c. By way of example, if 17 trucks are required to be serviced during the peak hour of the use, and each requires 45 minutes (0.75 hours) to service, it equates to 17 trucks per hour x 0.75 hours per truck = 12.75 docks required, rounded up to 13 docks. In the event a particular tenant has not been identified for the facility, a minimum of one (1) loading dock shall be provided per 5,000 square feet of building gross floor area.
5. An application shall indicate designated snow storage areas of sufficient size and at appropriate locations on the site. Snow storage areas shall not include any areas necessary to meet minimum parking, staging, or loading space requirements.
6. No storage of garbage (other than what is routinely produced on site and awaiting regular collection) shall be permitted.

Exceptions to Parking Requirements

The following language demonstrates options for allowing exceptions to parking requirements (Dowell et al., 2022):

1. To prove that fewer parking spaces are needed, the applicant shall provide existing and projected employment, customer, resident, or other relevant data. Such data may include a study of parking at similar developments during peak periods of use.
2. An applicant may seek to prove that parking permanently shared with another use or another lot with shared internal access will reduce the total amount of parking needed because the uses have different peak times of parking need or overlapping customers.
3. Parking areas for trucks may be shared between adjacent business. An industrial development with multiple businesses may provide a consolidated parking area for truck staging and parking serving all uses.
4. If this section permits a reduction, the reservation of areas for use in future parking may be required permanently or for a specified number of years:
 - a. Reservations should be legally documented, such as in a binding deed restriction.
 - b. Plans should be submitted showing where and how additional parking could be accomplished.
 - c. The lot owner shall be required to provide such additional parking within 1 year after notification that such parking has become needed. Such determination shall be based on an onsite review on least 3 different days.

Routing

To minimize logistical and traffic issues, Felix and Pollack (2021) recommend that parking for all vehicular operations remain on site. It is critical that the onsite circulation plan be designed to reduce potential conflicts with different vehicle types, pedestrians, and bicyclists and to minimize vehicles queuing in the street. In addition, restricting truck and van access during certain times of day or days of week may be appropriate in cases such as where warehouses are adjacent to residential areas. This measure can reduce congestion and the road impacts of the facility on nearby neighborhoods. New Jersey suggests the following model ordinance language for truck route plans (NJOPA, 2024):

1. The applicant shall submit and comply with a truck route plan and map identifying anticipated routes and supporting signage proposed to and from the facility to the nearest arterial roads, highway interchange, and locality boundary, consistent with the data presented in the traffic impact study section.
2. The truck route plan shall further outline how truck drivers will be instructed on the acceptable travel routes (relative to the class of vehicle) that serve to prohibit and keep semi-trailers away from residential neighborhoods, retail commercial centers, school zones, daycare centers, places of worship, and overburdened communities, including the installation of signs in these areas where deemed necessary by the approving planning board, noting that truck and employee parking is prohibited.
3. The truck route plan shall propose:
 - a. The extent to which traffic will be diverted, either on a regular basis or on an alternate route basis, into neighboring municipalities in scenarios including but not limited to instances of nuisance flooding or major storm events where site accessibility issues arise.
 - b. Strategies that will be put in place to prevent unsuited alternative routes from becoming the “go-to” route.
 - c. Strategies that will be put in place to prevent highway toll road avoidance resulting in undesirable routes being favored.

Amenities

A Huffman and Shirk (2024) study found that 39.1% of women truck drivers and 23.1% of men truck drivers reported having limited to no access to restroom facilities on a daily basis. Requiring facilities to provide restroom access can be accomplished through locality ordinances or state and federal legislation (ATRI, 2024). NJOPA (2024) recommends localities include amenities in ordinance facility design standard language, whereby an applicant should detail the amenities that will be provided for truck drivers and operators using the facility in addition to any similar amenities provided to onsite employees. The suggested language is the following:

1. The amenities shall include, at a minimum, one driver and operator lounge for the first 30 truck loading and unloading docks and doorways included in the application. Each driver-operator lounge shall include restroom facilities with showers, sleeping areas, an entertainment area, and dispensing machines or other facilities to provide food and beverages. The lounge area should be available during operational hours or when overnight parking is allowed.

2. At least one additional driver-operator lounge for every additional 30-truck loading and unloading docks and /doorways shall be included in the application.
3. Each amenity shall contain no less than one seat per 10 docks and doorways, with a minimum area to accommodate six seats and one four-person table.
4. At least one 12-ft. x 75-ft. truck parking space shall be provided per each required lounge seat of the amenity, in addition to the required parking in the Staging, Storage, and Loading section. Such parking spaces shall be provided in close proximity to the amenity and in a suitable, safe, and separately defined location.
5. Electrical outlets shall be provided for drivers and operators to use at each amenity parking space.
6. Appropriate signage shall be provided directing trucks to park in the designated amenity parking spaces while awaiting access to a loading or unloading dock or doorway, unless all such spaces are already occupied.
7. Mechanical scraper systems shall be installed at each truck exit for the purpose of removing snow, slush and ice from trailer and truck rooftops. During winter months, all trucks must pass under these mechanical scrapers prior to exiting the warehouse facility.

Whereas Clauses for Adopting Ordinance

(Adopted and adapted from NJOPA [2024])

WHEREAS, the XX Locality Planning Board adopted comprehensive updates to the Master Plan that supports several recommended zoning changes throughout the Locality.

WHEREAS, the Locality Committee of XX Locality, XXX County, Virginia (“Locality Committee”), consistent with the comprehensive updates to the Master Plan adopted in XXXX, finds that to avoid potential adverse effects on local roads and intersections, residential and mixed-use neighborhoods, retail commercial development primarily serving the municipality, sensitive receptors, and the character and general welfare of the Locality, the most appropriate location for large-format distribution facilities and warehouses is and should be limited to the Industrial (I) Zoning District.

WHEREAS, the Locality Committee of XX Locality, XXX County, Virginia (“Locality Committee”), consistent with the comprehensive updates to the Master Plan adopted in XXXX, finds that to avoid potential adverse effects on local roads and intersections, residential and mixed-use neighborhoods, retail commercial development primarily serving the municipality, sensitive receptors, and the character and general welfare of the Locality, the most appropriate location for large-format distribution facilities and warehouses is and should be limited to the Industrial (I) Zoning District.

WHEREAS, the Locality Committee, also consistent with the comprehensive updates to the Master Plan adopted in XXXX, finds that requiring the use of large-format distribution facilities and warehouses within the Locality be approved as conditional use, with special design and site requirements and operating characteristics, to avoid potential adverse effects on local roads and intersections, residential, mixed-use neighborhoods and retail commercial development primarily

serving the municipality, sensitive receptors, and the character and general welfare of the Locality.

WHEREAS, the Locality Committee believes the most appropriate location and means for regulating large-format distribution facilities and warehouse use is as a permitted conditional use in the Industrial Zoning District.

WHEREAS, the Locality Committee has supplemented the Locality's permitted conditional use by adding warehouse use and related conditions, which apply to warehouses greater than 100,000 square feet up to 350,000 square feet to the Industrial (I) Zoning District, where the use shall be permitted only as conditional use.

WHEREAS, the Locality Committee further finds that this amendment to the Locality's Land Development Ordinance is substantially consistent with the land use plan element and the housing plan element of the Locality's Master Plan.

WHEREAS, the Locality Committee further finds that this amendment to the Locality's Land Development Ordinance bears a real and substantial relationship to land regulation within its boundaries.

WHEREAS, the Locality Committee further finds that the public interest of the Locality will be served by amending the Locality's Land Development Ordinance in the manner set for the herein.