

Article

A GIS-Based Planning Methodology for Prioritizing Highway Corridors for New Truck Stops from a Safety Perspective

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Abstract

Most truck stops in rural areas are located along high-demand highway corridors, consistent with current methods based on capacity and demand models. However, these models underestimate the safety aspect, failing to detect highway corridors with low traffic demand and low truck stop accessibility. This study proposes a Geographic Information System (GIS)-based planning methodology to identify highway corridors affected by atypical crash rates involving commercial trucks and truck stop shortages. The proposed methodology defines two indexes to measure commercial truck safety and truck stop supply, serving as a basis for identifying four levels of need for new truck stops using reclassification and map algebra techniques. Results reveal that the identified highway corridors exhibit atypical crash rates and largely coincide with areas of low truck stop accessibility and low to moderate truck demand. Thus, the methodology introduces an important component, truck safety, in identifying new parking locations, usually dismissed by existing models.

Keywords: truck stop; safety; commercial vehicle; crash; highway; GIS

1. Introduction

Truck stops in rural areas are parking facilities intermittently located along highway corridors. They serve as long-term spots where truck drivers can rest and satisfy other essential needs. Recently, several surveys and studies have documented truck parking shortages existing in various corridors along the national highway system in the United States (U.S.) [1–4]. For example, approximately 72% of state Departments of Transportation (DOTs) have reported problems with commercial truck parking in their states [4]. Most recent efforts to address this issue have stemmed from Jason's Law, passed in late 2012, which allowed for increased federal funding to improve truck parking facilities as a national priority [4]. Nevertheless, truck parking shortages continue to be a problem for truck drivers who experience difficulties finding parking, especially during nights and weekends [5–7]. When no parking spaces are available, truck-drivers often park along the entrance and exit ramps and shoulders of highways to meet federal Hours of Service (HOS) regulations, increasing the crash risk to other motorists [4,5,8]. Most existing parking facilities are located along high-demand highway corridors [4]. This is consistent with existing truck stop guidelines, which are primarily based on capacity and demand models [3,4,9,10]. However, existing truck stop site location methodologies have not comprehensively incorporated



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safety considerations. Additionally, current approaches may overlook highway corridors characterized by low traffic demand. As a result, such low-demand corridors are often deficient in an adequate number of truck stops. This scarcity can lead to elevated risks of atypical commercial truck crashes, often attributable to insufficient truck parking and increased driver fatigue, thereby raising the probability of truck drivers becoming involved in collisions [1,11–13]. On the other hand, few studies have explored the spatial association between truck stop accessibility and commercial truck crashes to justify the inclusion of crash analysis as an essential criterion for defining the location of potential new truck stops [11,14].

Truck stop shortages on highway corridors can lead to higher crash rates due to driver fatigue, which is a major cause of commercial motor vehicle crashes [12,15,16]. GIS spatial analysis can help identify highway corridors that are affected by truck stop shortages from a truck safety approach. The primary objective of this study is to propose a GIS-based methodology for identifying truck stop shortages in the highway network from a safety perspective. The methodological contribution of this study extends beyond the application of GIS as a mapping tool. The proposed framework introduces a reproducible GIS-based planning methodology that integrates commercial truck safety and truck stop accessibility through two original exposure-normalized indicators for highway corridor prioritization. Unlike existing methodologies, which primarily rely on freight demand or optimization techniques for facility siting, the proposed approach incorporates safety as an explicit planning criterion while relying on transportation datasets routinely maintained by highway agencies, thereby facilitating practical implementation. The methodology is intended as a first-stage, network-level screening framework for identifying highway corridors where additional truck parking infrastructure may be warranted from a safety perspective. Once priority corridors have been identified, existing Multi-Criteria Decision-Making (MCDM) methodologies can subsequently be applied to determine the optimal location of individual truck stop facilities within those corridors.

The approach of this study is to illustrate the proposed GIS-based methodology through a case study in rural Texas. Texas has the maximum length of roadways and the experiences the highest rate of traffic accidents caused by driver fatigue in the U.S. [1,17]. This key statistic heavily influenced our decision to select Texas as the ideal case study for implementing this novel methodology. Ultimately, this methodology empowers analysts to identify the highway corridors in the region of interest where future truck stops should be strategically located from a safety perspective.

The remainder of this paper is structured as follows. Section 2 reviews the literature related to truck parking shortages, commercial truck safety, fatigue-related crashes, and existing approaches for truck stop location planning. Section 3 presents the proposed GIS-based methodology, including the study area, data requirements, processing procedures, core model formulation, and analytical framework used to identify truck stop needs from a safety perspective. Section 4 presents the spatial analysis results obtained for the trunk highway system in rural Texas, and discusses the principal findings, practical implications, and contributions of incorporating safety considerations into truck stop planning. Finally, Section 5 summarizes the main conclusions and outlines directions for future research.

2. Literature Review

2.1. Truck Driver Fatigue and Commercial Truck Safety

Driver fatigue is widely recognized as a major contributor to commercial truck crashes. The Large Truck Crash Causation Study conducted by the U.S. Department of Transportation identified fatigue as one of the principal factors associated with truck-related crashes [18]. It has been estimated that fatigue and drowsiness contribute to approx-

imately 328,000 crashes annually in the United States, resulting in 6400 fatalities and 109,000 injuries [17,19]. Furthermore, the National Academies of Sciences, Engineering, and Medicine estimated that between 10% and 20% of all truck and bus crashes are related to driver fatigue [12].

To mitigate fatigue-related risks, several strategies have been proposed, including health programs, fatigue management systems, advanced driver assistance technologies, and safety interventions targeting commercial drivers [15,16,20,21]. Within this context, truck stops constitute critical infrastructure by providing drivers with safe and convenient locations for rest and recovery [22,23].

The importance of truck parking is closely linked to Hours of Service (HOS) regulations. According to the Federal Motor Carrier Safety Administration, truck drivers may generally remain on duty for up to 14 h, including no more than 11 h of driving and a maximum of 8 consecutive hours of operation without a break, followed by at least 10 consecutive hours off duty [24,25]. Previous studies have reported that requirements such as the 34 h restart provision and mandatory rest breaks significantly influence truck parking demand [4]. Consequently, an adequate supply of truck parking facilities is essential to support regulatory compliance and reduce fatigue-related safety risks.

The safety implications of commercial truck crashes are substantial. Between 2008 and 2020, fatalities associated with large-truck crashes increased by 14.1%, rising from 4245 to 4842 deaths annually in the United States [26]. Beyond human consequences, truck crashes impose considerable economic costs. In Oregon, the average cost per crash ranges from \$18,342 for property-damage-only incidents to more than \$4.3 million for fatal crashes [3], while comparable estimates in Texas are approximately three times higher [27]. These statistics underscore the importance of identifying strategies capable of reducing commercial truck crashes associated with fatigue and insufficient parking opportunities.

2.2. Truck Parking Shortages and Existing Planning Approaches

Truck parking shortages have become a persistent concern throughout the United States. Surveys conducted by the Federal Highway Administration indicate that approximately 72% of state transportation agencies report truck parking deficiencies within their jurisdictions [4]. Despite increased attention following the enactment of Jason's Law in 2012, which established truck parking as a national transportation priority, shortages continue to affect many highway corridors [4]. For instance, recent evidence from Nebraska indicates that truck parking shortages continue to rank among the most important concerns in the trucking industry [8]. Similarly, recent surveys indicate that truck drivers frequently experience difficulties locating available parking, particularly during nighttime and weekend periods [5–7]. Such difficulties can increase working hours and generate substantial stress and fatigue among long-haul truck drivers [28].

The FHWA report Jason's Law Truck Parking Survey Results and Comparative Analysis (2015) reviewed the principal methodologies used to evaluate truck parking adequacy and identified six general approaches: facility-based models, corridor-based models, corridor-based models incorporating trip-end considerations, enhanced corridor-based approaches, real-time parking data collection systems, and anecdotal or qualitative assessments [4]. Similarly, Chen et al. (2023) classified parking location approaches into Mixed Integer Programming and Multi-Criteria Decision-Making frameworks [29]. Although these approaches differ in complexity and scale, they share a common characteristic: truck parking adequacy is primarily assessed as a function of parking supply and freight demand. A comprehensive review by Duah et al. (2025) further confirmed that truck parking shortages remain a persistent challenge, with implications for road safety, regulatory compliance, operational efficiency, and environmental sustainability [30]. The

review highlighted that recent research has largely focused on intelligent truck parking information systems, parking availability prediction, and parking behavior analysis to improve truck parking management. However, it also emphasized the continued need for analytical methodologies capable of supporting strategic truck parking planning and infrastructure investment.

Recent work has also emphasized the role of user-centered and information-based approaches in truck parking planning. Kouta and Stephanedes (2023) proposed a disaggregate parking choice model for safe and secure truck parking areas, considering distance, cost, information provision, and security level as key factors influencing driver selection [14]. Their results indicated that distance was the dominant factor in parking choice, followed by security and cost, suggesting that accessibility remains central to truck parking decisions even when safety and security attributes are considered.

As a result, existing planning methodologies provide limited consideration of safety outcomes associated with truck parking shortages. Highway corridors characterized by moderate or low truck demand may therefore receive limited attention despite potentially experiencing elevated safety risks associated with insufficient truck parking infrastructure.

2.3. Relationship Between Truck Parking Availability and Commercial Truck Crashes

Although the relationship between truck parking shortages and driver fatigue is widely recognized, relatively few studies have explicitly examined the association between truck parking accessibility and commercial truck crash occurrence.

One of the earliest efforts was conducted by the National Association of Truck Stop Operators through the study Examination of the Relationship between Truck Crash Rates and Truck Parking Shortfall Estimates [31]. While the study found no direct association between parking shortfalls and crash rates, it reported a correlation between fatal crashes and truck vehicle miles traveled. However, the analysis was based primarily on aggregated statistical data and did not incorporate spatial analysis techniques.

Bunn, Slavova, and Rock (2017) evaluated the relationship between fatigue-related commercial vehicle crashes and proximity to rest areas and truck stops in Kentucky [32]. Using a multiple logistic regression model, the authors found that fatigue-related crashes were more likely to occur on highways where truck stops were located at least 20 miles from the crash location. In contrast, Huynh et al. (2026) analyzed the relationship between truck parking occupancy and truck-involved crashes along I-80 in Nebraska and found no statistically significant association between full parking occupancy and crash occurrence [8]. These contrasting findings suggest that the relationship between truck parking availability and commercial truck safety remains complex and may vary depending on the spatial scale, analytical approach, and definition of parking adequacy employed.

The Texas Department of Transportation conducted the Truck Parking Crash Analysis [1], which examined truck parking supply, demand, and safety conditions throughout Texas. The study found that approximately half of truck drivers parked in unauthorized locations because of HOS restrictions, while one-fourth cited a lack of overnight parking facilities. The analysis also revealed that the highest rates of fatigue-related truck crashes occurred along rural highway corridors. Additional evidence from the Appalachian Regional Truck Parking Study (2024) identified 406 fatigue-related truck crashes and 1146 crashes associated with undesignated truck parking along priority freight corridors between 2018 and 2022 [5]. More than half of these crashes resulted in injuries, while approximately 6% produced severe injuries or fatalities. These findings suggest that truck parking shortages remain an important safety concern and that their impacts may be particularly pronounced in rural areas.

Similarly, Alkhatni et al. (2023) used GIS-based hotspot analysis to examine the contribution of parking service facilities to crashes along limited-access roadways [11]. Using Getis-Ord G_i^* and network Kernel Density Estimation (KDE), the study showed that crash hotspots can be spatially associated with the influential segments of parking facilities, including criteria related to heavy vehicles and injury severity. Although the study focused on crash risk near existing facilities rather than truck stop shortages, it reinforces the need for spatially explicit methods to examine the safety implications of parking infrastructure.

Collectively, these studies suggest a plausible relationship between truck parking availability and commercial truck safety. However, the spatial association between truck stop accessibility and commercial truck crash patterns remains insufficiently explored, particularly at the network level.

2.4. Research Gap

The literature identifies four important observations. First, truck parking shortages continue to represent a significant transportation safety concern throughout the United States [1,4]. Second, existing methodologies for evaluating truck parking adequacy are predominantly based on capacity and demand considerations [3,4,9,10,29]. Third, truck safety has not been explicitly incorporated as a central criterion in most truck stop planning frameworks. Finally, although previous studies have investigated fatigue-related crashes and truck parking availability, the spatial relationship between commercial truck crashes and truck stop accessibility has not been comprehensively examined [1,8,11,31,32].

These gaps highlight the need for methodologies capable of integrating safety and accessibility considerations into truck stop planning. Accordingly, the proposed methodology is intended as a GIS-based decision-support tool for transportation planning. It integrates widely available GIS datasets, including commercial truck crashes, truck stop locations, highway characteristics, and truck traffic demand, to identify highway corridors where additional truck parking facilities may be required from a safety perspective. By relying on data commonly maintained by transportation agencies, the methodology is designed to facilitate practical implementation without requiring specialized or proprietary information.

3. Proposed GIS-Based Methodology

The primary objective of this study is to propose a GIS-based methodology for identifying truck stop shortages within the highway network, incorporating a safety perspective that is absent in current guidelines for truck stop adequacy. A GIS approach provides significant advantages, such as its capacity for intricate spatial analysis and its ability to integrate diverse types of data, traffic patterns, crash spots, and existing infrastructure, which are crucial for informed decision-making [11]. Rather than determining the precise location of a new truck stop, the methodology is intended as a network-level decision-support framework that identifies highway corridors where additional truck parking facilities may be needed. The proposed approach relies primarily on GIS datasets that are already available in most transportation agencies, making the methodology practical and readily transferable to other regions. Once priority corridors have been identified, existing site-selection methodologies, such as Multi-Criteria Decision-Making (MCDM) approaches, can be applied to determine the optimal location of individual truck stop facilities.

The proposed methodology consists of four main steps, as illustrated in Figure 1: (1) GIS Data Collection, (2) GIS Data Processing, (3) Core Model (for defining a level of need), and (4) Maps Depicting Results.

The methodology is detailed in the subsequent sections through a case study in rural Texas. The case study was conducted considering a highway network on a state-wide

scale. However, the general processes outlined herein could be applicable to other state or regional network studies.

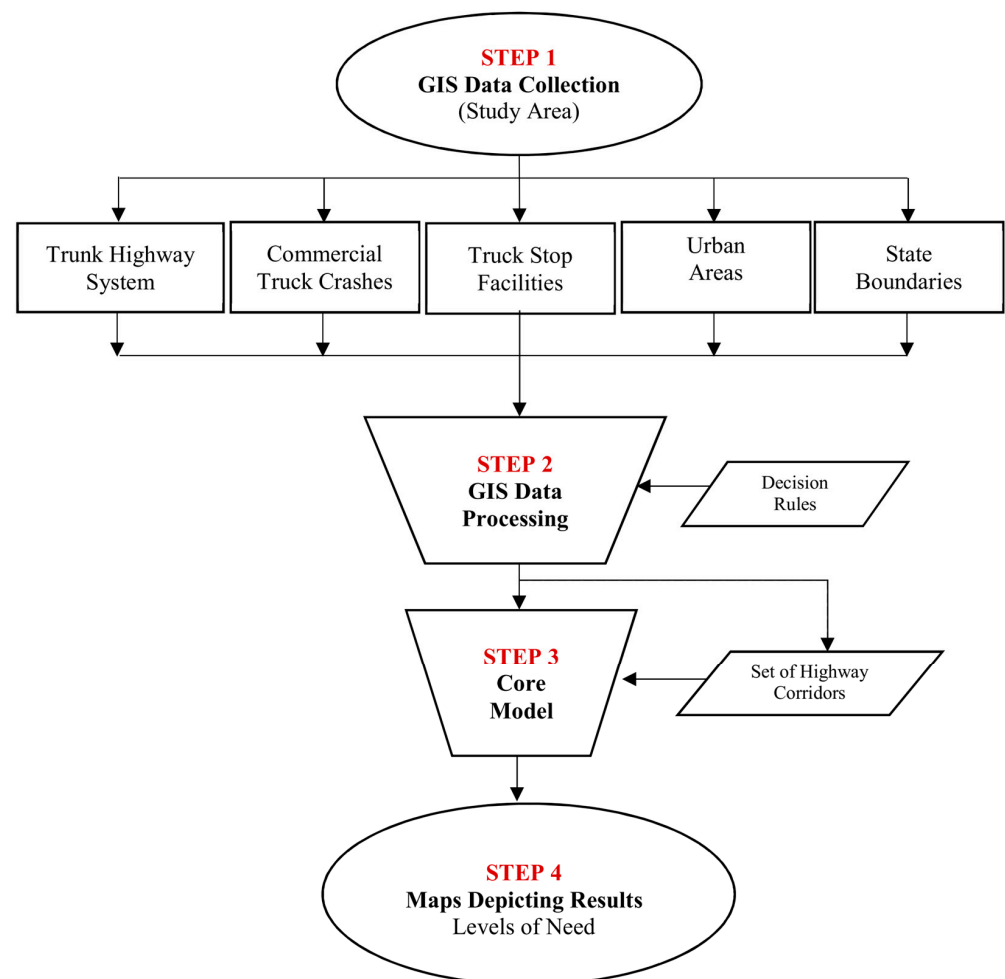


Figure 1. Flow chart of the proposed methodology.

This study assumed that the identified set of commercial truck crashes was partially due to fatigue caused by truck stop shortages. Previous studies indicate that most crash reports lack sufficient information to determine whether fatigue was a causal factor in a truck-related accident [3]. Nonetheless, it is widely acknowledged that a fatigued driver is more susceptible to involvement in a traffic accident. Despite the familiarity with routes and skills of truck drivers, fatigue remains a major cause of commercial truck crashes [2,12]. Another consideration is that urbanized areas were excluded from the analysis due to their unique challenges and conditions. Truck drivers typically do not encounter the same difficulties in finding parking in these urbanized areas, if required. Furthermore, crashes in urbanized settings may arise from different factors and conditions unrelated to fatigue. Consequently, the analysis is solely focused on rural areas.

3.1. Study Area

Texas is recognized as the largest state in the conterminous U.S., encompassing 268,597 mi². It holds the distinction of being the largest in terms of freight transportation movement in the U.S. [2]. Additionally, the state leads in several factors relevant to this study, such as annual truck fatal crashes, truck stop parking facilities (both urban and rural), traffic demand in the highway system, the number of registered commercial truck vehicles, and the length of the highway system [33–36]. Table 1 provides a detailed comparison of

these Texas statistics against nationwide values. Regarding road safety, the Texas Department of Transportation (TxDOT) has developed the Crash Records Information System (C.R.I.S.), considered one of the most comprehensive crash databases in the U.S. [37]. It is important to note that this study concentrates on rural areas and the trunk highway system. This system includes the most critical transportation routes for commercial trucks and is characterized as a network of rural highways that supplement and interconnect with the interstate highway system [38]. This network incorporates the principal corridors of the Texas Highway Freight Network, as defined by [38], but excludes segments of urban and minor highways. Figure 2 shows the set of highway corridors constituting the trunk highway system of Texas.

Table 1. Relevant transportation statistics in the State of Texas. Source: Authors' compilation based on data reported in [33–36].

Factor	Unit	Year	U.S.A.	Texas	Rank of Texas	Percentage of U.S.A.
Large-truck fatal crashes	Crash	2024	5218	699	1	13.4
Truck stops (urban & rural)	Stop	2020	8253	696	1	8.4
Large-truck demand	Million veh-km	2024	329,600	35,000	1	10.6
Registered trucks	Truck	2024	189,754,931	15,933,517	2	8.4
Highway system length (rural)	Lane-mi	2021	384,655	34,313	1	8.9

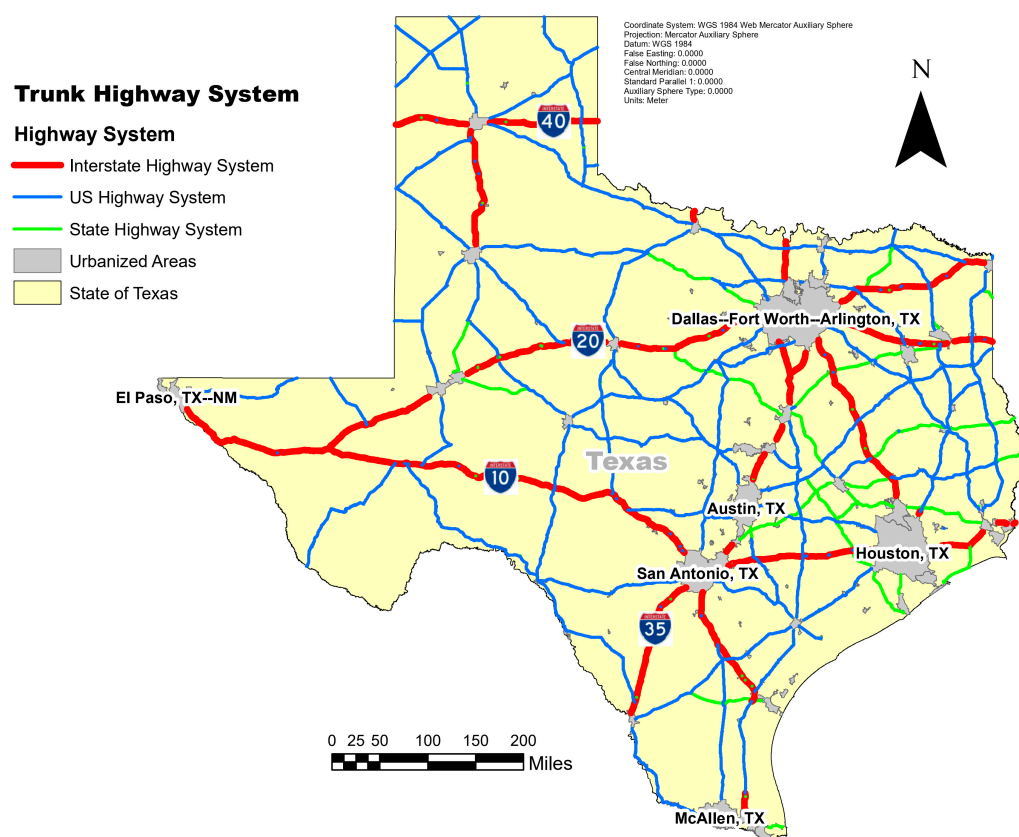


Figure 2. Trunk highway system of the state of Texas.

3.2. STEP 1. GIS Data Collection

The fundamental factors selected for this analysis include the locations of commercial truck crashes, truck stop parking facilities, and the trunk highway system. Such information is currently available for most of the states in the U.S. For the case study, the source and a brief description of the data are summarized below.

- **Truck Crashes:** The geographical locations of commercial truck crashes were obtained from the Crash Record Information System (C.R.I.S. Query) of the Texas Department of Transportation [37]. The following query filters were applied: (1) crash years from 2014 to 2018 (5-year period), (2) all Texas crashes in only rural areas, (3) involving only commercial motor vehicles, and (4) with vehicle body styles listed as trailer combination, truck, or truck tractor. The system permits the user to download a comma-separated values (CSV) file that includes the latitude and longitude coordinates for each crash, which were used to create the corresponding point features (vector data) in a GIS software (ArcMap 10.8). The five-year period for crash data analysis was assumed to mitigate potential bias introduced by years affected by the COVID-19 pandemic, during which a temporary reduction in truck crashes was reported [39].
- **Truck Stop Facilities:** Geographical data on existing truck stop parking facilities were obtained from the U.S. Department of Transportation (USDOT), last updated on 24 February 2020 [40]. This information was collected as part of Jason's Law initiatives to address the shortage of long-term parking for commercial vehicles. The layer includes vector data, also known as point features, for all available truck stops across the U.S.A. A total of 8253 facilities providing 378,700 parking spaces were identified. It was found that 77% of truck stops are private, while 23% are public. The total number of truck spaces per facility was of particular interest in this study. The attribute "total spaces" accurately reflected the total number of truck spaces for private truck stops. Conversely, for public truck stops, the attribute "total spaces" represented the sum of both truck and car spaces, while the attribute "truck spaces" specified the total number of truck spaces. A new attribute was created in the dataset to accurately indicate the number of truck spaces available at each facility.
- **Trunk Highway Network:** The trunk highway system was constructed by merging two vector data layers sourced from the Texas Department of Transportation: (1) the TxDOT Texas Trunk System and (2) the TxDOT Roadway Inventory on System, last updated on 23 January 2019 [38]. The first layer includes the highway corridors that make up the trunk highway system of Texas, comprising all interstate highways, U.S. highways, and a select set of state highways (Figure 2). However, this layer lacked information on traffic demand per highway segment, which was essential for the analysis. Conversely, the roadway inventory layer provided extensive and detailed information about traffic, geometry, and physical conditions for each highway segment across the entire highway system of Texas. A selection by location was performed to isolate, within the roadway inventory layer, only those highway segments that are part of the trunk highway system (24,555 segments). A key aspect of the methodology involves modelling truck demand, the results of which are more reliable when data are available for shorter highway segments rather than complete corridors.
- **Urban Areas and Geographic Boundaries:** Additional complementary layers used for the analysis included the state boundary of Texas and urbanized areas. These layers were also downloaded from the Texas Department of Transportation, last updated on 30 March 2019 [38]. This dataset was needed to define the study area and identify urbanized areas, which served as a spatial reference for filtering the GIS data.

3.3. STEP 2. GIS Data Processing

It is important to note that this study focuses on rural areas and the trunk highway system of the State of Texas. For this reason, the collected GIS data was processed using GIS software to identify the features of interest exclusively. To enable the execution of spatial analysis tools, some of which require distance computation, the collected data were projected into the same coordinate system. The 'NAD 1983 State Plane Texas Central FIPS

4203' system was applied in this case. Another significant purpose of this layer projection was to avoid any feature displacement, offset, or overlay.

In the trunk highway system, it was equally important to consider both highway segments and the associated traffic demand for each segment. It is well-established that a highway segment is more likely to experience more crashes as traffic demand or segment length increases. Therefore, analyzing the crashes in the context of the truck traffic flow on each highway segment was necessary. This study measured traffic in terms of Daily Truck Vehicle Miles Traveled (DTRKVTM), a metric previously associated with commercial truck crashes [31]. DTRKVTM estimates the volume of truck traffic traversing a roadway during an average 24 h period [41]. To facilitate this, a new field was added to the attribute table of the trunk highway system layer to compute DTRKVTM for each segment. Equation (1) illustrates the formula to calculate the DTRKVTM.

$$DTRKVTM_i = AADT_{ADJ_i} \cdot TRK\%_{AADT_i} \cdot LEN_{SEC_i} \quad (1)$$

where $DTRKVTM_i$ is the daily truck vehicle miles traveled of highway segment i (truck-mi/day); $AADT_{ADJ_i}$ is the annual average daily traffic adjusted for seasonal variation in highway segment i (veh/day); $TRK\%_{AADT_i}$ is the percentage of truck in the vehicle composition of the annual average daily traffic of highway segment i (veh/veh); and LEN_{SEC_i} is the length of highway segment i (mi).

3.3.1. Decision Rules

The following criteria were used for the decision rules, which are intended to assign each crash spot and truck stop to a specific highway segment. For the commercial truck crashes, a selection by location was performed to identify the crash locations (point features) within a buffer distance of 75 ft, taking the trunk highway system layer (polyline features) as reference. This buffer distance corresponds to the minimum right-of-way for a four-lane interstate highway [42]. In total, 27,967 commercial truck crashes were identified along the trunk network for the 5-year period covered by the crash data. The buffer distance of 75 ft was also set to avoid the inclusion of accidents occurring upstream on ramps and roads intersecting the trunk system, as it is considered that such accidents are not closely related to crashes due to fatigue produced by truck stop shortages. Additionally, crashes within urbanized areas were excluded from the layer dataset as was discussed above.

Another selection by location was performed on the truck stop layer to identify existing truck stops available along the trunk highway system, excluding urban areas. A lateral buffer distance of 0.5 mi was used to select only the truck stops near the highway alignment. A total of 314 facilities were identified. When considering a buffer distance of 5 mi, the difference was merely an additional ten facilities, most with fewer than 10 parking spaces. This indicates that most truck stops tend to be located relatively close to highways, which is unsurprising as they are often situated for easy access by truck drivers. Therefore, the applied buffer distance was deemed appropriate.

To provide a summary, the study employed the following decision rules:

1. Identification of truck crashes within a buffer distance of 75 feet from the trunk highway system;
2. Identification of truck stops within a buffer distance of 0.5 miles from the trunk highway system;
3. Exclusion of urbanized areas, as the analysis was specifically focused on rural regions.

3.3.2. Set of Highway Corridors

The proposed methodology provides results at a highway corridor level. For this reason, the analyst must define the set of highway corridors to be evaluated. The aim is that these corridors present homogeneous conditions (e.g., geometry, operation, demand, etc.) to the maximum possible length. In the case study, the criteria for defining highway corridors were based on the highway number; in other words, highway segments with the same highway number were considered a single continuous corridor. However, if an urbanized area splits a highway corridor, the resulting segments would be analyzed separately as different highway corridors. The ‘dissolve’ function was employed to achieve this, taking the highway number as the dissolve field. It is critical for the analysis that the new layer (‘Highway Network’ in the core model) includes the summation of the length and the DTRKVT for each highway segment, thereby providing the total value of these key variables for each highway corridor. Note that the proposed indices in “STEP 3—Core Model” were computed for each highway corridor defined here.

3.4. STEP 3. Core Model

The core model delineates the primary approach of the methodology employed in the study, as depicted in Figure 3. The yellow rectangles represent the tools applied to the processed data, while the ovals indicate the inputs (in blue) and outputs (in green) of these tools.

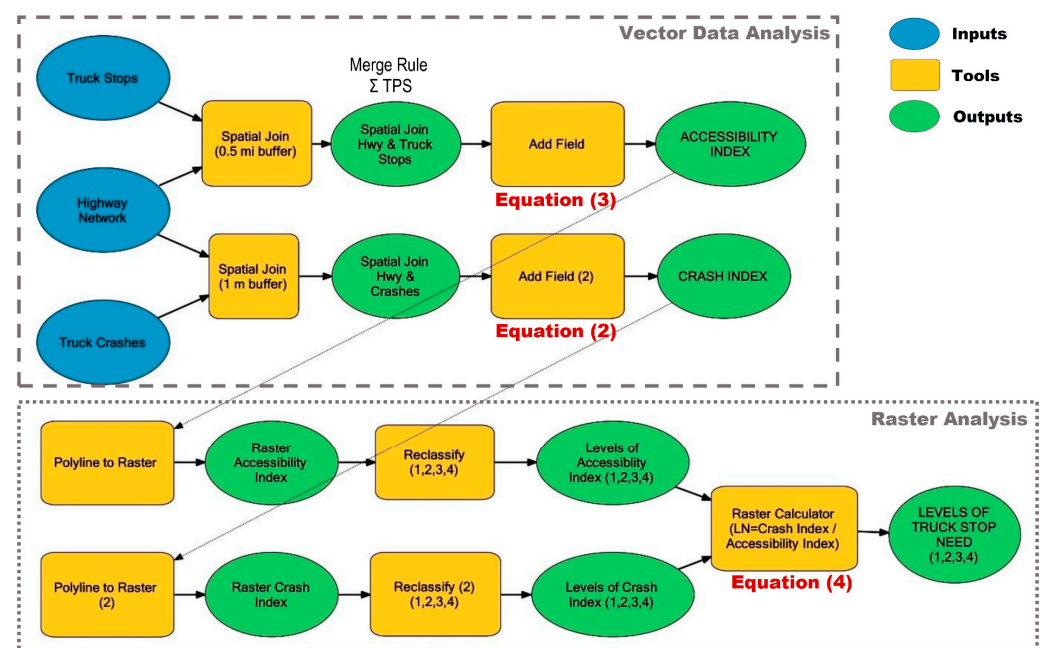


Figure 3. Core-model layout applied in the methodology.

3.4.1. Vector Data Analysis

The projected highway network layer, which comprises the set of highway corridors, serves as the target layer for executing a ‘spatial join’. The objective is to aggregate the number of truck crashes and truck stops that occur within each individual highway corridor. In the attribute tables of the resultant output layers, the ‘join_count’ denotes the number of units, either crashes or truck stops.

For truck crashes, a radius search of 3.3 ft was employed in the spatial join, calibrated through a heuristic approach to minimize the error caused by overlapping radius searches in successive segments. This overlap issue could result in double-counting of crash locations at the ends of highway segments, necessitating a reduced buffer. An error rate of 0.56% for

duplicated crashes was observed. After the spatial join, a new attribute field, designated as 'Crash_Index,' was incorporated into the newly generated layer. This attribute serves as an input for raster analysis aimed at calculating the levels of need for truck parking facilities within each corridor. The Crash Index was computed using Equation (2), which is a function of the crash count derived from the spatial join and the previously defined DTRKVMT, but adjusted to correspond with the same 5-year period considered for the crash dataset. By incorporating DTRKVMT, the Commercial Truck Crash Index represents crash occurrence relative to truck traffic exposure rather than absolute crash frequency, thereby allowing meaningful comparisons among highway corridors with different traffic demand levels. Consequently, the Crash Index is expressed in terms of the number of crashes occurring per million truck vehicle miles travelled.

$$\text{Crash Index}_i = \frac{\text{Crash Count}_i \cdot 1,000,000}{\text{DTRKVMT}_i \cdot 365 \cdot T} \quad (2)$$

where CrashIndex_i is the crash index of highway corridor i (crashes per million of truck vehicle miles traveled); CrashCount_i is the number of crashes occurred in the highway corridor i (crash); DTRKVMT_i is the daily truck vehicle miles traveled of highway corridor i (truck-mi/day); and T is the analysis period of the crash dataset (year).

For truck stops, the spatial join employed a radius search of 0.5 mi, consistent with the data processing step. A merge rule (sum) is needed to aggregate all available truck parking spaces within the highway corridor. This aggregated data served to establish a new attribute field named 'Accessibility_Index,' which functions as a second input in the raster analysis for computing the levels of need. The Accessibility Index is derived using Equation (3), which is a function of the total sum of truck parking spaces obtained from the spatial join and the DTRKVMT. Implicitly, this index accounts for the dimensions of available truck stops as well as the volume of truck traffic traversing the entire length of the highway corridor. Thus, the Accessibility Index is calculated in terms of the number of truck parking spaces available per thousand daily truck vehicle miles travelled within the highway corridor.

$$\text{Accessibility Index}_i = \frac{\sum \text{TPS} \cdot 1000}{\text{DTRKVMT}_i} \quad (3)$$

where $\text{Accessibility Index}_i$ is the accessibility index of highway corridor i (truck parking spaces per thousand of daily truck vehicle miles traveled); $\sum \text{TPS}$ is the total truck parking spaces in the highway corridor i (spaces); and DTRKVMT_i is the daily truck vehicle miles traveled of highway corridor i (truck-mi/day).

The Commercial Truck Crash Index is intended to represent the relative safety conditions of each highway corridor, whereas the Truck Stop Accessibility Index represents the availability of truck parking infrastructure. Rather than using crash frequency alone, the methodology combines both indicators to identify highway corridors where elevated crash occurrence and limited parking accessibility coexist, thereby supporting transportation planning decisions. Together, these complementary indicators provide the basis for defining the Level of Need for additional truck stops.

3.4.2. Raster Analysis

After the formulation of both indices, the raster analysis process, aimed at identifying the levels of need, mandates the conversion of vector layers from polyline to raster format for the application of reclassification and map algebra techniques. The foundational principles underlying these techniques can be found elsewhere [43]. For the raster maps, the State of Texas layer functioned as the mask, with a specified cell size resolution of 100 m.

Four distinct levels (1, 2, 3, and 4) were established for reclassifying both the Crash and Accessibility Indices. This reclassification process was based on the observed cell statistics within each respective raster map, following the procedure utilized in previous studies [44,45]. The mean and standard deviation were employed to establish the thresholds for each level. For instance, Level 3 comprises cell values (indices) that lie approximately within one standard deviation above the mean, while Level 4 is designated for values exceeding one standard deviation above the mean. Analogously, Levels 1 and 2 are associated with values that fall below the mean. It is advisable to examine the histogram of cell samples to ascertain appropriate thresholds tailored to each specific study.

The final stage of the raster analysis entails the application of map algebra to compute the Level of Need (LoN) for new truck stops. Four distinct levels were delineated to identify highway corridors exhibiting truck stop shortages from a safety perspective. These levels are categorized as: (1) Not Needed, (2) Low Need, (3) Moderate Need, and (4) High Need. The LoN is estimated through Equation (4), which is a function of both the crash index level and the accessibility index level, as determined in the prior reclassification step. For example, an increase in the crash index level within a highway corridor (indicative of higher commercial truck crash rates) will consequently increase the LoN. Conversely, an increase in the accessibility level (reflecting a larger quantity of available truck parking spaces, normalized to truck flow) will result in a reduction in the LoN. The detailed relationship between the crash index level, accessibility index level, and LoN values is shown in Figure 4.

$$\text{LoN} = \frac{\text{Crash Index Level}}{\text{Accessibility Index Level}} \quad (4)$$

where LoN is the level of need for new truck stops in the highway corridor i rounded up to the nearest integer (integers from 1 to 4 inclusive); Crash Index Level is from the reclassifying step (integers from 1 to 4 inclusive); and Accessibility Index Level is also from the reclassifying step (integers from 1 to 4 inclusive).

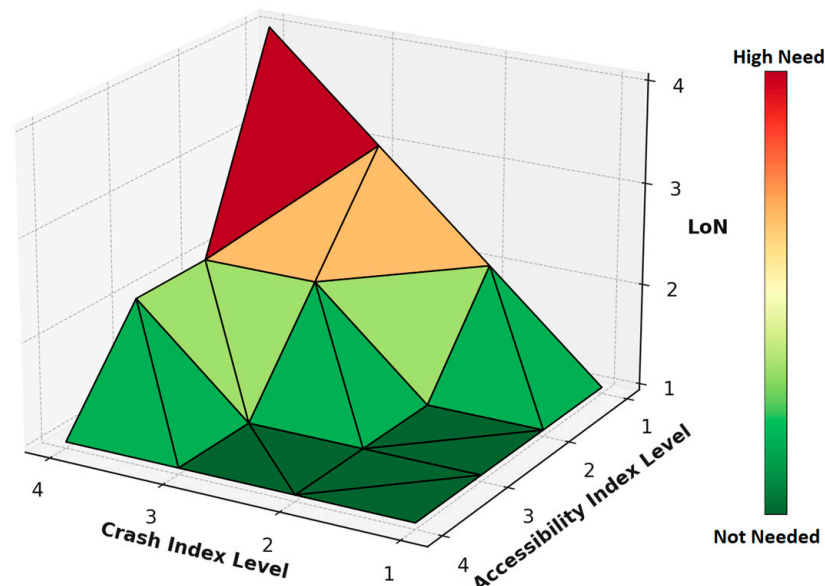


Figure 4. Relationship between Crash Index Level, Accessibility Index Level, and Level of Need (LoN).

The resulting Level of Need is intended to support strategic transportation planning by identifying highway corridors that warrant further evaluation for additional truck parking infrastructure. The methodology therefore serves as an initial screening tool for prioritizing investment rather than a procedure for selecting specific truck stop locations.

3.5. STEP 4. Maps Depicting Results

The concluding step of the proposed methodology involves generating a series of maps, predicated on the calculated crash index, accessibility index, and LoN. These maps aim to inform the analyst of highway corridors exhibiting atypical commercial truck crash rates (crash index), corridors facing truck stop deficits (accessibility index), and corridors necessitating new truck stops from a road safety perspective (LoN). For an effective representation of the LoN map, it is recommended to convert the raster map to a polyline format and execute a spatial join to incorporate the LoN values into the attribute table of the highway network layer (corridors). This approach renders the map interpretation more lucid. It should be noted that while the results can also be presented in tabular form, maps frequently offer geographic insights that tables lack.

In summary, the proposed GIS-based methodology provides a comprehensive framework aimed at identifying truck stop shortages within the highway network at a macroscale level, incorporating a previously neglected safety perspective. This methodology is structured around four main steps: (1) GIS Data Collection serves as the initial stage, aggregating diverse data types such as traffic patterns, crash locations, and existing infrastructure; (2) GIS Data Processing involves refining the collected data to ensure it is formatted consistently and is suitable for analytical purposes; (3) the Core Model utilizes the processed data to determine the level of need for truck stops, incorporating demand and safety variables; and (4) maps depict results, where the outcomes of the Core Model are visually represented for actionable insights. This methodology leverages the capabilities of GIS for complex spatial analysis and data integration, thereby facilitating informed decision-making.

4. Results and Discussion

4.1. Spatial Analysis Results

In the map depicted in Figure 5, the existing truck stop locations and the traffic demand for each highway segment of the trunk system are visible, quantified in terms of DTRKVT. Most existing truck stops, both private and public, are situated along the highway corridors experiencing the highest traffic demand. This distribution aligns with current guidelines, which define the suitability of potential new truck stops primarily based on capacity and demand models, as articulated in the literature review. It should be noted that the majority of the identified truck stops are private (245 private versus 69 public). In the case of public truck stops, these also serve as rest stop facilities, boasting an average of 16.7 truck spaces per facility, with a standard deviation of 13.5.

The crash index map displayed in Figure 6 indicates a notable visual association in certain highway corridors where elevated crash index values correspond with reduced truck stop accessibility. Corridors designated as Level 4 (exceeding one crash per million truck vehicle miles traveled) are those with atypical crash rates. These corridors predominantly consist of U.S. highways that connect to interstate highways or urban areas, primarily in a north-to-south direction.

It should be noted that the connectivity of the interstate system in Texas varies between north-to-south directions. Level 4 encompasses 29 highway corridors with a cumulative length of 928 miles (mean = 32.0 mi & StdDev = 24.9 mi per corridor) and accommodates a total truck flow of 0.902 million of DTRKVT. Within Level 4, the average crash index stands at 2.99 crashes per million of DTRKVT. If this crash index is considered, approximately 984 commercial truck crashes per year could be anticipated along these corridors given their corresponding demand in terms of DTRKVT.

Figure 7 presents the accessibility index across the examined highway corridors. Level 1 designates the corridors with the most limited truck stop accessibility, registering fewer than 0.1 parking spaces per thousand DTRKVT. A sum of 110 highway corridors fall

within Level 1, collectively spanning 5090 miles (mean = 46.3 mi & StdDev = 54.0 mi per corridor). These corridors are predominantly U.S. and state highways and accommodate a cumulative truck flow of 6.93 million of DTRKVTM.

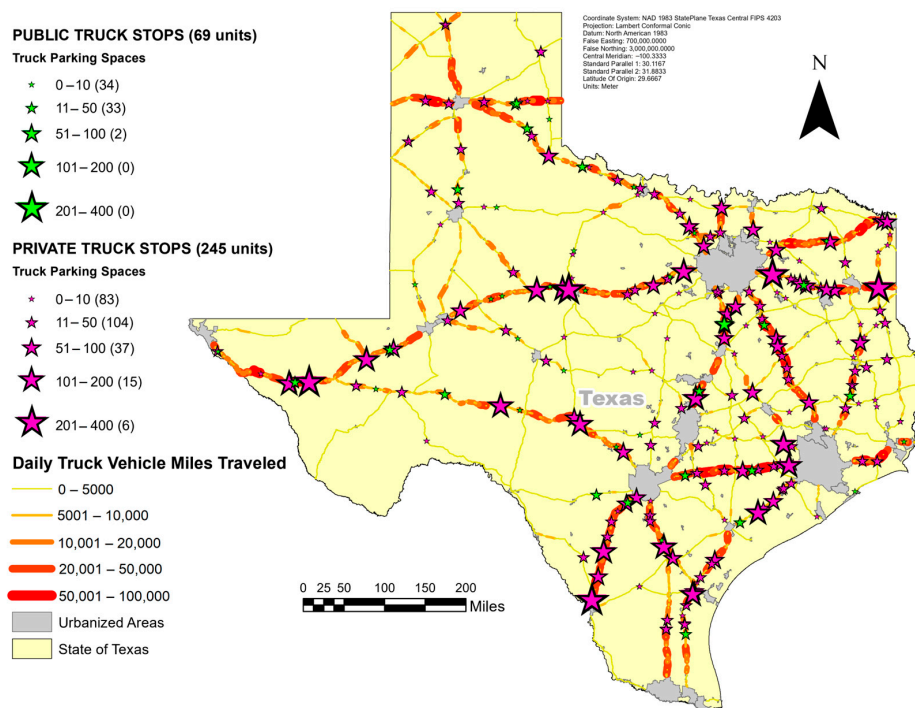


Figure 5. Truck stops versus traffic demand in the trunk highway system.

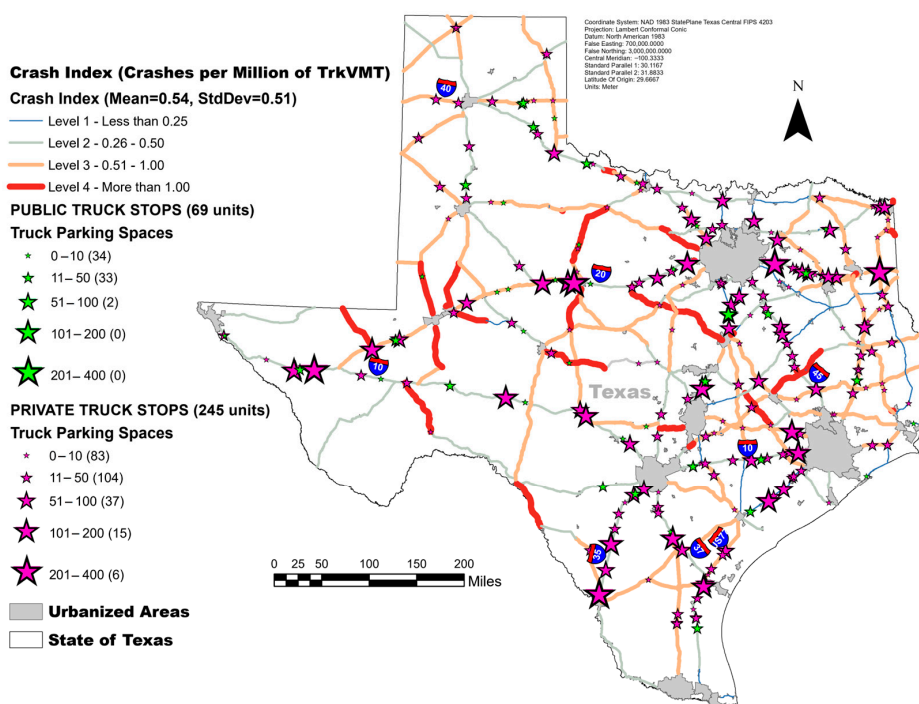


Figure 6. Crash Index per Highway Corridor.

The LoN values are illustrated in Figure 8. Level 4, categorized as “High Need,” comprises 22 highway corridors with a combined total length of 495 miles (mean = 22.5 mi & StdDev = 20.7 mi per corridor). These corridors equate to approximately 7.6 h of travel time, based on an average speed limit of 65 mph within the trunk system. Predominantly consisting of U.S. and state highways, these corridors facilitate a total truck flow of 0.39 million of

DTRKVTM. As inferred from Equation (4), only corridors that possess a crash index level of 4 and an accessibility level of 1 can attain a high level of need. Given that the mean crash index for these corridors is 2.99, an estimated 426 commercial truck crashes per year could be anticipated on these routes. Conversely, the analyzed trunk highway network spans a total length of 12,125 miles and averages 5593 commercial truck crashes per year. As such, the identified corridors account for 7.6% of commercial truck crashes while comprising merely 4.1% of the entire trunk system's length.

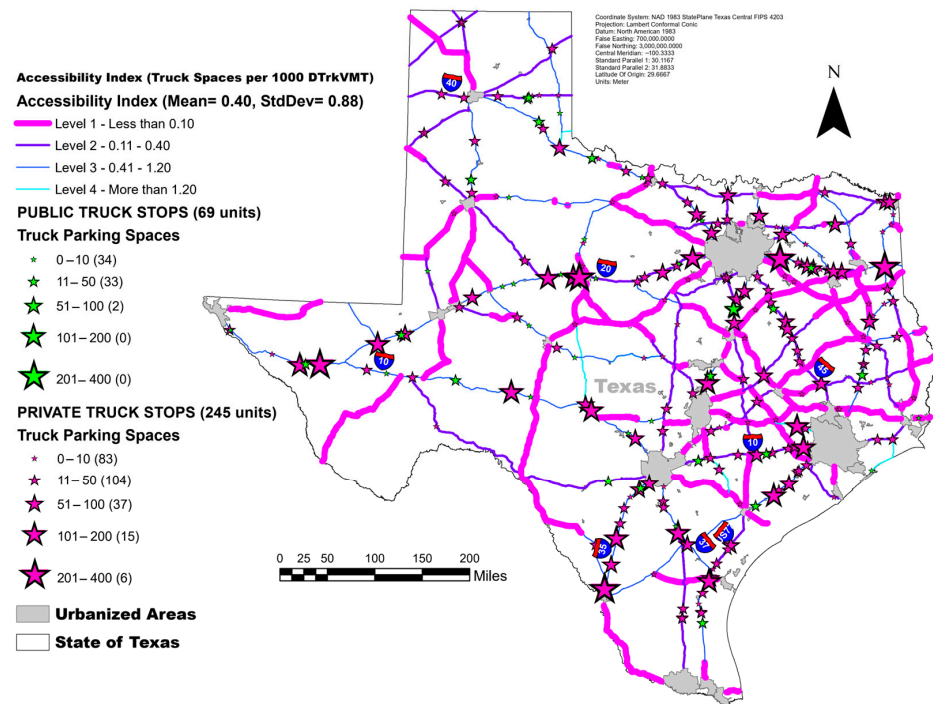


Figure 7. Accessibility Index per Highway Corridor.

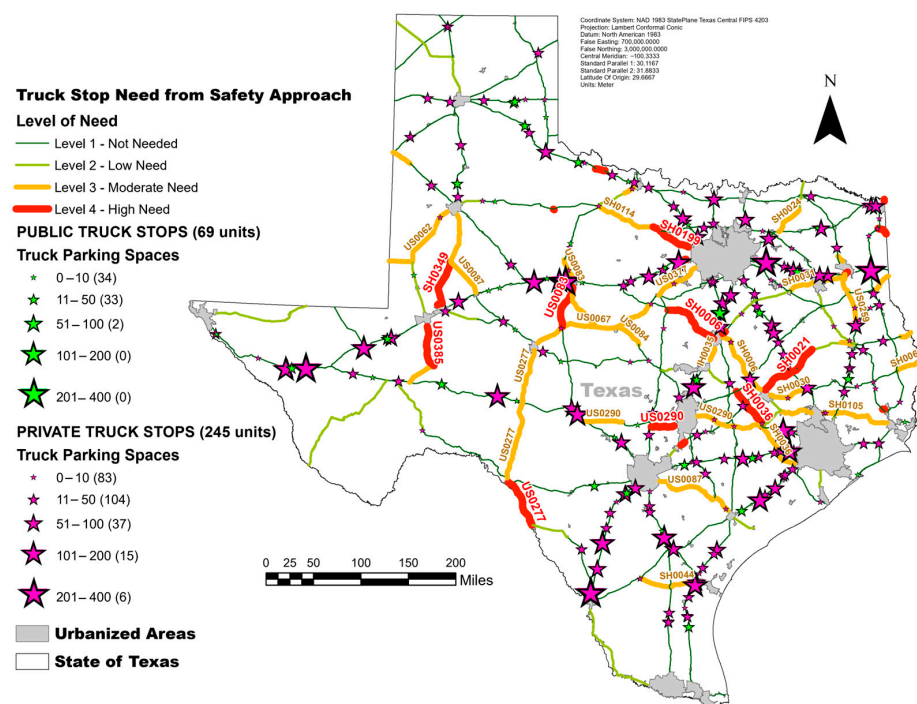


Figure 8. Level of need (LoN) for new truck stops per highway corridor.

4.2. Discussion and Implications

The spatial distribution of the identified priority corridors reveals several important patterns with practical implications for truck stop planning and highway safety. One noteworthy observation is that the majority of highway corridors classified under high or moderate LoN are situated in proximity to the largest cities in Texas, namely Dallas, Austin, San Antonio, and Houston. The highway numbers corresponding to these corridors are indicated in Figure 8. One plausible rationale for this distribution could be that truck drivers may utilize these U.S. and state highways as alternative conduits to interstate highways. This behavior potentially elevates both truck flow and crash rates on routes where accessibility to truck stops is generally limited.

The findings of this study reinforce recent research advocating the use of spatial and data-driven approaches to support truck parking planning. Alkhatni et al. (2023) demonstrated that GIS-based hotspot analysis can identify parking service facilities associated with elevated crash risk and provide valuable information for transportation planners and safety engineers when evaluating roadside infrastructure [11]. Similarly, the proposed methodology applies GIS techniques at the highway corridor level by integrating commercial truck crash occurrence and truck stop accessibility to prioritize corridors where additional truck parking facilities may be warranted from a safety perspective. More broadly, a recent comprehensive review by Duah et al. (2025) concluded that truck parking shortages continue to present significant safety challenges and emphasized the need for data-driven analytical tools to support strategic planning and infrastructure investment [30]. The proposed methodology contributes to this objective by providing a network-level framework that explicitly incorporates truck safety into corridor prioritization.

It is important to emphasize that the safety perspective adopted in this study does not imply a direct causal relationship between truck stop shortages and every commercial truck crash. Rather, commercial truck crash occurrence is incorporated as one component of a broader corridor screening framework intended to identify locations where truck parking deficiencies may warrant further investigation.

An important advantage of the proposed methodology is that it relies on transportation datasets routinely collected by many highway agencies. Consequently, it can be implemented with relatively limited additional data collection, facilitating its adoption as a practical first-stage planning tool for identifying highway corridors where additional truck stop capacity may be needed. The methodology is intended to support subsequent site-specific location analyses rather than replace them. This capability is particularly valuable because traditional truck stop planning guidelines do not explicitly incorporate road safety into the corridor prioritization process.

5. Concluding Remarks

Existing guidelines for establishing truck stop locations primarily rely on capacity and demand models. Regrettably, these methodologies have overlooked the crucial safety perspective and spatial associations. This oversight in determining truck stop locations has been linked to an increased number of crashes involving fatigued drivers. The objective of this study was to introduce a GIS-based methodology for identifying highway corridors characterized by atypical crash rates and limited truck stop accessibility, with the ultimate objective of recommending new truck stops along these routes. The methodology was structured around four principal components: (1) GIS-data collection, (2) GIS-data processing, (3) core model comprising both vector and raster analyses, and (4) presentation of results through maps. Within this framework, two indices were formulated to quantify commercial truck safety (crash index) and truck stop availability (accessibility index) across a chosen array of highway corridors. Both indices are functions of the volume of truck

traffic traversing each corridor, expressed in terms of DTRKVTM, which has shown a correlation with commercial truck crashes in previous studies. Employing raster analysis, facilitated by reclassification and map algebra techniques, enabled the definition of four distinct LoN for new truck stop locations within each highway corridor.

The methodology was applied to a case study focusing on the trunk highway system in rural Texas to elucidate the primary steps and specific processes involved. The study revealed that most existing truck stops are situated along highway corridors experiencing the highest traffic demand. This alignment is congruent with current guidelines predominantly based on capacity and demand models. However, the proposed methodology found that most of the highway corridors that need new truck stops are U.S. and state highways with moderate to low truck demand and atypical high crash rates. This suggests that traditional methods may face challenges in identifying such corridors as candidates for new truck stops in contrast to the proposed approach.

Finally, it is worth noting that most existing truck stops have originated from the private sector, which bases decisions on profitability. Given that the identified highways experience moderate to low traffic demand, the primary responsibility for making these routes safer for commercial drivers should fall on the public sector. It is essential to highlight that a fatigued truck driver presents a significant risk to all users of the national highway system.

Limitations and Future Research

It is recommended that a panel of experts, aligned with the study's objectives and type, establish criteria for determining the highway corridor set, the thresholds demarcating each level of the crash and accessibility indices (via raster analysis), and the levels of need. Although the present study defines these thresholds using the mean and standard deviation to provide an objective and reproducible classification procedure, alternative threshold definitions may be explored according to the characteristics and objectives of future applications. The fuzzy analytic hierarchy process can serve as a useful tool for incorporating experts' and practitioners' judgments into the criteria and weightings, while also addressing challenges related to non-linearity and uncertainty in decision-making rules. Lastly, as the proposed methodology is designed to yield results at a macroscale level, a segment-specific analysis should be undertaken to ascertain the precise location for a new truck stop along an identified highway corridor. In this context, Multi-Criteria Decision-Making (MCDM) techniques, such as AHP, TOPSIS, or VIKOR, may provide an effective framework for evaluating multiple quantitative and qualitative criteria during the site-selection process.

Future research should explore predictive modeling approaches, including machine learning and artificial neural networks, to distinguish commercial truck crashes that are more likely to be associated with truck parking shortages by incorporating qualitative safety factors, thereby improving the quality and representativeness of the crash dataset used to compute the Commercial Truck Crash Index.

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Abbreviations

The following abbreviations are used in this manuscript:

AADT	Annual Average Daily Traffic
AI	Accessibility Index
CI	Crash Index
C.R.I.S.	Crash Records Information System
CSV	Comma-Separated Values
DTRKVM	Daily Truck Vehicle Miles Traveled
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRMS	Fatigue Risk Management Systems
GIS	Geographic Information System
HOS	Hours of Service
LoN	Level of Need
NAD	North American Datum
NAFMP	North American Fatigue Management Program
NASEM	National Academies of Sciences, Engineering, and Medicine
NATSO	National Association of Truck Stop Operators
NCSA	National Center for Statistics and Analysis
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
TPS	Truck Parking Spaces
TxDOT	Texas Department of Transportation
TxDPS	Texas Department of Public Safety
U.S.	United States

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