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MINETA TRANSPORTATION INSTITUTE

Researching Relationships Between Truck Travel Time Performance Measures and On-Network and Off-Network Characteristics

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Mineta Transportation Institute

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16. Abstract

Trucks serve significant amount of freight tonnage and are more susceptible to complex interactions with other vehicles in a traffic stream. While traffic congestion continues to be a significant 'highway' problem, delays in truck travel result in loss of revenue to the trucking companies. There is a significant research on the traffic congestion mitigation, but a very few studies focused on data exclusive to trucks. This research is aimed at a regional-level analysis of truck travel time data to identify roads for improving mobility and reducing congestion for truck traffic. The objectives of the research are to compute and evaluate the truck travel time performance measures (by time of the day and day of the week) and use selected truck travel time performance measures to examine their correlation with on-network and off-network characteristics. Truck travel time data for the year 2019 were obtained and processed at the link level for Mecklenburg County, Wake County, and Buncombe County, NC. Various truck travel time performance measures were computed by time of the day and day of the week. Pearson correlation coefficient analysis was performed to select the average travel time (ATT), planning time index (PTI), travel time index (TTI), and buffer time index (BTI) for further analysis. On-network characteristics such as the speed limit, reference speed, annual average daily traffic (AADT), and the number of through lanes were extracted for each link. Similarly, off-network characteristics such as land use and demographic data in the near vicinity of each selected link were captured using 0.25 miles and 0.50 miles as buffer widths. The relationships between the selected truck travel time performance measures and on-network and off-network characteristics were then analyzed using Pearson correlation coefficient analysis. The results indicate that urban areas, high-volume roads, and principal arterial roads are positively correlated with the truck travel time performance measures. Further, the presence of agricultural, light commercial, heavy commercial, light industrial, single-family residential, multi-family residential, office, transportation, and medical land uses increase the truck travel time performance measures (decrease the operational performance). The methodological approach and findings can be used in identifying potential areas to serve as truck priority zones and for planning decentralized delivery locations.

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Contents

List of Figures

List of Tables

Executive Summary

A nation's freight transportation system is a direct indicator of its economy. E-commerce and trade practices (involving physical movement of goods) have witnessed significant growth in recent years, amplifying freight transportation activity. The growth in the freight industry and associated truck traffic raises concerns in an already congested highway network. Analyzing truck travel times and identifying performance measures corresponding to trucks would help to better understand the influence of trucks on the transportation system and identify potential areas for "truck priority zones" and "truck traffic signal priority."

The just-in-time approach adopted by trucking companies demands dynamic travel scheduling and quick delivery times. A comprehensive traffic operational analysis of the existing network is needed to better plan and implement truck routes. Probe data—for example, travel times classified based on vehicle type—from private data sources facilitate the examination of truck operational performance for a better understanding of the current traffic patterns.

Truck travel times influence the routing strategies adopted by the shipping companies and dispatchers. Both travel times and routing strategies also depend on the on-network characteristics and off-network characteristics within the vicinity of links. However, the literature documents limited to no research dedicated to truck travel time performance measures or their correlation with on-network and off-network characteristics. There is a need to examine the relationship between truck travel time performance measures and on-network and off-network characteristics to proactively plan, improve mobility, and reduce congestion on roads.

The objectives of the research, therefore, are (1) to compute, evaluate, and compare the truck travel time performance measures by time of the day and day of the week, (2) to examine the relationship between the selected truck travel time performance measures and on-network characteristics like speed limit and traffic density condition, and (3) to examine the relationship between the selected truck travel time performance measures and off-network characteristics like land use and demographic characteristics.

Truck travel time data for the year 2019 were obtained and processed at the link level for Mecklenburg County, Wake County, and Buncombe County in North Carolina, United States. To account for the temporal aspects of the truck travel time performance measures, four times of the day and two days of the week were considered. Various descriptive travel time measures, travel time percentile measures, and travel time reliability measures were computed using truck travel time data. Pearson correlation coefficient analysis was performed to examine correlations and select suitable truck travel time performance measures. The average travel time (ATT), planning time index (PTI), travel time index (TTI), and buffer time index (BTI) were selected for further analysis.

On-network characteristics such as speed limit, reference speed, annual average daily traffic (AADT), and the number of through lanes were extracted for each link. Similarly, off-network characteristics such as land use and demographic data in the near vicinity of each selected link were captured using 0.25 and 0.50 miles as buffer widths. The relationships between the selected truck travel time performance measures and on-network and off-network characteristics were then analyzed using Pearson correlation coefficient analysis.

The results indicate that urban areas, high-volume roads, and principal arterial roads are positively correlated with truck travel time performance measures like ATT, indicating higher truck travel times are likely in areas comprising these features. Further, the presence of agricultural, light commercial, heavy commercial, light industrial, single-family residential, multi-family residential, office, transportation, and medical land uses increase the selected truck travel time performance measures. The presence of these areas could increase truck travel times or related reliability performance measures. The correlations with the off-network characteristics differ depending on the buffer width used to capture the data in addition to the time of day and day of the week.

The methodology and findings could be proactively used in identifying factors influencing truck travel time performance measures, and potential areas to serve as truck priority zones and in planning decentralized delivery locations.

1. Introduction

Our lives depend on an efficient and reliable transportation system.[1] The transportation system impacts a nation in many ways, ranging from personal mobility to trade practices. A nation's freight transportation system is a direct indicator of its economy. In the United States, the freight transportation system accounted for an average movement of 51 million tons per day in 2018.[2] Over 5 million people were employed in the freight transportation sector as of 2016, contributing to approximately 8.9% of the nation's gross domestic product.[3] Non-transportation-related firms also contribute to in-house transportation activity, costing them about $1,067 billion in 2016.[3]

Trade and e-commerce activity associated with physical movement of goods contribute significantly to the overall freight transportation demand. The e-commerce market has witnessed significant growth, resulting in an increase in trucking activity.[4] Based on current trends, truck freight tonnage of the United States is expected to increase by 44% by 2045 compared to the year 2015.[4]

Typically, goods are transported through one mode or a combination of modes. Notably, highways account for the highest contribution of all modes of freight, with nearly 71% of the freight tonnage being carried by trucks.[5] They have a pronounced influence on a traffic stream and its operational performance due to their enormous size as well as their braking abilities, which sets them apart from passenger cars.[6] Besides, large trucks in the traffic stream affect the sight distance of the following vehicles, resulting in higher gaps between the vehicles and a fluctuation in the overall operational performance.[7] Generally, higher congestion rates are anticipated to occur with the presence of trucks in high road density conditions.[6]

American Transportation Research Institute's (ATRI) analysis of trip times by motor carriers indicated a delay of 1.2 billion hours due to congestion, which adds up to an increased cost of $6,478 per truck.[8] It is expected to increase further in coming years at a higher rate, as an estimated growth of 21% is anticipated in truck traffic by the year 2025 compared to the year 2015, per the report published in 2019.[9]

The operational performance of a traffic stream is measured using travel time, travel speed, vehicle delay, traffic density, and volume-to-capacity ratio. Particularly, travel time is considered as a robust performance measure to improve mobility and mitigate congestion in an area.[10] Moreover, the travel time statistics capture the variability in terms of travel time from a road user perspective.[11]

Recent technological advancements and data collection strategies are enabling practitioners to capture travel time data by vehicle type. Thus, the availability of travel time data associated exclusively with trucks adds value and opens avenues for computation and comparison of the operational performance of various vehicles. This helps to proactively plan, design, and build transportation systems.

Trucking comprises of freight transportation, e-commerce shipments, commercial/industrial activity and in-house transportation. Ultimately, trucking activity in an area is governed by surrounding area type, land use development, and population in the near vicinity.[12] A regional-level analysis to identify the performance measures based on the available data will aid in identifying choke points from the truck traffic perspective. However, it is not clear how truck travel time performance measures differ from performance measures related to passenger cars or mixed traffic streams; neither it is clear which performance measure to use for assessments, nor whether these performance measures are correlated with various on-network and off-network characteristics. Investigating these aspects will help in identifying "truck priority zones" and implementing "truck traffic signal priority" at a regional level. Furthermore, the findings will help in identifying suitable areas to serve as distribution centers, or decentralized delivery locations in the near future.

1.1 Problem Statement

The importance of freight transportation mobility and infrastructure to the United States is evident from policies and recent legislations like the Moving Ahead for Progress in the 21st Century (MAP-21) Act and Fixing America's Surface Transportation (FAST) Act. A significant growth in freight demand has been witnessed in recent decades due to the growth in e-commerce and trade activities. These growth patterns remain unaffected even during the ongoing global pandemic.

Increasing freight demand triggers a significant growth in warehousing and distribution centers for ground shipment and last-mile deliveries. Hence, the number of trucks in traffic streams is also expected to increase as companies seek to cater to this elevated demand. The increase in truck volumes ultimately affects the traffic flow and the level of congestion. To ensure the timely delivery of goods, there is a need to evaluate the operational performance of trucks in the traffic stream and use this information to plan, design, and build efficient transportation systems.

As stated previously, road congestion influences truck travel times and increases delivery times. Typically, these congestion implications are not limited to any one road section or facility. Instead, they are often region-wide. Given the magnitude of the problem, there is a need for effective measures to mitigate congestion.

Various travel time performance measures are currently used to assess the operational performance of a traffic stream due to the availability of data at almost all times of the day and for all days of the week. Many transportation agencies at the federal, state, and local levels incorporate these performance measures to assess the operational performance of a road. However, most existing research studies on operational performance measures were conducted based on passenger car travel data or mixed traffic conditions such as a traffic stream.

Trucking and traffic activity could be different on a Wednesday compared to a Sunday. It could be different during peak and off-peak hours. Likewise, trucking and traffic activity could differ by the area type (urban, suburban, and rural). Therefore, the operational performance of trucks (say, travel time) varies with these factors. The influence of spatial characteristics along with temporal aspects on truck travel time performance measures has not been widely explored in existing research. Further, the influence of the area type (such as rural or urban) was not accounted for in the past. There is a need to use truck travel time data and evaluate the performance measures for various area types, ranging from urban to rural areas and times of the day as well as days of the week.

The road characteristics like the type of facility, the speed limit, and the road functional class have a distinctive influence on trucks and passenger cars, so it is debatable whether passenger car or traffic stream performance measures are applicable to trucks. In addition to the road network characteristics, truck traffic depends on the type of developments (distribution centers, warehouses, and industries) and area demographics within the proximity of a road link. Hence, there is a need to incorporate these explanatory variables and examine their correlation with truck travel time performance measures.

1.2 Research Objectives

This research is aimed at improving mobility and reducing congestion by conducting an analysis of truck travel times and assessing possible correlations with on-network and off-network characteristics. The objectives of the research are:

- To compute, evaluate, and compare the truck travel time performance measures by time of day and day of the week,

- To examine the relationships between the truck travel time performance measures by speed limit and traffic density condition, and,

- To examine the relationships between the selected truck travel time performance measure(s) and on-network and off-network characteristics (such as area type, demographic characteristics, and land use characteristics).

The selected truck travel time performance measures and findings about their relationship with the on-network and off-network characteristics will help in identifying the vulnerable areas or chokepoints that arise due to truck traffic; it will also help in identifying truck priority zones, for implementing truck traffic signal priority, and also in identifying suitable areas to serve as distribution centers or decentralized delivery locations.

1.3 Organization of the Report

The remainder of the report comprises seven chapters. Chapter II summarizes past literature related to freight planning and management, truck performance, and travel time reliability studies. Further, a synthesis on truck travel time reliability and performance is presented, along with the limitations of past research. Chapter III discusses the methodological framework adopted for this research. Chapter IV presents a description of the study area, data collection and processing methods, and summary statistics of the data used in this research. Chapter V discusses the results from an analysis of truck travel times used to select suitable truck travel time performance measures. Chapter VI presents the correlations between the selected truck travel time performance measures and on-network characteristics. Similarly, Chapter VII presents the correlations between the selected truck travel time performance measures and off-network characteristics. Chapter VIII discusses the conclusions from this research and suggests the scope of future research.

2. Literature Review

This chapter presents an overview of past research associated with freight mobility, travel time reliability, operational performance, and the impacts of truck traffic on congestion, as well as existing practices by state agencies. Further, additional discussions related to travel time performance measures and their correlations with the on-network and off-network characteristics are presented.

2.1 Influence of Trucks on the Traffic Stream

The presence of trucks in the traffic stream has a profound impact on the overall operational performance of a road facility. The capacity of a road facility decreases with an increase in the percentage of trucks.[13] The Highway Capacity Manual (HCM) computes the level of service (LOS) of a facility as an indicator of its operational performance. Typically, the LOS of a road facility is determined using parameters like travel times, density conditions, delays, queue lengths, and the number of stops.

Apart from the conventional parameters, HCM emphasizes the significance of user perceptions in determining the overall performance measure of a road facility.[13] These additional parameters include driver experience, traffic composition, surrounding scenery or aesthetics, and pavement conditions. Trucks on freeways and at signalized intersections contribute indirectly to the overall LOS considering user perceptions .[13] In particular, the presence of trucks in the traffic stream result in "psychological and practical" effects, which are quantified by the additional spacing with the heavy vehicles and speed differences in the traffic stream.[13] The concept of passenger car equivalent factor was introduced to consider the influence of trucks on the traffic stream and is discussed in the next subsection.

2.2 Passenger Car Equivalent (PCE) Estimation Methods

The HCM proposed a unit named "passenger car equivalent (PCE)" to account for the variations in traffic stream composition.[14] PCE indicates the number of passenger cars which will result in the same operational performance as a single heavy vehicle considering similar traffic, control, and road conditions.[15] The PCE of trucks varies depending on parameters such as grade, vehicle speed, and facility type.[14, 15] PCE estimation aids in determining the LOS measures.[14] The HCM estimates trucks' PCE to analyze the capacity, delay, and LOS of a road facility.[16]

The HCM defines heavy vehicles as buses, recreational vehicles, and trucks. However, one of the main drawbacks of the PCE estimation is that it does not consider the weight and vehicle power characteristics (such as the weight to horsepower ratios), something which distinguishes trucks from passenger cars.[16] The service measures used in HCM do not account for travel time reliability measures.[16]

Traffic stream parameters are highly distinct and complex.[14, 15] The PCE values would be highly beneficial in evaluating the overall traffic flow, considering the far-reaching impact of trucks on the overall traffic stream. In the past, researchers have proposed various PCE estimation methods based on parameters such as headway,[17, 18] delay,[19] speed,[20] queue discharge flow,[21] density,[22] and travel time.[23]

Greenshield et al. (1946)[17] proposed a headway-based passenger car unit (PCU) for signalized intersections, which is estimated by computing the ratio of the average headway of the vehicle type 'i' (H_i) with the average headway of the passenger car (H_c). Krammes and Crowley (1986)[18] found out that the influence of the vehicle type on the vehicle spacing varies based on the vehicle type (even within different combinations of trucks). In other words, the spacing between truck-to-truck is far lower than the truck-to-car spacing. On the other hand, passenger cars maintained slightly larger spacing with trucks than other passenger cars.[18] Hence, researchers proposed a spatial-headway-based method to compute the heavy vehicle PCE for freeways.[18] Unlike the Greenshield model, this equation considered the lagging time headway for passenger cars and the mean lagging time for trucks (with trucks or passenger cars leading).[18]

Craus et al. (1980)[19] proposed a methodology to compute PCE using vehicle delays. They suggested computing the ratio of delay caused by trucks to that of passenger cars.[19] Some of the assumptions made in their research include the consideration of only free-flow speed conditions, and maintenance of constant speed of the following vehicle after the lead vehicle overtakes.[19] Further, the study only accounts for trucks with low speeds.[19]

Using the Greenshield traffic flow model, Huber (1982) proposed computing the PCE of trucks using the flow and traffic density parameters as the ratio of traffic volume of mixed conditions to the passenger cars.[22] One of the prime assumptions is the equality of mean travel times for mixed and basic vehicle flows. Static speed and volume parameters were assumed while computing the PCE values. Further, the concept of vehicle travel times was not explored. Al-Kaisy et al. (2002)[21] computed PCE using the queue discharge at the freeways. The values proposed by HCM are much lower than the ones obtained by simulation. Similarly, Giuffrè et al. (2015)[24] considered a simulation-based approach to compute PCE for trucks on freeways. However, in this case, the PCE values were nearly equivalent to the ones predicted by HCM.

Keller and Saklas (1984)[23] proposed the PCE estimation of trucks using vehicle travel times in association with the data obtained from vehicle simulations. The PCE estimated is computed as the ratio of the vehicle type's total travel time over the network to the total travel time of the base vehicle time over the network (in hours).[23] However, these findings are not applicable to all real-world scenarios (for example, with high turning volumes).

Measures such as travel times of a road are highly beneficial, considering their role in PCE estimation and as a performance measure. Some recent studies have explored the PCE of trucks from a travel time perspective.[25, 26]

2.3 Concept of Travel Time Reliability

Travel time reliability is one of the commonly used terms to indicate the consistency in the particular service, mode, trip, or corridor for a specific time period.[12, 27] Travel time reliability, in other words, is an indicator of the user perspective, which indicates how reliable the system is .[12, 27, 28] Travel time data from probe sources are majorly used to compute the travel time reliability due to their higher frequency of vehicle samples and the accuracy of the collected samples.[29] Truck travel time reliability plays a significant role in traffic analysis intending to avoid disruptions or inconsistencies in travel times attributed to fluctuation in service patterns.[29] Further, the concept of travel time reliability also assists in evaluating transportation alternatives.[30, 31]

One of the main steps in assessing the operational performance using the travel time measures is identifying the appropriate measure. The United States Department of Transportation (USDOT) proposed using planning time (PT), buffer time (BT), planning time index (PTI), and buffer time index (BTI) to compute the travel time reliability.[32] Other commonly used reliability measures for congestion management include standard deviation (of travel time) and travel time index (TTI).[29]

The travel time measures selected should be tailored to the study purpose, type of problem, and data used. Yazici et al. (2012)[33] analyzed the travel time reliability trends and variation based on the time of the day and day of the week in New York City. Their results indicated that the congestion was best captured using the coefficient of variance and indices of skewness and variance (λ^{skew} and λ^{var}). However, each measure showed variability based on the specific time period considered for analysis. Based on the travel time trends, off-peak periods such as the mid-night and early morning (until 7 AM) indicated unreliability mainly due to the signal timing patterns (Yazici et al., 2012).[33]

By considering the travel time variations, Franklin and Karlstorm (2009)[34] investigated the travel time reliability over a typical weekday on selected arterial segments in Stockholm. Lateness factor was modeled using the road characteristics and location parameters (like core urban area, fringe, and outer areas).

The instability in congestion rates during the peak periods is better captured by the lateness factor.[34] Carrion and Levinson (2012)[35] performed the meta-analysis of travel time to research the differences among travel time reliability measure estimates. Their results indicated that mean and variance of travel times are better indicators of travel time variability based on the temporal aspects than other travel time measures.[35]

Chen et al. (2003)[11] computed the travel time reliability measures for the Interstate 5 corridor in the City of Los Angeles, CA, to examine the LOS. Their results indicated that the mean, median, and 90th percentile travel time had shown similar trends in indicating the variability over various times of the day. Overall, few studies have explored the travel time reliability concept to assess truck travel time performance or the PCE of trucks.[25, 26]

2.4 Correlations with Travel Time Reliability Measures

The relationship between travel time reliability measures is of great significance, especially when choosing a single or limited number of performance measures to assess the performance of a road. Pu (2011)[36] explored relationships within travel time reliability measures (variance, BTI, PTI, standard deviation, and frequency of congestion) by assuming a log-normal relationship. Their results implied that the coefficient of variance serves as a "proxy" for many variables such as PTI, median-based buffer index, and skew-statistic.[36] However, the consideration of standard deviation while computing the coefficient of variance raises concerns, as it is termed "unstable".[36] Chase et al. (2013)[37] chose semi-standard deviation travel time as an appropriate performance measure to analyze the freeway segments. Their results also indicated that the majority of the travel time performance measures are correlated to the average travel rate.[37]

Inter-relationships between the travel time performance measures were explored in the past to understand the degree of relationships and select suitable travel time performance measures for assessment.[38–40] The average travel time (ATT), BT, and BTI were found appropriate for assessing the operational performance, congestion, or reliability of a facility.[38, 40]

While many researchers proposed using the variance-based travel time measures, some of the studies contradict the usage of these variance-based measures, such as the standard deviation and covariance of travel times.[41] Van Lint et al. (2008)[41] conducted travel time reliability analysis to establish a comparison between the classical measures (like standard deviation and covariance) and skew-based measures (λ^{skew} and λ^{var}). Their results indicated that the travel time distribution is left-skewed, and hence, classical measures do not explicitly indicate reliability by considering the skewness factor. Further, none of the measures indicated consistency in terms of the temporal aspects of the travel times (time of the day factors).

2.5 Truck Operational Performance Measurement

Performance measurement in terms of travel times is important exclusively for trucks due to their need for just-in-time delivery strategies. Some of the travel time data collection strategies associated with the trucks include the usage of Global Positioning Systems (GPS),[42–45] probe data sources (Bluetooth or Wi-Fi data),[46, 47] or sensors near Weigh-in-Motion Stations (WIMs).[48–50] Despite the advantages of each data collection strategies, some of the potential challenges include the data cleaning difficulties, inaccuracies,[42] loss of signals during collection,[42] data security/privacy,[43, 49] resource constraints,[49] and the presence of a large number of outliers in the data.[46]

Truck operational performance measures from the GPS data include the number of trips in the traffic analysis zones,[42, 43] travel time reliability measures, [25, 43, 45] sample size,[43] vehicle speeds,[42, 43] daily truck delay and delay cost,[44] and reliability index (80th percentile travel time/travel time at specified threshold speed).[44, 45] Considering the Intelligent Transportation System (ITS)-based approaches like the WIM, researchers used performance measures like standard deviation of travel time,[49, 50] ATT,[25, 42, 49, 50], 80th and 95th percentile travel times,[48] TTI,[50] PTI,[50] reliability rating,[50] and misery index.[50] Travel time performance measures based on the probe vehicle-based data also included the usage of percentile travel time measures.[46]

2.6 Existing Efforts on the Freight Mobility and Performance

The freight industry contributes to the national economy by transporting a wide range of goods and providing jobs to millions of people.[51] On the other hand, growth in the freight industry raises concern due to increased demand in an "already congested" highway network.[13] Freight infrastructure and mobility have become an even bigger priority in the United States since the emergence of MAP-21.[52] Particularly, Section 1115 of MAP-21 requires an evaluation of the freight-specific projects to invest in and improve the performance of the transportation system.[52]

Many state agencies have developed and initiated projects focusing on freight mobility and operational performance by bottleneck identification/assessment,[52–55] freight planning models,[56, 57] intermodal plans,[58–60] and freight improvement.[61] Further, FHWA recommends some of the measures like average speed, reliability, variance, and crash rates to be classified under the measures of freight performance.[62]

2.7 Limitations of Past Research

Considering the significant contribution of trucks, it is important to study their operational performance. Particularly, the availability of probe data by the vehicle type enables researchers to rely on real-world travel time information exclusive to trucks. However, not many researched on freight or truck performance and management using travel time data. Past studies in the field of travel time reliability and performance have explored the concept of using best possible measures and their interpretation to study a particular segment or route.

One of the main aspects of truck travel is its significance at regional level (city or county-level). There is fairly limited research on a regional-level travel time analysis. In addition, majority of the truck travel time research mainly focused on data collection strategies and importance of WIM stations. There is a significant research gap especially in the field of truck travel time reliability and performance.

Travel times of the users in a region are influenced by the land use characteristics, demographic and socioeconomic patterns.[63] In addition, the trucking activity in a region is also governed by the network parameters (road characteristics, land use, demographic, socioeconomic and other area characteristics) in the near vicinity.[12] Majority of the past research conducted in the past did not account for the influence of on-network (road characteristics) and off-network characteristics (land use, demographic and area characteristics) in the near vicinity on truck operational performance measures.

Researching the relationships to recommend suitable truck travel time performance measures and identifying influencing factors would contribute to the body of knowledge and assist decision-makers.

3. Methodology

This chapter presents the methodological framework to investigate truck travel time performance measures and their correlation with the on-network and off-network characteristics.

3.1 Selection of the Study Area and Data Collection

Truck travel performance is highly dependent on area characteristics. The selection of the study area plays a crucial role as this research is intended to capture the potential on-network and off-network characteristics influencing truck travel time performance. In order to do so, multiple counties with diverse characteristics should be considered. The criteria to select a study area are based on three attributes: area type, geographic location, and the quality of available data. Therefore, three counties in North Carolina, United States, were considered for this research: Mecklenburg County, Buncombe County, and Wake County. Mecklenburg and Wake counties were identified as the urban counties in the piedmont region with a significant amount of truck traffic activity. Buncombe, on the other hand, is a rural county in the mountains region.

Link-level truck travel time data is needed to assess truck travel time performance measures, while on-network and off-network characteristics such as land use, and demographic variables influence truck travel times and are needed for this research. Some of the on-network characteristics like the number of lanes, traffic volume, and functional class of road are available in the travel time data developed and maintained by the private data sources. Other variables like the speed limit are typically available in the open-source road characteristics data maintained by the state, regional, or local agencies.

Truck traffic demand and activity rates are not confined to a single area type. Land use characteristics play a significant role in capturing the truck operational performance. Inspecting land use information enables the planners and practitioners to better plan for strategic distribution center locations in the future. Land use data is typically available in open-source platforms at the parcel-level.

Land uses and their associated changes influence the demographic characteristics in the near vicinity. Trucking activity is highly dependent on the surrounding employment, demographic, and other characteristics like the household size. While the land use describes the type of zoning, comprehensive information about the population or employment estimates helps in understanding the truck traffic patterns better. The demographic estimates are typically available at varying levels like the census block, census tract, and traffic analysis zones (TAZs). The regional transportation planning model uses the demographic information at the TAZ-level to model travel demand and is a good source data source.

Two attributes should be considered for selecting an appropriate data source: demographic data collection time frame and the measured entity. TAZ estimates are updated once every five years, whereas census data, on the other hand, are typically collected once every ten years. TAZ-level data was considered due to the superior reliability and quality compared to the census data in this research.

Demographic estimates data are also available in the regional transportation planning model databases and could be obtained from Metropolitan Planning Organizations (MPOs) of the respective counties. Chapter 4 provides a detailed overview of the study area, data collection, and processing.

3.2 Data Processing

This step involves travel time data processing and filtering, followed by the extraction of on-network and off-network characteristics.

Raw travel time of trucks obtained at the link-level was processed to compute travel time performance measures by the time of the day and day of the week. Data filtering was performed based on the number of vehicle samples collected and the presence of outliers prior to travel time data processing.

The on-network characteristics were extracted from the available data sources. Quantifying variables is one of the most important steps considering the distinctive properties of each variable. The explanatory variables like the annual average daily traffic (AADT) were scaled to 1000 to match with other values in the dataset. Further, variables like the functional class and data density were considered as the categorical variables.

Capturing off-network characteristics depends on the extent of influence of truck traffic. They can be captured using a spatial method named buffer analysis. A buffer along a selected road link defines the influence area. Varying buffer widths need to be explored to capture the explanatory variables and select a suitable buffer width for defining the truck influence area.

In a particular buffer, there are multiple land uses. The land use data are quantified as the area of each land use category in the buffer. Similarly, weighted average values of the population and other demographic variables from TAZs are computed and included in the dataset.

3.3 Truck Travel Time Performance Measures and their Correlation with On-Network and Off-Network Characteristics

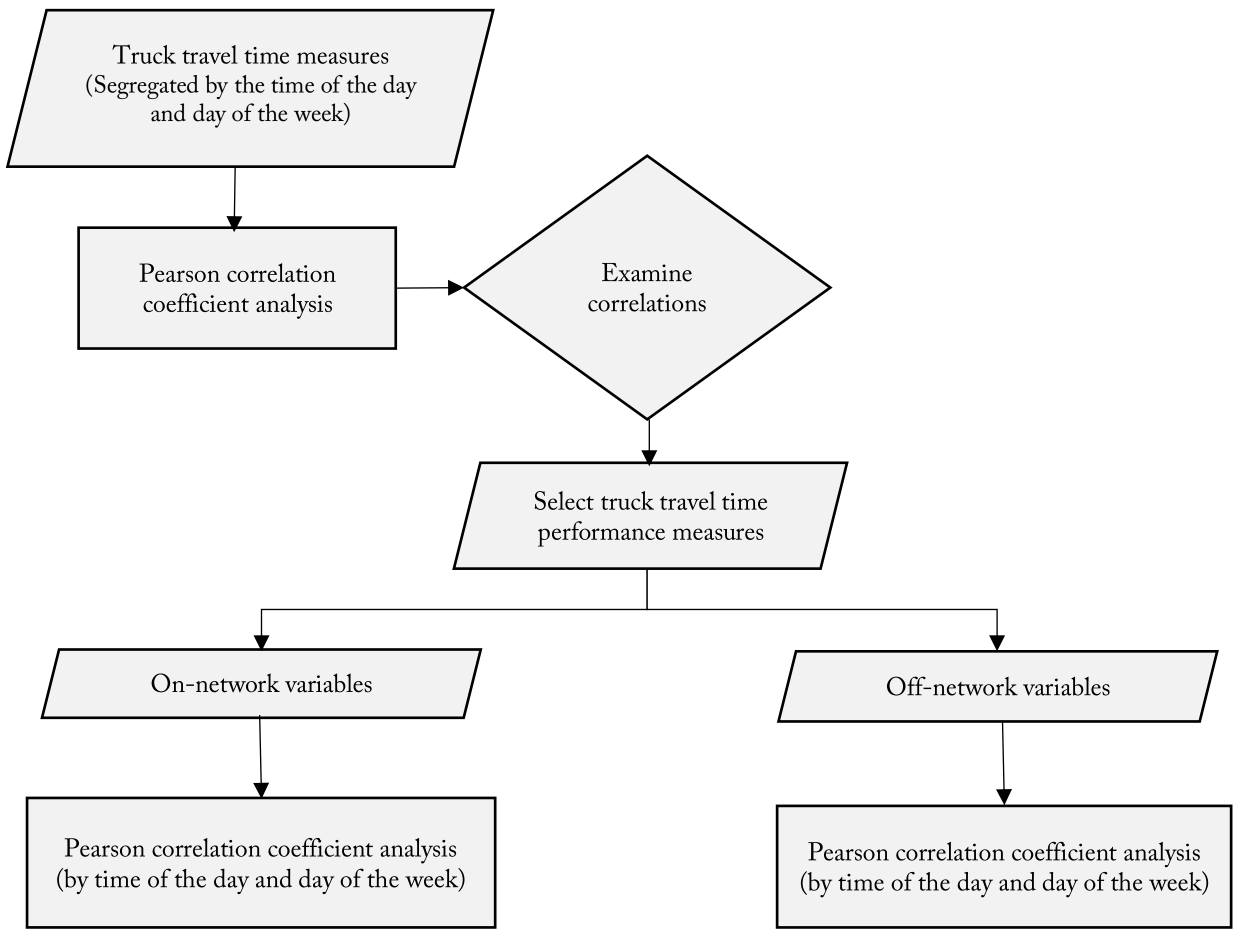
Truck travel times vary based on the time of the day and day of the week. Various travel time measures are currently used to assess the operational performance of passenger cars or traffic streams. The research on truck traffic and their operational performance is fairly new. Hence, there are no defined or widely acceptable truck travel time performance measures at present.

Examining relationships between the travel time performance measures is important to select suitable performance measures based on the study purpose. The applicability of these performance measures for trucks is examined using Pearson correlation coefficient analysis.

Pearson correlation coefficient is a popular measure to examine the linear association between two variables.[64] The Pearson correlation coefficient can be equal to 0 (indicating no correlation), equal to ±1 (indicating a strong positive or negative correlation) or range from -1 to +1. The degree of relationship is explained based on the confidence level and the Pearson correlation coefficient. Correlation coefficients which are at least significant at a 95% confidence level are considered to define the correlation between any two selected travel time performance measures.

Figure 1 summarizes the methodology adopted in this research.

Figure 1. Methodological Framework



The truck travel time measures computed are analyzed using the Pearson correlation coefficient analysis. The data is segregated based on the time of the day and day of the week. The travel time performance measures, which are correlated with a majority of other travel time measures, by the time of the day and day of the week, are considered as suitable performance measures. They are also identified by their suitability to conduct transportation studies, such as assessing operational performance and LOS, trip planning, before-after evaluation, and ranking segments. The influence of the on-network (road) characteristics and off-network characteristics (land use, demographic and characteristics) on the selected truck travel time performance is then examined.

4. Study Area, Data Collection, and Processing Methods

This chapter provides an overview of the study area, data, and data processing. Descriptive statistics are also presented in this chapter.

4.1 Study Area and Data

Three counties in North Carolina, United States, were considered for this research based on the geographic location, development type, and availability of data. They are Mecklenburg County, Buncombe County, and Wake County. Mecklenburg County and Wake County are urban counties in the piedmont region, while Buncombe is a rural county in the mountainous region of North Carolina, United States. Travel time data for the year 2019 was obtained from National Performance Management Research Dataset (NPMRDS) dataset at five-minute intervals. NPMRDS is part of the INRIX with a coverage of over 400,000 road links across the United States with high accuracy in travel time data.

Each road link is identified with a unique nine-digit Traffic Message Channel (TMC) Code. The raw truck travel time data set for each road link consists of the variables such as the date-time stamp of record, average speed, truck travel time, reference speed, and data density. The date-time stamp ensures the time and date of collection, corresponding speed information, reference speed, and the data density condition. The reference speed variable is defined as the free-flow mean speed of the corresponding road link. This measure is computed using the 85th percentile speed amongst all the time periods. Data density indicates the number of possible reporting vehicles in the corresponding time interval. It is classified into three groups with density condition "A" indicating one to four vehicles, density condition "B" indicating five to nine vehicles, and density condition "C" indicating ten or more vehicles . The on-network characteristics in the database include the length of the segment, route characteristics, and other traffic characteristics (such as the traffic volume).

The raw travel time dataset also consists of supporting data associated with location referencing metadata and the shapefiles. The network characteristics such as the AADT, road functional class, and number of through lanes were collected from the shapefiles.

Off-network characteristics like land use and demographic data were also considered in this research. The demographic and socioeconomic data were obtained from the MPOs in GIS-shapefile format, represented at the TAZ level. TAZ is defined as the areas where the demographic, socioeconomic and the traffic characteristics are considered to be similar all across the zone.

The land use data for the selected counties were obtained from the open-source data platform in GIS-shapefile format with information represented at a parcel-level.

4.2 Data Processing and Descriptive Statistics

Data processing steps involved the raw travel time data processing and filtering, followed by the extraction of on-network characteristics and off-network characteristics.

Link-level truck travel times for selected times of the day, weekday, and weekend traffic were extracted. A total of four times of the day were considered (morning peak hour: 8:00 AM - 9:00 AM, afternoon peak hour: 12:00 PM - 1:00 PM, evening peak hour: 5:00 PM - 6:00 PM and night-time hour: 10:00 PM - 11:00 PM). Descriptive travel time measures, travel time percentile measures, and travel time reliability measures were computed for each link by the time of the day and day of the week. In addition to the travel time measures, the reference speed and data density were also processed.

The percentage of samples falling under each category were computed to quantify the data density. The processed data was joined with the link characteristics to extract details like the length of the road link and AADT. The AADT was scaled by thousands for analysis. The final dataset has descriptive travel time measures and other variables such as time of the day, day of the week, reference speed, the total number of samples, AADT (in thousands), and the percentages of samples in each density condition.

Road links with lower number of samples and smaller link lengths could lead to some bias as travel time performance measures are expressed by the mile. Hence, data filtering was performed by excluding the links with sample size less than 52 and segment length of less than 0.06 miles (approximately, 300 feet).

The filtered travel time data were divided into eight individual datasets (one for each time of the day and day of the week) to extract the common links in all the datasets. This step was performed to ensure that the links for the research contained travel time data associated with all the times of the day and days of the week considered.

The final dataset consists of a total of 631 road links with 344 links in Mecklenburg County, 181 links in Wake County, and 106 links in Buncombe County. Figures 2, 3, and 4 show the road links considered for analysis in each respective county.

Figure 2. Road Links Considered in Mecklenburg County, NC

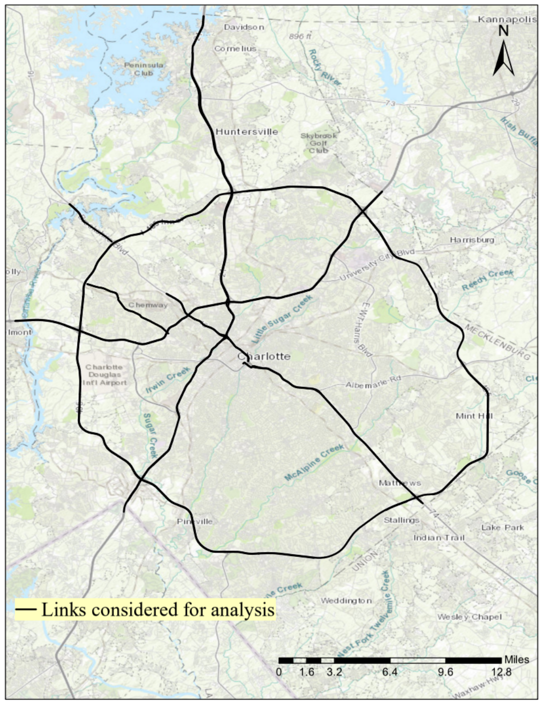


Figure 3. Road Links Considered in Buncombe County, NC

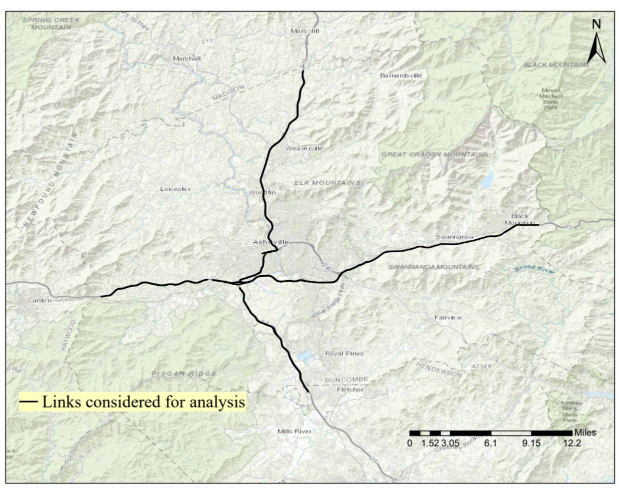
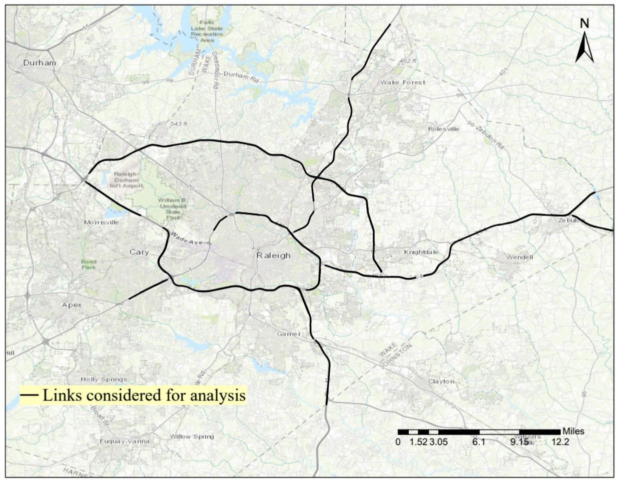


Figure 4. Road Links Considered in Wake County, NC



The truck travel times were examined to identify any outliers and anomalies in the data. Table 1 summarizes statistics of truck travel time data by time of day and day of the week.

Table 1. Summary Statistics of the Truck Travel Times

		Travel Time Measures (in minutes)				
		Minimum	Maximum	Median	Average	Standard Deviation
Morning peak	Weekday	0.66	5.05	1.00	1.11	0.45
	Weekend	0.64	2.18	0.83	0.85	0.15
Afternoon peak	Weekday	0.66	3.21	0.86	0.90	0.20
	Weekend	0.65	3.32	0.85	0.90	0.25
Evening peak	Weekday	0.67	6.15	1.15	1.30	0.61
	Weekend	0.63	2.95	0.85	0.89	0.22
Night-time	Weekday	0.63	3.44	0.84	0.88	0.25
	Weekend	0.64	2.57	0.83	0.87	0.20

There is a significant difference between the maximum travel times for the weekend compared to the weekday (irrespective of the time of the day). Similarly, for all times of the day (with the exception of the night-time hour), a higher standard deviation in travel times was observed for the weekday than the weekend.

Truck travel time performance measures were then computed using the processed travel time data. The travel time measures are divided into three categories: the descriptive travel time measures, percentile travel time measures, and travel time reliability measures. The descriptive measures considered include minimum travel time (MinTT), maximum travel time (MaxTT), ATT, and standard deviation of the travel time. The percentile travel time measures considered include 5th, 10th, 15th, 25th, 50th, 75th, 85th, 90th, and 95th percentile travel times. The travel time reliability measures considered include the PT, PTI, BT, BTI, TTI, and skew-width measures (λ^{Skew} and λ^{Var}). Measures like PTI and TTI of a link are based on the free-flow travel time, which was computed using historical free-flow travel time patterns of the corresponding link. The other measures are defined as follows.

- Planning time (PT): PT is defined as the 95th percentile travel time.[27, 32] It is an indicator of travel time during congested conditions.
- Planning time index (PTI): PTI is the ratio of the PT to the free-flow travel time (Equation 1).[27, 32]

$$PTI = \frac{PT}{Free-flow\ travel\ time} \quad (1)$$

- Buffer time (BT): BT is the difference between the PT and the ATT (Equation 2).[27, 32] It is an indicator of extra time the motorists consider planning for reaching their destination on time.

$$BT = PT - ATT \quad (2)$$

- Buffer time index (BTI): BTI is the ratio of the BT to the ATT (Equation 3).[27, 32] It represents the percentage of extra time the motorists consider planning for reaching their destination on time.

$$BTI = \frac{BT}{ATT} \quad (3)$$

- Travel time index (TTI): TTI is the ratio of the ATT to the free-flow travel time (Equation 4).[27] It represents the extra time the motorists consider than the free-flow travel time for reaching their destination on time.

$$TTI = \frac{ATT}{Free-flow\ travel\ time} \quad (4)$$

- Skew-width measures: λ^{Skew} is defined as the ratio of the difference between the 90th and the 50th percentile travel times to the difference between the 50th and the 10th percentile travel times. λ^{Var} is defined as the ratio of the difference between the 90th and the 10th percentile travel times to the 50th percentile travel time. Larger magnitudes of λ^{Skew} implies higher probability travel times of road to be extreme (either high or low). Larger magnitudes of λ^{Var} implies a wider distribution of travel times with respect to its median (the 50th percentile travel time). λ^{Skew} and λ^{Var} are computed using equations 5 and 6.[41]

$$\lambda^{Skew} = \frac{(90th\ percentile\ travel\ time - 50th\ percentile\ travel\ time)}{(50th\ percentile\ travel\ time - 10th\ percentile\ travel\ time)} \quad (5)$$

$$\lambda^{Var} = \frac{90th\ percentile\ travel\ time - 10th\ percentile\ travel\ time}{50th\ percentile\ travel\ time} \quad (6)$$

The 15th percentile travel time is used as the free-flow travel time.

The on-network characteristics considered include the road functional class (as three binary variables for each class), AADT, reference speed, speed limit, area type (as a binary variable), and data density (A, B, and C).

Table 2 summarizes the frequency distribution of the on-network characteristics considered for analysis in this research.

Table 2. Frequency Distribution of On-Network Characteristics

Variable	Category	Frequency (%)
Functional class	Interstate	499 (79.10)
	Principal arterial: other freeways and expressways	71 (11.30)
	Principal arterial: other	61 (9.70)
Speed limit	35 mph	228 (36.10)
	45 mph	17 (2.70)
	50 mph	12 (1.90)
	55 mph	143 (22.70)
	60 mph	69 (10.90)
	65 mph	64 (10.10)
	70 mph	98 (15.50)

As stated previously, the data density was quantified as the percentage of samples in the condition. It is an indicator of the frequency of congestion. The data density C indicates a relatively greater number of vehicles in a single timestamp compared to data density A and data density B. Table 3 summarizes the data density descriptive statistics.

Table 3. Summary of Data Density

		Density Condition	Minimum	Maximum	Median	Average	Standard Deviation
Weekday	Morning peak	A	6.44	100.00	94.88	82.59	22.40
		B	0.00	65.70	5.12	16.04	19.70
		C	0.00	56.34	0.00	1.37	4.31
	Afternoon peak	A	3.86	100.00	91.44	76.16	27.49
		B	0.00	65.58	8.56	20.71	22.41
		C	0.00	77.49	0.00	3.14	7.68
	Evening peak	A	8.86	100.00	97.55	88.06	17.92
		B	0.00	71.45	2.44	11.26	16.05
		C	0.00	43.80	0.00	0.68	3.10
	Night-time	A	42.58	100.00	99.65	96.92	6.24
		B	0.00	54.00	0.35	3.05	6.09
		C	0.00	3.43	0.00	0.03	0.22
Weekend	Morning peak	A	72.79	100.00	100.00	98.89	2.60
		B	0.00	26.88	0.00	1.11	2.60
		C	0.00	0.33	0.00	0.00	0.02
	Afternoon peak	A	50.24	100.00	99.65	97.35	5.49
		B	0.00	47.47	0.35	2.64	5.42
		C	0.00	2.28	0.00	0.01	0.12
	Evening peak	A	44.82	100.00	100.00	97.77	5.16
		B	0.00	52.10	0.00	2.21	5.02
		C	0.00	3.07	0.00	0.02	0.19
	Night-time	A	73.57	100.00	100.00	99.34	1.78
		B	0.00	25.93	0.00	0.66	1.76
		C	0.00	0.51	0.00	0.00	0.02

Land use data obtained in the GIS-shapefile format contains information of each parcel such as the make year, type of land use, land use code, land use description, and area of the parcel. The raw data consisted of multiple categories of the land use description. Hence, these categories were reclassified for each county separately to ensure consistency in the final dataset. In the final dataset, a total of 19 categories were considered. The categories and their descriptions are shown in Table 4.

Table 4. Land Use Variables and Descriptions

Land Use Variable	Description
Agricultural	Land use parcels such as farms, commercial forestry, pasture, and tree farms
Airport	Airport or air-related parcels
College	School and college/university parcels; both public- and private-owned institutions
Government	Land use parcels owned by state or municipal authorities
Institutional	Parcels where services are provided for the community, such as daycare and church
Medical	Hospitals, pharmacy, and medical-based parcels
Light commercial	Constrained to community-based services such as fast-food centers, commercial stores (like laundry), and service stations
Heavy commercial	Commercial land use parcels such as shopping mall, furniture stores, and other areas with significant commercial activity
Light industrial	Light manufacturing-based industries and warehouse-based land use parcels
Heavy industrial	Industry-based land use parcels involving small manufacturing services and wastewater treatment plans
Single-family	Residential: fully detached, semi-detached, a row house or a townhome
Multi-family	Residential: condominium houses, multi-dwelling residential units, apartment buildings, and mobile home parks
Office	Land use parcels mainly for administrative, office-related, or business parks
Recreational	Land use parcels such as the bowling alley, theatre, golf course, gaming facility, and other areas designated for amusement
Resource	Resource land use parcels include wetlands and creeks
Retail	Parcels allocated for retail purposes; include convenience/department stores and supermarkets
Transportation	Parcels such as trucking rest areas, right-of-way, or transportation/parking services
Unknown	Unknown parcels
Vacant	No land use category is allocated

Demographic data at the TAZ level were obtained from the corresponding MPOs in GIS-shapefile format. Selected variables considered include household size, population density, and employment density. The raw data consists of the population and employee estimates in the TAZs. Hence, the population and employment density were computed using equations 7 and 8.

$$Population\ density = \frac{Number\ of\ people\ in\ the\ TAZ}{Area\ of\ the\ TAZ\ (in\ square\ miles)} \quad (7)$$

$$Employement\ density = \frac{Number\ of\ people\ employed\ in\ the\ TAZ}{Area\ of\ the\ TAZ\ (in\ square\ miles)} \quad (8)$$

Buffers are used to capture the proximity relationships for an entity (roads in this case). They create a border with the specified buffer width indicating the influence area. Network buffers are created as the links are linear.

A buffer width of at least 0.25 miles is preferred to assess the influence of off-network characteristics on trucks and their associated performance.[65, 66] Two different buffer widths were considered to define the influence area (0.25 miles and 0.50 miles) and examine their correlations with the truck travel time performance measures in this research.

Land use data and demographic data were overlaid on the generated buffers. The “intersect” feature was used to extract the data in each buffer. The area of influence for each land use category was computed. Figures 5 and 6 shows a sample network buffer along with the overlaid land use and TAZ data. The buffer is divided into numerous units after the “intersect” operation is performed.

Figure 5. Buffer Overlaid on Land Use Data

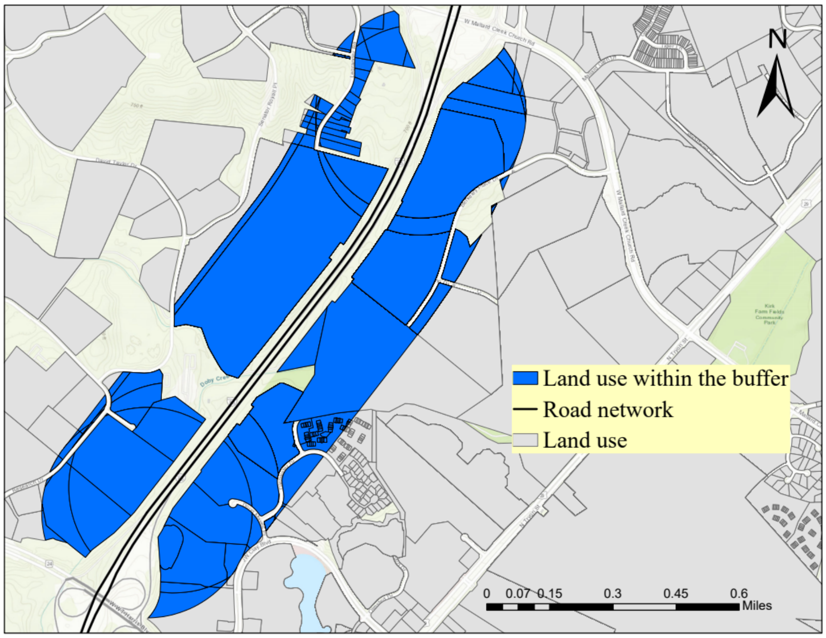
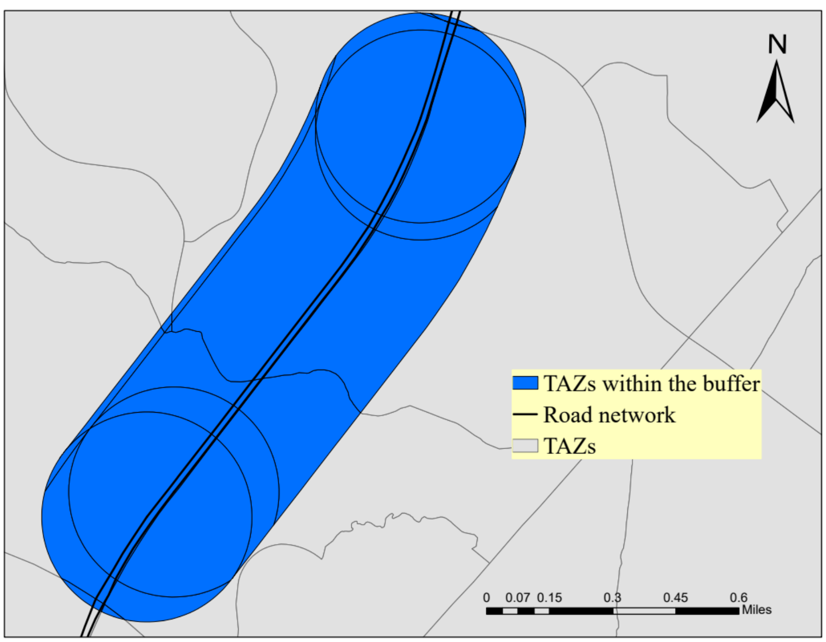


Figure 6. Buffer Overlaid on TAZ Data



The population estimates, number of household units, population density, and employment density are computed using equations 9 and 10.

$$P_i = \sum_j \frac{A_{j,i}}{A_j} \times P_j \quad (9)$$

where P_i is the population estimate or the number of household units of the buffer "i", $A_{j,i}$ is the area of the TAZ "j" in the buffer "i", P_j is the population estimate or the number of household units of the TAZ "j", and A_j is the total area of the TAZ "j".

$$PD_i = \frac{\sum_j A_{j,i} \times PD_j}{A_i} \quad (10)$$

where PD_i is the population (or employment) density of the buffer "i", $A_{j,i}$ is the area of the TAZ "j" in the buffer "i", PD_j is the population (or employment) density of the TAZ "j", and A_i is the total area of the buffer "i".

As stated previously, the area of each land use type in the considered buffer widths (0.25 miles and 0.50 miles) are captured to examine their correlations with the selected truck travel time performance measures. Table 5 summarizes the total area of each land use (sum of portions around all the links by buffer width).

Table 5. Summary of Land Use Characteristics

Land Use Category	Total Area in Square Miles	
	0.25-mile	0.50-mile
Agricultural	10.73	29.39
Airport	0.70	2.11
College	17.87	81.45
Government	4.18	12.13
Heavy commercial	9.06	23.13
Heavy industrial	8.50	26.57
Institutional	16.41	46.56
Light commercial	53.48	145.78
Light industrial	45.22	131.54
Medical	1.73	3.57
Multi-family residential	172.24	540.70
Office	23.23	59.05
Recreational	8.46	24.38
Resource	5.21	16.87
Retail	7.68	17.33
Single family residential	99.16	306.37
Transportation	0.61	1.70
Unknown	16.44	51.65
Vacant	22.34	56.28

The population estimates, number of household units, population density, and employment density were also computed for each buffer width dataset. Table 6 summarizes the demographic characteristics.

Table 6. Summary of Demographic Characteristics

Variable	Buffer Width (in miles)	Minimum	Maximum	Median	Average	Standard Deviation
Population estimates	0.25	0	4444	330	503	518
	0.50	0	9826	1032	1348	1144
Number of household units	0.25	0	1823	131	202	213
	0.50	0	4024	396	540	470
Population density	0.25	0.17	9241.37	1243.96	1600.61	1428.54
	0.50	0.18	7710.48	1398.24	1651.59	1312.25
Employment density	0.25	2.57	9830.88	1146.13	1809.33	1888.07
	0.50	2.48	27556.99	1169.87	2103.01	3321.10

5. Selection of Performance Measures Based on Truck Travel Time

This chapter presents the results from the Pearson correlation coefficient analysis using truck travel time performance measures. A total of eight datasets (by time of the day and day of the week) were considered, yielding a total of eight correlation tables. The travel time variables (descriptive, percentiles, and reliability measures) by time of the day and day of the week are used to examine the correlations. The variables considered for correlation analysis are:

- Min: Minimum travel time
- Max: Maximum travel time
- ATT: Average travel time
- Var: Variance of travel time
- Std: Standard deviation of travel time
- TT5: 5th percentile travel time
- TT10: 10th percentile travel time
- TT15: 15th percentile travel time
- TT25: 25th percentile travel time
- TT50: 50th percentile travel time
- TT75: 75th percentile travel time
- TT85: 85th percentile travel time
- TT90: 90th percentile travel time
- TT95: 95th percentile travel time
- PT: Planning time
- BT: Buffer time
- BTI: Buffer time index
- PTI: Planning time index

- TTI: Travel time index
- λ^{Skew} and λ^{Var}: Skew width measures

The Pearson correlation coefficients, which are at least significant at a 95% confidence level are considered. They are presented in Appendix A (Tables A1–A8). They were classified into six categories and represented in Tables 7 through 14 accordingly with color-coded cells.

- High positive (HP) correlation coefficient: >0.5
- Moderate positive (MP) correlation coefficient: 0.3 to 0.5
- Low positive (LP) correlation coefficient: 0 to 0.3
- Low negative (LN) correlation coefficient: -0.3 to 0
- Moderate negative (MN) correlation coefficient: -0.5 to -0.3
- High negative (HN) correlation coefficient: <(-0.5)

Table 7. Correlations between the Truck Travel Time Measures (Morning peak, weekday)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	MP	HP	HP																	
Std	HP	HP	HP	HP																
TT5	HP	HP	HP	MP	HP															
TT10	HP	HP	HP	MP	HP	HP														
TT15	HP	HP	HP	HP	HP	HP	HP													
TT25	HP	HP	HP	HP	HP	HP	HP	HP												
TT50	HP	HP	HP	HP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP					
BTI		MP	LP	LP	HP			LP	LP	LP	LP	MP	MP	MP	MP	HP				
PTI		MP	MP	LP	HP		LP	LP	LP	LP	MP	MP	MP	HP	HP	HP	HP			
TTI		MP	MP	LP	MP		LP	LP	LP	MP	MP	MP	MP	MP	MP	HP	HP	HP		
λ^{Skew}		LP	LP	LP	MP						LP	LP	LP	LP	LP	MP	HP	MP	LP	
λ^{Var}		MP	LP	LP	HP			LP	LP	LP	MP	MP	MP	MP	MP	HP	HP	HP	HP	HP

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table 8. Correlations between the Truck Travel Time Measures (Morning peak, weekend)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	MP	HP	MP																	
Std	MP	HP	HP	HP																
TT5	HP	HP	HP	MP	MP															
TT10	HP	HP	HP	MP	MP	HP														
TT15	HP	HP	HP	MP	MP	HP	HP													
TT25	HP	HP	HP	MP	MP	HP	HP	HP												
TT50	HP	HP	HP	MP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	MP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	MP	HP	HP	HP	HP	MP	MP	MP	MP	MP	HP	HP	HP	HP	HP					
BTI		LP	LP	MP	MP				LP	LP	LP	LP	MP	MP	MP	HP				
PTI		LP	LP	MP	MP					LP	LP	LP	LP	MP	MP	HP	HP			
TTI		MP	LP	MP	MP					LP	LP	LP	LP	MP	MP	MP	HP	HP		
λ^{Skew}		LP	LP	MP	MP				LP	LP	LP	LP	LP	MP	MP	HP	HP	HP	HP	
λ^{Var}		LP	LP	MP	HP		LP	LP	LP	LP	LP	LP	MP	MP	MP	HP	HP	HP	HP	HP

Color scale	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table 9. Correlations between the Truck Travel Time Measures (Afternoon peak, weekday)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	MP	HP	HP																	
Std	HP	HP	HP	HP																
TT5	HP	HP	HP	MP	HP															
TT10	HP	HP	HP	HP	HP	HP														
TT15	HP	HP	HP	HP	HP	HP	HP													
TT25	HP	HP	HP	HP	HP	HP	HP	HP												
TT50	HP	HP	HP	HP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	MP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP					
BTI		MP	LP	MP	HP	LP	LP	LP	LP	LP	LP	MP	MP	MP	MP	HP				
PTI		MP	LP	LP	MP		LP	LP	LP	LP	LP	LP	MP	MP	MP	HP	HP			
TTI		MP	LP	LP	MP		LP	LP	LP	LP	LP	MP	MP	MP	MP	HP	HP	HP		
λ^{Skew}		LP			LP							LP	LP	LP	LP	LP	HP	MP	LP	
λ^{Var}		MP	LP	LP	MP		LP	LP	LP	LP	LP	MP	MP	MP	MP	HP	HP	HP	HP	MP

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table 10. Correlations between the Truck Travel Time Measures (Afternoon peak, weekend)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	MP	HP	HP																	
Std	HP	HP	HP	HP																
TT5	HP	HP	HP	MP	HP															
TT10	HP	HP	HP	MP	HP	HP														
TT15	HP	HP	HP	MP	HP	HP	HP													
TT25	HP	HP	HP	MP	HP	HP	HP	HP												
TT50	HP	HP	HP	MP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	MP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP					
BTI	LP	MP	MP	MP	HP	LP	LP	LP	LP	LP	MP	MP	MP	HP	HP	HP				
PTI	LP	MP	MP	MP	HP	LP	LP	LP	LP	LP	MP	MP	MP	MP	MP	HP	HP			
TTI	LP	MP	LP	LP	MP	LP	LP	LP	LP	LP	MP	MP	MP	MP	MP	HP	HP	HP		
λ^{Skew}	LP	MP	LP	LP	MP	LP	LP	LP	LP	LP	LP	LP	MP	MP	MP	MP	HP	HP	MP	
λ^{Var}	LP	MP	LP	MP	HP	LP	LP	LP	LP	LP	MP	MP	MP	MP	MP	HP	HP	HP	HP	HP

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table 11. Correlations between the Truck Travel Time Measures (Evening peak, weekday)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	HP	HP	HP																	
Std	HP	HP	HP	HP																
TT5	HP	HP	HP	HP	HP															
TT10	HP	HP	HP	HP	HP	HP														
TT15	HP	HP	HP	HP	HP	HP	HP													
TT25	HP	HP	HP	HP	HP	HP	HP	HP												
TT50	HP	HP	HP	HP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	MP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP					
BTI		LP	LP	LP	MP					LP	LP	MP	MP	MP	MP	HP				
PTI		LP	MP	LP	MP		LP	LP	LP	MP	MP	MP	HP	HP	HP	HP	HP			
TTI		LP	MP	LP	MP	LP	LP	LP	MP	MP	HP	HP	HP	HP	HP	HP	HP	HP		
λ^{Skew}		LP			LP				LN	LN				LP	LP	LP	HP	LP		
λ^{Var}		LP	LP	LP	MP				LP	LP	MP	MP	MP	MP	MP	HP	HP	HP	HP	HP

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table 12. Correlations between the Truck Travel Time Measures (Evening peak, weekend)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	MP	HP	HP																	
Std	HP	HP	HP	HP																
TT5	HP	HP	HP	MP	HP															
TT10	HP	HP	HP	MP	HP	HP														
TT15	HP	HP	HP	MP	HP	HP	HP													
TT25	HP	HP	HP	MP	HP	HP	HP	HP												
TT50	HP	HP	HP	MP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	MP	HP	HP	HP	HP	MP	MP	MP	HP	HP	HP	HP	HP	HP	HP					
BTI	LP	MP	LP	MP	HP	LP	LP	LP	LP	LP	LP	MP	MP	MP	MP	HP				
PTI		LP	LP	LP	MP		LP	LP	LP	LP	LP	LP	MP	MP	MP	HP	HP			
TTI		LP	LP	LP	MP				LP	LP	LP	LP	MP	MP	MP	MP	HP	HP		
λ^{Skew}	LP	MP	LP	MP	MP	LP	LP	LP	LP	LP	LP	LP	MP	MP	MP	HP	HP	MP	MP	
λ^{Var}	LP	MP	LP	MP	HP	LP	LP	LP	LP	LP	LP	MP	MP	HP	HP	HP	HP	HP	HP	HP

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table 13. Correlations between the Truck Travel Time Measures (Night-time, weekday)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	HP	HP	HP																	
Std	HP	HP	HP	HP																
TT5	HP	HP	HP	HP	HP															
TT10	HP	HP	HP	HP	HP	HP														
TT15	HP	HP	HP	HP	HP	HP	HP													
TT25	HP	HP	HP	HP	HP	HP	HP	HP												
TT50	HP	HP	HP	HP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	MP	HP	HP	HP	HP	MP	MP	MP	MP	MP	MP	HP	HP	HP	HP					
BTI		LP	LP	MP	MP							LP	LP	MP	MP	HP				
PTI		LP	LP	LP	MP							LP	LP	MP	MP	HP	HP			
TTI		LP	LP	LP	MP							LP	LP	MP	MP	HP	HP	HP		
λ^{Skew}		LP		MP	MP							LP	LP	MP	MP	HP	HP	HP	MP	
λ^{Var}		LP	LP	LP	MP							LP	LP	MP	MP	HP	HP	HP	HP	HP

Color scale	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table 14. Correlations between the Truck Travel Time Measures (Night-time, weekend)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	HP																			
ATT	HP	HP																		
Var	MP	HP	MP																	
Std	MP	HP	HP	HP																
TT5	HP	HP	HP	MP	MP															
TT10	HP	HP	HP	MP	MP	HP														
TT15	HP	HP	HP	MP	MP	HP	HP													
TT25	HP	HP	HP	MP	HP	HP	HP	HP												
TT50	HP	HP	HP	MP	HP	HP	HP	HP	HP											
TT75	HP	HP	HP	MP	HP	HP	HP	HP	HP	HP										
TT85	HP	HP	HP	MP	HP	HP	HP	HP	HP	HP	HP									
TT90	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP								
TT95	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP							
PT	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP	HP						
BT	MP	HP	HP	HP	HP	MP	MP	MP	MP	MP	HP	HP	HP	HP	HP					
BTI		LP	LP	MP	MP							LP	LP	MP	MP	HP				
PTI		LP		LP	MP								LP	MP	MP	HP	HP			
TTI		LP		LP	MP							LP	LP	LP	LP	HP	HP	HP		
λ^{Skew}		LP		LP	LP								LP	LP	LP	MP	HP	HP	MP	
λ^{Var}		LP	LP	LP	MP						LP	LP	LP	LP	LP	HP	HP	HP	HP	HP

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

The correlation results indicate variation in trends from weekdays to weekends. Weekday travel times are typically expected to be higher on a link with high variance during almost all times of the day compared to the weekend. The three times of the day - morning, afternoon, and evening hours considered are termed as peak hours. The night-time hour, on the other hand, is categorized as an off-peak hour.

The results for the weekday datasets (Tables 7, 9, 11, and 13) indicate a high positive correlation (>0.5) among descriptive truck travel time and truck travel time percentile measures. The results for the weekend datasets (Tables 8, 10, 12, and 14) also indicate a similar trend (in most of the cases) in descriptive truck travel time and truck travel time percentile measures. However, variance and standard deviation are positively correlated with the minimum travel time (moderate positive correlation coefficient: 0.3–0.5) and some of the truck travel time percentile measures (<50^{th} percentile) for all times of the day considered.

Travel time reliability measures have mixed correlations with other truck travel time performance measures. BT indicates the extra time the passenger requires to consider while planning a trip. PT indicates the total travel time of the link (which includes BT). PT and BT are moderately or highly correlated with the descriptive truck travel time and travel time percentile measures.

PTI is an indicator of how much the total travel time varies from the free-flow time, while BTI indicates the percent of extra time with respect to the ATT. The results indicate low to moderate positive correlation with all the descriptive truck travel time and truck travel time percentile measures. Conversely, in the case of morning and afternoon peak hours, results from weekday datasets indicate high positive correlation with the standard deviation.

TTI represents the extra time needed for a traveler during peak hours compared to the off-peak hours. The results indicate a low to moderate positive correlation between TTI and the descriptive truck travel time and travel time percentile measures. Higher truck travel time percentile measures (>50^{th} percentile) have a moderate to high positive correlation with the TTI, whereas lower truck travel time percentile measures (<50^{th} percentile) have low to moderate positive correlation with the TTI.

Skew width measures indicate the reliability of a trip in terms of its value computed from the distribution. A high standard deviation with respect to the ATT of a road gives rise to a large value of λ^{Skew}. Similarly, a large value of λ^{Var} indicates dispersed distribution. Hence, larger values of λ^{Skew} or λ^{Var} are deemed unreliable. The results indicate a low to moderate positive correlation with the descriptive truck travel time and travel time percentile measures.

Overall, the correlations are mixed, indicating variations in trends based on the time of the day and day of the week. A scoring mechanism was used to integrate the eight Pearson correlation coefficient matrices into one matrix and examine consistency in the observed relationships. The score was allocated based on the Pearson correlation coefficient value, segregated into low, moderate, and high categories. They are listed next.

- High positive correlation coefficient: >0.5 (score = 3)
- Moderate positive correlation coefficient: 0.3 to 0.5 (score = 2)
- Low positive correlation coefficient: 0 to 0.3 (score = 1)
- Low negative correlation coefficient: -0.3 to 0 (score = 1)
- Moderate negative correlation coefficient: -0.5 to -0.3 (score = 2)
- High negative correlation coefficient: <(-0.5) (score = 3)

The sum of scores was first computed. As there are eight Pearson correlation coefficient matrices, the maximum score would be 8 3 = 24. The minimum score would be 0. The percentages are then computed by dividing the summed scores with the maximum score, i.e., 24. The percentages are summarized in Table 15. A higher percentage in Table 15 indicates a high correlation, while a lower percentage indicates a low/moderate correlation between the two truck travel time performance measures.

The descriptive truck travel time measures (MinTT, MaxTT, ATT, variance, and standard deviation) have high percentage scores (50) when compared with the truck travel time percentiles and BT but low percentage scores (<50) when compared with BTI, PTI, TTI, λ^{Skew}, and λ^{Var}. A similar pattern was observed in the case of truck travel time percentile measures. The percentage scores are 50 when PT, BT, BTI, PTI, TTI, λ^{Skew}, and λ^{Var} are compared with each other.

Overall, the descriptive truck travel time measures, truck travel time percentiles, PT, and BT are strongly correlated with each other. PT and BT are moderately or strongly correlated with BTI, PTI, TTI, λ^{Skew}, and λ^{Var}. Likewise, BTI, PTI, and TTI are moderately correlated with the descriptive travel time measures.

Selecting performance measures for the trucks involved two criteria, correlation results and findings from past research. Trip patterns and their associated travel times are influenced by the variability and reliability in travel time performance measures.[28] Measures such as the PTI and TTI were recommended by the FHWA for congestion management.[28] Previous studies conducted using data for North Carolina, United States recommend the application of ATT and BTI for before-and-after studies, evaluation of transportation alternatives/projects, congestion management, and ranking/allocation of resources.[30, 31, 39]

Based on the correlation results and past literature, ATT, PTI, TTI, and BTI were selected as truck travel time performance measures for further analysis. ATT represents the average time needed to traverse a road link. TTI indicates the extent of additional time required compared to the ATT during peak hours, while BTI represents the additional time needed above ATT during peak hours to plan a trip for travel. The selected truck travel time performance measures help in identifying patterns associated with the truck travel.

Table 15. Scores (in terms of percentage) Indicating Correlation between the Truck Travel Time Performance Measures

	Min TT	Max TT	ATT	Var	Std	TI5	TI10	TI15	TI25	TI50	TI75	TI85	TI90	TI95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max TT	100																			
ATT	100	100																		
Var	75	100	92																	
Std	92	100	100	100																
TI5	100	100	100	75	92															
TI10	100	100	100	79	92	100														
TI15	100	100	100	83	92	100	100													
TI25	100	100	100	83	96	100	100	100												
TI50	100	100	100	83	100	100	100	100	100											
TI75	100	100	100	92	100	100	100	100	100	100										
TI85	100	100	100	96	100	100	100	100	100	100	100									
TI90	100	100	100	100	100	100	100	100	100	100	100	100								
TI95	100	100	100	100	100	100	100	100	100	100	100	100	100							
PT	100	100	100	100	100	100	100	100	100	100	100	100	100	100						
BT	71	100	100	100	100	83	83	83	88	88	96	100	100	100	100					
BTI	8	50	38	58	83	13	13	17	21	25	29	54	58	71	71	100				
PTI	4	46	42	42	75	4	21	21	21	29	38	42	58	75	75	100	100			
TTI	4	50	38	38	67	8	17	17	25	33	42	54	58	67	67	92	100	100		
λ^{Skew}	8	42	17	38	54	8	8	8	17	17	17	25	38	50	50	71	100	79	54	
λ^{Var}	8	50	33	46	83	8	17	21	25	25	42	54	58	67	67	100	100	100	100	96

6. Relationships Between On-Network Characteristics and the Selected Performance Measures Based on Truck Travel Time

This chapter presents the correlations between the selected truck travel time performance measures and on-network characteristics. The on-network characteristics considered for analysis include the functional class, AADT, reference speed, speed limit, area type (as a binary variable), and data density (A, B, and C). The variables used for the correlation analysis are listed next.

- Functional class: three separate binary variables for each functional class of the road in the dataset
    - Interstates
    - Principal arterials (Freeways and expressways)
    - Principal arterials – Others
- # of through lanes: number of lanes serving the through traffic on the road link
- AADT: indicator of vehicular volume on the road link
- Ref. Speed: the 85^{th} percentile speed of the road link, an indicator of the free-flow speed
- Speed limit: posted speed limit of the road link
- Area type: an indicator of urban or rural area type (1 indicates urban and 0 indicates rural)
- Data density: an indicator of data density condition (each sample in the raw database has a data density value which was quantified in the final database as the percentage of samples falling under A, B and C categories)

The Pearson correlation coefficients which are at least significant at a 95% confidence level are considered. The Pearson correlation coefficients were classified into six categories and represented as color-coded cells.

The Pearson correlation coefficient results between the selected truck travel time performance measures and the on-network characteristics are presented in Appendix B (Table B1). Table 16 summarizes the color-coded categories.

Interstates and principal arterials (freeways and expressways) are negatively correlated with the selected truck travel time performance measures. Principal arterials, on the other hand, are positively correlated with the selected truck travel time performance measures. The Pearson correlation coefficients are higher in magnitude for the weekend. These results associated with the truck travel time performance measures are attributed to the presence of uninterrupted facilities at freeways compared to the case of arterial roads.

Urban area type is positively correlated with the selected truck travel time performance measures. This could be attributed to large truck activity near access points such as the commercial areas. It could also be attributed to the presence of more interrupted flow facilities (like signals and stop signs) in urban areas. However, the association is relatively low.

The selected truck travel time performance measures by time of the day and day of the week are negatively correlated with the number of through lanes and AADT, in most cases. The coefficients are observed to be marginally higher on weekends compared to the weekdays.

The selected truck travel time performance measures are negatively correlated with the reference speed variable. PTI, TTI, and BTI are negatively correlated with the speed limit. The reference speed data is considered to be more reliable than the speed limit because of the data quality issues.

PTI and TTI are positively correlated with the density condition A during the morning peak hour. The selected truck travel time performance measures are negatively correlated with the data density condition A during the evening peak and night-time hours. Likewise, the selected truck travel time performance measures are negatively correlated with the data density condition B during weekday morning and afternoon peak hours. However, in the case of the weekend, ATT is positively correlated with the data density condition B during all the selected times of the day. TTI and PTI, on the other hand, are negatively correlated with the data density condition C during the weekend morning peak hour. The selected truck travel time performance measures are positively correlated with the data density condition C during all the selected times of the day. ATT is significantly correlated with the data density condition C during all the selected times of the day. PTI and TTI, on the other hand, are positively correlated with the data density condition C during the weekday night-time hour.

Overall, the road functional class and reference speed are moderately or highly correlated with the selected travel time performance measures. AADT, number of through lanes, and data density conditions are less or moderately correlated with the selected truck travel time performance measures.

Table 16. Correlation between the Selected Truck Travel Time Performance Measures and On-Network Characteristics

		Travel Time Measure	Functional Class			# of Through Lanes	AADT	Ref. Speed	Speed Limit	Area Type	Data Density		
			I	PA (FE)	PA - O						A	B	C
Weekday	Morning peak	ATT	LN		LP	LN	LN	LN					LP
		PTI	LN		LP			LN	MN	LP	LP	LN	
		TTI	LN		LP			MN	LN	LP	LP	LN	
		BTI	LN		LP			LN	MN	LP			
	Afternoon peak	ATT	LN		MP	LN	LN	LN					LP
		PTI	MN		HP	LN	LN	HN	LN	LP	LP	LN	
		TTI	MN		HP	LN	LN	HN	LN	LP	LP	LN	
		BTI	MN		HP	LN	LN	HN	LN	LP	LP	LN	
	Evening peak	ATT	LN	LN	LP	LN	LN	LN			LN	LP	LP
		PTI		LN			LP	LN	LN	LP			
		TTI		LN			LP	LN		LP			
		BTI		HN			LP	MN	HN	LP			
	Night-time	ATT	LN		LP	LN	LN	LN			LN	LP	LP
		PTI	LN		LP			MN	LN	LP	LN	LP	LP
		TTI	LN		MP		LN	HN	LN	LP			
		BTI			LP			MN	LN	LP	LN	LP	LP
Weekend	Morning peak	ATT	LN		LP	LN	LN	LN					LP
		PTI	MN		HP	LN	LN	HN	LN		LP	LN	
		TTI	MN		HP	LN	MN	HN	LN		LP	LN	
		BTI	MN		HP	LN	LN	HN	LN		LP	LN	
	Afternoon peak	ATT	LN		MP	LN	LN	LN					LP
		PTI	MN		HP	LN	LN	HN	LN		LP	LN	
		TTI	MN		HP	LN	LN	HN	LN		LP	LN	
		BTI	MN		HP	LN	LN	HN	LN				
	Evening peak	ATT	LN		LP	LN	LN	LN			LN	LP	LP
		PTI	MN		HP	LN	LN	HN	LN	LP			
		TTI	MN		HP	LN	LN	HN	LN	LP			
		BTI	MN		MP	LN	LN	HN	LN	LP			
	Night-time	ATT	LN		LP	LN	LN	LN			LN	LP	LP
		PTI	LN		MP			MN	LN	LP	LN	LP	LP
		TTI	MN		MP		LN	HN	LN	LP			
		BTI	LN		LP			MN	LN	LP			

Note: I is interstates, PA(FE) is principal arterials (freeways and expressways), and PA-O is principal arterials (others).

Color scale						
	HN	MN	LN	LP	MP	HP

7. Relationships Between Off-Network Characteristics and the Selected Performance Measures Based on Truck Travel Time

This chapter presents the correlations between the selected truck travel time performance measures and off-network characteristics, categorized into land use and demographic variables. The variables used for the correlation analysis are listed next.

Land use variables:

- Agri.: Agricultural land use
- Airport: Airport land use
- College: College land use
- Gov.: Government land use
- Commercial: Light and heavy commercial land uses
- Industrial: Light and heavy industrial land uses
- Inst.: Institutional land use
- Med.: Medical land use
- Residential: Single-family and multi-family residential land uses
- Ofc.: Office land use
- Rec.: Recreational land use
- Resource: Resource land use
- Retail: Retail land use
- Transport: Transportation land use
- Unkn: Unknown land use
- Vacant: Vacant

Demographic variables:

- Population estimates
- Household units
- Population density
- Employment density

The Pearson correlation coefficients which are at least significant at a 95% confidence level are considered. The Pearson correlation coefficients were classified into six categories and represented as color-coded cells. As stated previously, the area of each land use type in the considered buffer widths (0.25 miles and 0.50 miles) are captured to examine the correlations with the selected truck travel time performance measures. The Pearson correlation coefficients between the selected truck travel time performance measures and off-network characteristics are presented in Appendix B (Tables B2–B5). Tables 17 and 18 summarize the correlations between the selected truck travel time performance measures and land use characteristics captured using 0.25-mile and 0.50-mile buffer widths.

The college or educational land use parcels are not significantly correlated with any of the selected truck travel time performance measures. Hence, the college/educational land use is not included in Tables 17 and 18. Similarly, airport land use is not significantly correlated with the selected truck travel time performance measures, in particular when analyzed using the dataset with a 0.50-mile buffer width. Hence, airport land use is not included in Table 18. Agricultural, light industrial, light commercial, residential (single- and multi-family), transportation, and office land uses are significantly correlated with the selected truck travel time performance measures during the weekday (all times of the day). During the weekend, light commercial, light industrial, agricultural, and transportation land uses are significantly correlated with the selected truck travel time performance measures.

Agricultural land use is positively correlated with the ATT. However, the presence of agricultural land use in the vicinity has a negative correlation with PTI, BTI, and TTI. Airport land use in the vicinity (within 0.25 miles) has a low positive correlation with the ATT during the weekend afternoon peak hour.

Land uses - government, institutional, medical, recreational and retail in the vicinity of 0.25 and 0.50 miles are positively correlated with the ATT. Land uses such as commercial (light and heavy), industrial (light and heavy), and multi-family residential in the vicinity of 0.25 and 0.50 miles are positively correlated with the selected truck travel time performance measures. On the other hand, single-family residential in the vicinity of 0.25 and 0.50 miles has a high positive correlation with the ATT and low negative correlation with PTI, BTI and TTI.

Overall, land uses correlated with the selected truck travel time performance measures had low to moderate correlation coefficients with the exception of single-family residential land use.

The population estimates, the number of household units, the population density, and the employment density were also computed for each dataset. Tables 19 and 20 summarize the correlations between the selected truck travel time performance measures and demographic characteristics within 0.25 and 0.50 miles of a link.

Table 17. Correlation between the Truck Travel Time Performance Measures and Land Use Characteristics (0.25-mile buffer)

			Agri.	Airport	Gov.	Commercial		Industrial		Inst.	Medical	Residential		Ofc.	Rec.	Resource	Retail	Transp.	Unknown	Vacant
						Light	Heavy	Light	Heavy			SF	MF							
Weekday	Morning peak	ATT	LP		LP	LP	LP	LP	LP	LP	LP	HP	LP	LP	LP	LP				
		PTI	LN			LP								LP						
		TTI	LN			LP								LP				LP	LP	LP
		BTI	LN			LP								LP				LP		
	Afternoon peak	ATT	MP		LP	LP	LP	LP	LP	LP		HP	LP		LP	LP	LP	LP		
		PTI	LN			LP	LP					LN						LP		
		TTI	LN			LP	LP					LN						LP	LP	LP
		BTI	LN			LP	LP				LP	LN	LP	LP				LP		
	Evening peak	ATT	LP		LP	LP	LP	LP	LP	LP	LP	MP	LP	LP	LP		LP	LP		LN
		PTI	LN					LP		LP		LN	LP	LP		LN		LP		LN
		TTI	LN				LP			LP		LN	LP	LP		LN		LP	LP	LP
		BTI	LN					LP				LN	LP	LP		LN				LN
	Night-time	ATT	MP		LP	LP	LP	LP	LP	LP	LP	HP	LP	LP	LP	LP				LN
		PTI	LN					LP	LN				LP	LP						LN
		TTI	LN			LP		LP				LN	LP	LP				LP	LP	MP
		BTI	LN					LP			LP		LP	LP		LN				LN
Weekend	Morning peak	ATT	MP		LP	LP	LP	LP	LP	LP		HP	LP		LP	LP		LP		
		PTI				LP												LP		
		TTI	LN			LP												LP	LP	LP
		BTI	LN			LP		LP										LP		
	Afternoon peak	ATT	MP	LP	LP	LP	LP	LP	LP	LP	LP	HP	LP		LP	LP	LP	LP		
		PTI				LP												LP		
		TTI				LP	LP											LP	LP	MP
		BTI			LP	LP		LP			LP							LP		
	Evening peak	ATT	MP		LP	LP	LP	LP	LP	LP		HP	LP		LP	LP		LP		
		PTI				LP												LP		
		TTI				LP												LP	LP	MP
		BTI				LP		LP										LP		
	Night-time	ATT	MP		LP	LP	LP	LP	LP	LP		HP	LP		LP	LP		LP		LN
		PTI	LN				LP	LP						LP				LP		
		TTI	LN			LP	LP	LP				LN								
		BTI	LN				LP	LP						LP						LN

Color scale						
	HN	MN	LN	LP	MP	HP

Table 18. Correlation between the Truck Travel Time Performance Measures and Land Use Characteristics (0.50-mile buffer)

			Agri.	Gov.	Commercial		Industrial		Inst.	Medical	Residential		Ofc.	Rec.	Resource	Retail	Transp.	Unknown	Vacant
					Light	Heavy	Light	Heavy			SF	MF							
Weekday	Morning peak	ATT	LP	LP	LP	LP	LP		LP	LP	HP	LP	LP	LP		LP	LP	LP	LP
		PTI	LN									LP	LP				LP		
		TTI	LN				LP					LP	LP				LP		LN
		BTI	LN							LP		LP	LP				LP		
	Afternoon peak	ATT	MP	LP	LP	LP	LP	LP	LP	LP	HP	LP		LP	LP	LP	LP	LP	LP
		PTI	LN		LP							LP					LP		
		TTI	LN		LP							LP					LP		
		BTI	LN		LP					LP		LP	LP				LP		
	Evening peak	ATT	LP	LP	LP	LP	LP	LP	LP	LP	MP	LP	LP	LP		LP	LP	LP	LP
		PTI	LN				LP		LP		LN	LP	LP		LN		LP		LN
		TTI	LN				LP		LP		LN	LP	LP		LN		LP		LN
		BTI	LN		LP		LP				LN	LP	LP		LN			LP	LN
	Night-time	ATT	MP	LP	LP	LP	LP	LP	LP	LP	HP	LP	LP	LP	LP	LP	LP	LP	LP
		PTI	LN				LP		LP			LP	LP						LN
		TTI	LN		LP		LP				LN	LP	LP				LP		LN
		BTI	LN				LP		LP	LP		MP	LP						LN
Weekend	Morning peak	ATT	LP	LP	LP	LP	LP		LP	LP	HP	LP	LP	LP		LP	LP	LP	LP
		PTI	LN									LP	LP				LP		
		TTI	LN				LP					LP	LP				LP		LN
		BTI	LN		LP		LP										LP		
	Afternoon peak	ATT	MP	LP	LP	LP	LP	LP	LP	LP	HP	LP		LP	LP	LP	LP	LP	LP
		PTI	LN		LP							LP					LP		
		TTI	LN		LP							LP					LP		
		BTI		LP	LP		LP			LP							LP		
	Evening peak	ATT	LP	LP	LP	LP	LP	LP	LP	LP	MP	LP	LP	LP		LP	LP	LP	LP
		PTI	LN				LP		LP		LN	LP	LP		LN		LP		LN
		TTI	LN				LP		LP		LN	LP	LP		LN		LP		LN
		BTI	LN		LP		LP										LP		
	Night-time	ATT	MP	LP	LP	LP	LP	LP	LP	LP	HP	LP	LP	LP	LP	LP	LP	LP	LP
		PTI	LN				LP		LP			LP	LP						LN
		TTI	LN		LP		LP				LN	LP	LP				LP		LN
		BTI	LN				LP					LP	LP						LN

Color scale						
	HN	MN	LN	LP	MP	HP

Table 19. Correlation between the Truck Travel Time Performance Measures and Demographic Characteristics (0.25-mile buffer)

		Performance Measure	Population Estimates	Household Units	Population Density	Employment Density
Weekday	Morning peak	ATT	LN	LN	LP	LP
		PTI	LN	LN	LP	LP
		TTI			HP	LP
		BTI	HP	HP	LN	LN
	Afternoon peak	ATT			LP	LP
		PTI			LP	LP
		TTI			LP	LP
		BTI	HP	HP		
	Evening peak	ATT	LN	LN	LP	MP
		PTI	LN	LN	LP	MP
		TTI	LN		MP	MP
		BTI	HP	HP	LN	LN
	Night-time	ATT	LN	LN		
		PTI	LN	LN	LP	LP
		TTI	LN	LN		
		BTI	HP	HP	LN	LN
Weekend	Morning peak	ATT			LP	
		PTI			LP	
		TTI			HP	
		BTI	HP	HP	LN	LN
	Afternoon peak	ATT				
		PTI				
		TTI				
		BTI	HP	HP	LN	LN
	Evening peak	ATT			LP	LP
		PTI			LP	LP
		TTI			LP	LP
		BTI	HP	HP	LN	LN
	Night-time	ATT	LN	LN		LP
		PTI	LN	LN	LP	LP
		TTI	LN	LN		LP
		BTI				

Color scale	HN	MN	LN	LP	MP	HP

Table 20. Correlation between the Truck Travel Time Performance Measures and Demographic Characteristics (0.50-mile buffer)

		Performance Measure	Population Estimates	Household Units	Population Density	Employment Density
Weekday	Morning peak	ATT	LN		LP	
		PTI	LN	LN	LP	LP
		TTI			LP	
		BTI	HP	HP	LN	LN
	Afternoon peak	ATT			LP	LP
		PTI			LP	LP
		TTI			LP	LP
		BTI	MP	MP		
	Evening peak	ATT	LN	LN	MP	MP
		PTI	LN		LP	MP
		TTI	LN	LN	MP	MP
		BTI	HP	HP	LN	LN
	Night-time	ATT	LN	LN	LP	
		PTI	LN	LN	LP	LP
		TTI	LN	LN	LP	
		BTI	HP	HP		LN
Weekend	Morning peak	ATT	LN		LP	
		PTI	LN	LN	LP	LP
		TTI			LP	
		BTI	HP	HP	LN	LN
	Afternoon peak	ATT			LP	LP
		PTI			LP	LP
		TTI				
		BTI	MP	MP		
	Evening peak	ATT	LN	LN	MP	MP
		PTI	LN		LP	MP
		TTI			LP	LP
		BTI	HP	HP	LN	LN
	Night-time	ATT	LN	LN	LP	
		PTI	LN	LN	LP	LP
		TTI	LN	LN		
		BTI				

Color scale						
	HN	MN	LN	LP	MP	HP

The results indicate that ATT is negatively correlated with the population estimates and household units. Significant correlation was observed when analyzed using the weekday datasets with 0.25- and 0.50-mile buffer widths. However, in the case of the weekend data with the 0.50-mile buffer, significant low negative correlations were observed between population estimates, household units, and ATT. A strong significant positive correlation was observed between BTI and population estimates and household units, while a low negative correlation was observed between PTI and population estimates and household units. Likewise, a negative correlation was observed between TTI and population estimates and household units.

BTI is positively correlated (moderate to high correlation) with population and employment estimates in the vicinity of 0.25 miles and 0.50 miles. However, PTI and TTI are negatively correlated with population and household estimates in the vicinity of 0.25 miles and 0.50 miles. The population and employment densities are positively correlated (low to moderate correlation) with ATT, PTI, and TTI but negatively correlated with the BTI.

8. Conclusions and Scope of Future Research

This research aims to recommend selected truck travel time performance measures and examine their correlations with various on-network and off-network characteristics captured using 0.25- and 0.50-mile buffer widths. The functional class, speed limit, reference speed, number of through lanes, AADT, and data density were considered as the on-network characteristics. Similarly, the land use and demographic characteristics were considered as the off-network characteristics.

ATT, PTI, TTI, and BTI were selected as the truck travel time performance measures based on an examination of correlations between descriptive truck travel times, truck travel time percentiles, and travel time reliability measures.

The correlation between the selected truck travel time performance measures and road functional class and reference speed are relatively stronger than other on-network variables. Contrarily, AADT and the number of through lanes are less (and negatively) correlated with the selected truck travel time performance measures. These findings indicate that trucks may benefit more from using interstates than principal arterial streets. Further, interstates are also considered as the roads with multiple through lanes and high traffic volume.

Agricultural, government, light industrial, light commercial, residential (single- and multi-family), transportation, and office land uses were found to be significantly correlated with the truck travel time performance measures (weekday and weekend). However, a low to moderate correlation was observed in the case of agricultural, government, light industrial, light commercial, transportation, and office land uses, whereas a high correlation was observed for single-family residential land use.

Like the residential land use characteristics, the population estimates and household units are positively correlated with the selected truck travel time performance measures. The correlations between the selected truck travel time performance measures and demographic characteristics depend significantly on the time of the day and day of the week.

The areas susceptible to higher truck travel times or lower operational performance are arterial streets, urban areas, and roads with high traffic volumes or number of through lanes. Similarly, the presence of agricultural, light commercial, heavy commercial, light industrial, single- or multi-family residential, office, transportation, and medical land uses in the near vicinity could significantly influence truck travel times or related operational performance measures. The correlations with the off-network characteristics differ depending on the buffer width used to capture the data in addition to the time of day and day of the week.

The results and findings provide an understanding of the level of influence of on-network or off-network characteristics on the truck travel time performance measures. While these findings are valuable insights, this research should be followed up with the development of statistical, geospatial, or machine learning approaches to predict truck travel times or related performance measures.

Prediction models also help in understanding the influence of each variable on the truck travel time performance.

In addition to the modeling mechanisms, visualization techniques should be explored to generate heatmaps and/or identify links susceptible to truck congestion. The outcomes of this research combined with further work will assist practitioners and transportation engineers to better plan, design facilities, allocate resources, and implement projects.

9. Appendix A

This appendix presents the Pearson correlation coefficient matrices for each truck travel time dataset (segregated by time of the day and day of the week). The Pearson correlation coefficients which are at least significant at a 95% confidence level are presented (color-coded based on the following categories).

- High positive (HP) correlation coefficient: > 0.5
- Moderate positive (MP) correlation coefficient: 0.3 to 0.5
- Low positive (LP) correlation coefficient: 0 to 0.3
- Low negative (LN) correlation coefficient: -0.3 to 0
- Moderate negative (MN) correlation coefficient: -0.5 to -0.3
- High negative (HN) correlation coefficient: < -0.5

A blank cell indicates that the corresponding Pearson correlation is not significant at a 95% confidence level.

Tables A1 and A2 summarize the Pearson correlation coefficient results of the morning peak weekday and weekend datasets. Tables A3 and A4 summarize Pearson correlation coefficient results of the afternoon peak weekday and weekend datasets. Tables A5 and A6 summarize the Pearson correlation coefficient results of the evening peak weekday and weekend datasets. Tables A7 and A8 summarize the Pearson correlation coefficient results of the night-time weekday and weekend datasets.

Table A1. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (Morning peak, weekday)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.68																			
ATT	0.87	0.83																		
Var	0.43	0.75	0.69																	
Std	0.57	0.93	0.84	0.83																
TT5	0.99	0.69	0.89	0.44	0.59															
TT10	0.98	0.72	0.92	0.48	0.62	0.99														
TT15	0.97	0.73	0.94	0.51	0.65	0.98	1.00													
TT25	0.95	0.74	0.96	0.54	0.68	0.96	0.98	1.00												
TT50	0.89	0.77	0.99	0.60	0.75	0.91	0.94	0.96	0.98											
TT75	0.81	0.80	0.99	0.71	0.85	0.83	0.87	0.90	0.92	0.97										
TT85	0.76	0.82	0.98	0.75	0.88	0.79	0.83	0.85	0.88	0.94	0.99									
TT90	0.75	0.83	0.97	0.77	0.91	0.77	0.80	0.83	0.86	0.92	0.98	1.00								
TT95	0.71	0.87	0.95	0.79	0.94	0.74	0.77	0.80	0.83	0.88	0.95	0.98	0.99							
PT	0.71	0.87	0.95	0.79	0.94	0.74	0.77	0.80	0.83	0.88	0.95	0.98	0.99	1.00						
BT	0.50	0.81	0.81	0.81	0.95	0.53	0.56	0.59	0.63	0.70	0.83	0.88	0.92	0.95	0.95					
BTI		0.37	0.27	0.24	0.51			0.08	0.11	0.17	0.28	0.36	0.40	0.46	0.46	0.60				
PTI		0.34	0.34	0.28	0.52		0.08	0.12	0.17	0.27	0.38	0.45	0.47	0.50	0.50	0.60	0.84			
TTI		0.31	0.35	0.26	0.47		0.10	0.14	0.20	0.31	0.41	0.45	0.45	0.46	0.46	0.52	0.64	0.94		
λ^{Skew}		0.22	0.09	0.15	0.30						0.08	0.16	0.20	0.25	0.25	0.36	0.66	0.38	0.17	
λ^{Var}		0.34	0.29	0.27	0.51			0.09	0.11	0.19	0.33	0.42	0.45	0.48	0.48	0.61	0.89	0.85	0.69	0.67

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table A2. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (Morning peak, weekend)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.58																			
ATT	0.97	0.68																		
Var	0.30	0.68	0.48																	
Std	0.46	0.88	0.62	0.89																
TT5	0.99	0.60	0.98	0.32	0.47															
TT10	0.99	0.61	0.98	0.32	0.48	1.00														
TT15	0.99	0.61	0.98	0.33	0.49	1.00	1.00													
TT25	0.99	0.62	0.99	0.34	0.50	1.00	1.00	1.00												
TT50	0.99	0.63	0.99	0.38	0.53	0.99	1.00	1.00	1.00											
TT75	0.97	0.66	1.00	0.48	0.61	0.97	0.97	0.98	0.98	0.99										
TT85	0.92	0.68	0.98	0.59	0.68	0.93	0.93	0.94	0.94	0.96	0.99									
TT90	0.89	0.71	0.97	0.65	0.73	0.90	0.91	0.91	0.92	0.94	0.97	0.99								
TT95	0.83	0.73	0.93	0.74	0.79	0.84	0.84	0.85	0.86	0.88	0.93	0.97	0.99							
PT	0.83	0.73	0.93	0.74	0.79	0.84	0.84	0.85	0.86	0.88	0.93	0.97	0.99	1.00						
BT	0.41	0.61	0.59	0.92	0.84	0.42	0.43	0.44	0.45	0.49	0.60	0.71	0.77	0.85	0.85					
BTI		0.27	0.18	0.43	0.48				0.09	0.12	0.19	0.26	0.31	0.39	0.39	0.58				
PTI		0.27	0.17	0.38	0.46					0.11	0.18	0.24	0.28	0.35	0.35	0.52	0.96			
TTI		0.30	0.17	0.35	0.50					0.11	0.18	0.23	0.26	0.32	0.32	0.46	0.88	0.95		
λ^{Skew}		0.28	0.16	0.41	0.43				0.08	0.10	0.16	0.22	0.28	0.34	0.34	0.50	0.72	0.63	0.52	
λ^{Var}		0.30	0.21	0.46	0.51		0.08	0.09	0.10	0.14	0.22	0.30	0.35	0.42	0.42	0.61	0.97	0.95	0.90	0.71

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table A3. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (Afternoon, weekday)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.61																			
ATT	0.96	0.75																		
Var	0.45	0.84	0.62																	
Std	0.55	0.95	0.73	0.87																
TT5	0.99	0.64	0.98	0.48	0.59															
TT10	0.99	0.66	0.98	0.50	0.61	1.00														
TT15	0.99	0.67	0.98	0.52	0.62	1.00	1.00													
TT25	0.99	0.68	0.99	0.54	0.64	1.00	1.00	1.00												
TT50	0.97	0.71	1.00	0.58	0.68	0.99	0.99	0.99	1.00											
TT75	0.95	0.74	1.00	0.63	0.73	0.97	0.97	0.98	0.98	0.99										
TT85	0.92	0.76	0.99	0.66	0.76	0.95	0.95	0.96	0.97	0.99	1.00									
TT90	0.90	0.77	0.99	0.68	0.79	0.93	0.94	0.94	0.95	0.97	0.99	1.00								
TT95	0.85	0.80	0.96	0.74	0.84	0.88	0.89	0.90	0.91	0.94	0.97	0.98	0.99							
PT	0.85	0.80	0.96	0.74	0.84	0.88	0.89	0.90	0.91	0.94	0.97	0.98	0.99	1.00						
BT	0.48	0.73	0.69	0.78	0.86	0.53	0.54	0.56	0.59	0.64	0.71	0.76	0.80	0.87	0.87					
BTI		0.34	0.24	0.31	0.50	0.10	0.11	0.12	0.14	0.19	0.26	0.31	0.35	0.43	0.43	0.67				
PTI		0.30	0.22	0.27	0.46		0.08	0.10	0.12	0.17	0.24	0.29	0.33	0.39	0.39	0.61	0.91			
TTI		0.32	0.22	0.27	0.46		0.08	0.10	0.12	0.18	0.25	0.30	0.33	0.38	0.38	0.58	0.83	0.98		
λ^{Skew}		0.13			0.18							0.09	0.11	0.13	0.13	0.24	0.50	0.30	0.21	
λ^{Var}		0.32	0.22	0.29	0.47		0.08	0.10	0.12	0.17	0.25	0.30	0.33	0.39	0.39	0.61	0.93	0.95	0.92	0.47

Color scale	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table A4. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (Afternoon, weekend)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.66																			
ATT	0.95	0.80																		
Var	0.38	0.76	0.60																	
Std	0.56	0.95	0.76	0.88																
TT5	1.00	0.67	0.96	0.41	0.58															
TT10	0.99	0.68	0.97	0.42	0.59	1.00														
TT15	0.99	0.68	0.97	0.42	0.59	1.00	1.00													
TT25	0.99	0.69	0.98	0.45	0.61	1.00	1.00	1.00												
TT50	0.98	0.72	0.99	0.49	0.66	0.99	0.99	0.99	1.00											
TT75	0.94	0.77	1.00	0.56	0.73	0.96	0.96	0.96	0.97	0.99										
TT85	0.90	0.81	0.99	0.67	0.81	0.91	0.92	0.92	0.93	0.96	0.99									
TT90	0.85	0.84	0.97	0.74	0.86	0.87	0.87	0.88	0.89	0.92	0.96	0.99								
TT95	0.79	0.86	0.93	0.78	0.91	0.81	0.81	0.82	0.84	0.87	0.92	0.96	0.99							
PT	0.79	0.86	0.93	0.78	0.91	0.81	0.81	0.82	0.84	0.87	0.92	0.96	0.99	1.00						
BT	0.50	0.81	0.72	0.86	0.93	0.52	0.53	0.54	0.56	0.62	0.71	0.80	0.86	0.92	0.92					
BTI	0.17	0.46	0.35	0.38	0.58	0.18	0.19	0.19	0.21	0.26	0.34	0.41	0.47	0.55	0.55	0.69				
PTI	0.13	0.39	0.31	0.33	0.52	0.14	0.15	0.15	0.18	0.23	0.32	0.38	0.44	0.50	0.50	0.62	0.93			
TTI	0.10	0.34	0.28	0.27	0.46	0.11	0.12	0.13	0.15	0.21	0.30	0.35	0.39	0.43	0.43	0.52	0.80	0.95		
λ^{Skew}	0.12	0.38	0.20	0.23	0.40	0.12	0.12	0.12	0.12	0.13	0.19	0.25	0.30	0.34	0.34	0.42	0.68	0.53	0.38	
λ^{Var}	0.12	0.42	0.30	0.38	0.53	0.12	0.13	0.14	0.16	0.20	0.30	0.39	0.45	0.49	0.49	0.62	0.90	0.92	0.84	0.71

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table A5. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (PM, weekday)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.68																			
ATT	0.81	0.81																		
Var	0.56	0.84	0.76																	
Std	0.59	0.93	0.87	0.91																
TT5	0.97	0.73	0.89	0.61	0.66															
TT10	0.94	0.74	0.93	0.62	0.69	0.99														
TT15	0.92	0.74	0.94	0.63	0.71	0.98	1.00													
TT25	0.89	0.75	0.96	0.65	0.74	0.96	0.99	1.00												
TT50	0.83	0.77	0.99	0.70	0.80	0.91	0.94	0.96	0.98											
TT75	0.74	0.77	0.99	0.73	0.85	0.83	0.87	0.89	0.92	0.98										
TT85	0.71	0.77	0.98	0.75	0.87	0.79	0.83	0.86	0.89	0.95	0.99									
TT90	0.69	0.77	0.97	0.76	0.89	0.77	0.81	0.84	0.87	0.94	0.98	1.00								
TT95	0.67	0.80	0.95	0.81	0.92	0.74	0.79	0.81	0.84	0.91	0.96	0.98	0.99							
PT	0.67	0.80	0.95	0.81	0.92	0.74	0.79	0.81	0.84	0.91	0.96	0.98	0.99	1.00						
BT	0.48	0.72	0.83	0.78	0.90	0.55	0.59	0.62	0.66	0.76	0.86	0.90	0.92	0.96	0.96					
BTI		0.25	0.20	0.22	0.40					0.13	0.24	0.30	0.33	0.40	0.40	0.54				
PTI		0.26	0.37	0.25	0.46		0.10	0.15	0.21	0.33	0.44	0.49	0.51	0.51	0.51	0.60	0.75			
TTI		0.26	0.43	0.24	0.44	0.09	0.17	0.22	0.30	0.41	0.50	0.53	0.53	0.51	0.51	0.55	0.54	0.95		
λ^{Skew}		0.10			0.13				-0.08	-0.08				0.10	0.10	0.20	0.64	0.22		
λ^{Var}		0.26	0.26	0.23	0.43				0.08	0.18	0.32	0.38	0.42	0.44	0.44	0.57	0.90	0.83	0.66	0.53

Color scale	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table A6. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (PM, weekend)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.68																			
ATT	0.95	0.78																		
Var	0.39	0.74	0.59																	
Std	0.57	0.92	0.76	0.86																
TT5	0.99	0.71	0.97	0.44	0.61															
TT10	0.99	0.71	0.97	0.45	0.62	1.00														
TT15	0.99	0.72	0.98	0.46	0.63	1.00	1.00													
TT25	0.98	0.72	0.98	0.47	0.64	1.00	1.00	1.00												
TT50	0.97	0.73	0.99	0.50	0.68	0.99	0.99	0.99	1.00											
TT75	0.94	0.75	1.00	0.56	0.73	0.96	0.97	0.97	0.98	0.99										
TT85	0.88	0.77	0.98	0.68	0.80	0.92	0.92	0.93	0.94	0.96	0.98									
TT90	0.83	0.77	0.96	0.74	0.83	0.87	0.88	0.89	0.89	0.92	0.96	0.99								
TT95	0.76	0.78	0.92	0.78	0.87	0.81	0.82	0.83	0.83	0.87	0.91	0.96	0.99							
PT	0.76	0.78	0.92	0.78	0.87	0.81	0.82	0.83	0.83	0.87	0.91	0.96	0.99	1.00						
BT	0.40	0.62	0.65	0.84	0.84	0.47	0.48	0.49	0.51	0.56	0.64	0.75	0.82	0.90	0.90					
BTI	0.09	0.32	0.27	0.35	0.52	0.11	0.12	0.13	0.14	0.20	0.26	0.33	0.39	0.49	0.49	0.65				
PTI		0.27	0.23	0.30	0.46		0.08	0.09	0.11	0.17	0.24	0.30	0.35	0.43	0.43	0.57	0.92			
TTI		0.25	0.20	0.23	0.42				0.09	0.15	0.23	0.27	0.31	0.36	0.36	0.47	0.80	0.96		
λ^{Skew}	0.15	0.34	0.25	0.35	0.45	0.16	0.17	0.17	0.17	0.19	0.22	0.28	0.34	0.41	0.41	0.52	0.64	0.46	0.33	
λ^{Var}	0.08	0.32	0.28	0.42	0.53	0.11	0.12	0.13	0.15	0.21	0.29	0.37	0.44	0.50	0.50	0.66	0.89	0.94	0.90	0.56

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table A7. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (Weekday, night-time hour)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.65																			
ATT	0.98	0.70																		
Var	0.50	0.87	0.59																	
Std	0.57	0.90	0.67	0.90																
TT5	0.99	0.65	0.99	0.51	0.58															
TT10	0.99	0.65	0.99	0.51	0.58	1.00														
TT15	0.99	0.65	0.99	0.51	0.58	1.00	1.00													
TT25	0.99	0.65	0.99	0.51	0.58	1.00	1.00	1.00												
TT50	0.99	0.65	0.99	0.52	0.59	1.00	1.00	1.00	1.00											
TT75	0.98	0.65	1.00	0.53	0.61	0.99	0.99	0.99	0.99	1.00										
TT85	0.96	0.66	0.99	0.56	0.65	0.97	0.97	0.98	0.98	0.99	0.99									
TT90	0.93	0.68	0.98	0.60	0.70	0.94	0.95	0.95	0.95	0.96	0.97	0.99								
TT95	0.83	0.72	0.91	0.72	0.82	0.85	0.85	0.85	0.86	0.87	0.88	0.91	0.95							
PT	0.83	0.72	0.91	0.72	0.82	0.85	0.85	0.85	0.86	0.87	0.88	0.91	0.95	1.00						
BT	0.37	0.52	0.50	0.68	0.79	0.38	0.39	0.39	0.40	0.41	0.44	0.51	0.61	0.81	0.81					
BTI		0.25	0.09	0.33	0.50							0.10	0.20	0.41	0.41	0.74				
PTI		0.22	0.08	0.30	0.46							0.10	0.20	0.38	0.38	0.68	0.96			
TTI		0.22	0.09	0.26	0.44							0.13	0.20	0.33	0.33	0.57	0.81	0.92		
λ^{Skew}		0.20		0.30	0.39							0.10	0.22	0.34	0.34	0.62	0.69	0.67	0.49	
λ^{Var}		0.18	0.09	0.27	0.40							0.14	0.26	0.36	0.36	0.63	0.78	0.86	0.83	0.84

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table A8. Pearson Correlation Coefficients between Truck Travel Time Performance Measures (Weekday, night-time hour)

	MinTT	MaxTT	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
MaxTT	0.57																			
ATT	0.98	0.65																		
Var	0.36	0.82	0.48																	
Std	0.47	0.94	0.59	0.89																
TT5	0.99	0.59	0.99	0.38	0.49															
TT10	0.99	0.59	0.99	0.39	0.50	1.00														
TT15	0.99	0.59	0.99	0.39	0.50	1.00	1.00													
TT25	0.99	0.59	0.99	0.40	0.51	1.00	1.00	1.00												
TT50	0.99	0.60	1.00	0.41	0.52	1.00	1.00	1.00	1.00											
TT75	0.98	0.61	1.00	0.44	0.55	0.99	0.99	0.99	0.99	1.00										
TT85	0.96	0.63	1.00	0.47	0.58	0.98	0.98	0.98	0.98	0.99	1.00									
TT90	0.94	0.65	0.99	0.53	0.63	0.95	0.96	0.96	0.96	0.97	0.99	0.99								
TT95	0.85	0.74	0.93	0.67	0.76	0.87	0.87	0.88	0.88	0.90	0.92	0.93	0.96							
PT	0.85	0.74	0.93	0.67	0.76	0.87	0.87	0.88	0.88	0.90	0.92	0.93	0.96	1.00						
BT	0.42	0.65	0.56	0.78	0.81	0.44	0.45	0.45	0.46	0.49	0.53	0.57	0.64	0.82	0.82					
BTI		0.28	0.08	0.32	0.46							0.08	0.14	0.36	0.36	0.68				
PTI		0.27		0.30	0.44								0.13	0.33	0.33	0.64	0.96			
TTI		0.26		0.26	0.42							0.11	0.16	0.28	0.28	0.50	0.73	0.87		
λ^{Skew}		0.17		0.17	0.29								0.10	0.20	0.20	0.40	0.57	0.52	0.40	
λ^{Var}		0.18	0.08	0.22	0.34						0.08	0.12	0.19	0.28	0.28	0.50	0.67	0.77	0.88	0.67

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

10. Appendix B

This appendix presents the Pearson correlation coefficient matrices for each truck travel time dataset (segregated by time of the day and day of the week). The tables with correlation coefficients which are at least significant at a 95% confidence level are presented (color-coded based on the following categories).

- High positive (HP) correlation coefficient: > 0.5
- Moderate positive (MP) correlation coefficient: 0.3 to 0.5
- Low positive (LP) correlation coefficient: 0 to 0.3
- Low negative (LN) correlation coefficient: -0.3 to 0
- Moderate negative (MN) correlation coefficient: -0.5 to -0.3
- High negative (HN) correlation coefficient: < -0.5

A blank cell indicates that the corresponding Pearson correlation coefficient is not significant at a 95% confidence level.

Table B1 summarizes the Pearson correlation coefficient results between the selected truck travel time performance measures and on-network characteristics. Tables B2 and B3 summarize the Pearson correlation coefficient results between the selected truck travel time performance measures and land use characteristics (0.25- and 0.50-mile buffer widths). Tables B4 and B5 summarize the Pearson correlation coefficient results between the selected truck travel time performance measures and demographic characteristics (0.25- and 0.50-mile buffer widths).

Table B1. Pearson Correlation Coefficients between the Selected Truck Travel Time Performance Measures and On-Network Characteristics

		Travel Time Measure	Functional Class			# of Through Lanes	AADT	Ref. Speed	Speed Limit	Area Type	Data Density		
			Interstate	Principal arterials (Freeways and expressways)	Principal arterials - Others						A	B	C
Weekday	Morning peak	ATT	-0.15		0.23	-0.18	-0.17	-0.23					0.11
		PTI	-0.15		0.20			-0.29	-0.31	0.16	0.08	-0.09	
		TTI	-0.13		0.21			-0.31	-0.27	0.17	0.08	-0.08	
		BTI	-0.11		0.13			-0.22	-0.37	0.12			
	Afternoon peak	ATT	-0.21		0.32	-0.22	-0.25	-0.27					0.14
		PTI	-0.40		0.57	-0.14	-0.22	-0.59	-0.20	0.10	0.16	-0.18	
		TTI	-0.42		0.60	-0.12	-0.23	-0.62	-0.21	0.10	0.18	-0.20	
		BTI	-0.37		0.50	-0.20	-0.20	-0.57	-0.21	0.11	0.13	-0.15	
	Evening peak	ATT	-0.09	-0.08	0.21	-0.18	-0.09	-0.23			-0.15	0.13	0.24
		PTI		-0.11			0.21	-0.24	-0.09	0.17			
		TTI		-0.11			0.21	-0.20		0.19			
		BTI		-0.90			0.19	-0.31	-0.85	0.12			
	Night-time	ATT	-0.14		0.24	-0.20	-0.22	-0.21			-0.16	0.16	0.10
		PTI	-0.13		0.25			-0.39	-0.15	0.12	-0.10	0.10	0.12
		TTI	-0.26		0.40		-0.09	-0.54	-0.19	0.11			
		BTI			0.18			-0.34	-0.14	0.12	-0.17	0.17	0.18
Weekend	Morning peak	ATT	-0.16		0.26	-0.22	-0.25	-0.21					0.11
		PTI	-0.40		0.53	-0.18	-0.27	-0.54	-0.15		0.08	-0.09	
		TTI	-0.44		0.57	-0.19	-0.31	-0.55	-0.15		0.08	-0.08	
		BTI	-0.42		0.54	-0.18	-0.28	-0.56	-0.17		0.13	-0.13	
	Afternoon peak	ATT	-0.19		0.30	-0.23	-0.26	-0.27					0.14
		PTI	-0.37		0.52	-0.20	-0.27	-0.59	-0.16		0.16	-0.18	
		TTI	-0.39		0.57	-0.18	-0.27	-0.62	-0.19		0.18	-0.20	
		BTI	-0.33		0.54	-0.24	-0.25	-0.56	-0.15				
	Evening peak	ATT	-0.18		0.29	-0.23	-0.25	-0.25			-0.15	0.13	0.24
		PTI	-0.36		0.53	-0.14	-0.20	-0.55	-0.15	0.10			
		TTI	-0.37		0.54	-0.15	-0.23	-0.55	-0.16	0.09			
		BTI	-0.34		0.48	-0.12	-0.15	-0.54	-0.16	0.10			
	Night-time	ATT	-0.15		0.25	-0.21	-0.23	-0.20			-0.16	0.16	0.10
		PTI	-0.20		0.31			-0.39	-0.15	0.09	-0.10	0.10	0.12
		TTI	-0.32		0.45		-0.14	-0.53	-0.19	0.09			
		BTI	-0.14		0.24			-0.34	-0.14	0.09			

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table B2. Pearson Correlation Coefficients between the Selected Truck Travel Time Performance Measures and Land Use Characteristics (0.25-mile buffer)

		Variable	Agri.	Airport	Gov.	Commercial		Industrial		Inst.	Med.	Residential		Ofc.	Rec.	Resource	Retail	Transport	Unknown	Vacant
						Light	Heavy	Light	Heavy			SF	MF							
Weekday	Morning peak	ATT	0.29		0.11	0.21	0.13	0.21	0.09	0.12	0.09	0.51	0.14	0.16	0.13	0.09				
		PTI	-0.13			0.09								0.17						
		TTI	-0.12			0.08								0.15				0.16	0.17	0.29
		BTI	-0.13			0.08								0.18				0.10		
	Afternoon peak	ATT	0.40		0.15	0.24	0.13	0.20	0.12	0.12		0.55	0.13		0.17	0.13	0.09	0.13		
		PTI	-0.09			0.18	0.10					-0.08						0.15		
		TTI	-0.09			0.19	0.10					-0.09						0.28	0.16	0.19
		BTI	-0.11			0.16	0.12				0.12	-0.08	0.12	0.17				0.12		
	Evening peak	ATT	0.25		0.12	0.24	0.14	0.21	0.11	0.20	0.12	0.38	0.20	0.16	0.17		0.09	0.11		-0.14
		PTI	-0.16					0.08		0.08		-0.19	0.13	0.16		-0.12		0.12		-0.12
		TTI	-0.14				0.08			0.09		-0.18	0.12	0.17		-0.10		0.11	0.17	0.29
		BTI	-0.19					0.12				-0.16	0.11	0.13		-0.16				-0.15
	Night-time	ATT	0.43		0.16	0.23	0.10	0.23	0.13	0.13	0.11	0.58	0.12	0.08	0.21	0.12				-0.13
		PTI	-0.11					0.18	-0.08				0.15	0.15						-0.13
		TTI	-0.13			0.12		0.16				-0.09	0.11	0.10				0.12	0.16	0.30
		BTI	-0.12					0.21			0.10		0.19	0.18		-0.09				-0.15
Weekend	Morning peak	ATT	0.43		0.16	0.21	0.10	0.20	0.13	0.14		0.59	0.10		0.19	0.12		0.11		
		PTI				0.10												0.12		
		TTI	-0.09			0.08												0.15	0.16	0.29
		BTI	-0.08			0.13		0.10										0.11		
	Afternoon peak	ATT	0.41	0.10	0.18	0.22	0.11	0.19	0.12	0.13	0.08	0.54	0.11		0.18	0.13	0.08	0.11		
		PTI				0.16												0.14		
		TTI				0.21	0.08											0.14	0.16	0.30
		BTI			0.08	0.12		0.09			0.11							0.10		
	Evening peak	ATT	0.42		0.15	0.22	0.11	0.20	0.12	0.13		0.56	0.11		0.18	0.14		0.10		
		PTI				0.15												0.11		
		TTI				0.17												0.12	0.17	0.31
		BTI				0.12		0.11										0.09		
	Night-time	ATT	0.44		0.16	0.22	0.11	0.21	0.13	0.14		0.58	0.10		0.20	0.13		0.08		-0.08
		PTI	-0.08				0.10	0.16						0.09				0.11		
		TTI	-0.10			0.09	0.09	0.12				-0.09								
		BTI	-0.08				0.12	0.18						0.13						-0.09

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table B3. Pearson Correlation Coefficients between the Selected Truck Travel Time Performance Measures and Land Use Characteristics (0.50-mile buffer)

		Variable	Agri.	Gov.	Commercial		Industrial		Inst.	Med.	Residential		Ofc.	Rec.	Resource	Retail	Transport	Unknown	Vacant
					Light	Heavy	Light	Heavy			SF	MF							
Weekday	Morning peak	ATT	0.24	0.09	0.18	0.11	0.18		0.11	0.12	0.5	0.11	0.18	0.12		0.11	0.12	0.11	0.19
		PTI	-0.15									0.08	0.18				0.1		
		TTI	-0.14				0.1					0.09	0.18				0.08		-0.08
		BTI	-0.16							0.09		0.1	0.17				0.12		
	Afternoon peak	ATT	0.34	0.12	0.21	0.11	0.17	0.09	0.1	0.1	0.53	0.09		0.18	0.09	0.14	0.16	0.1	0.25
		PTI	-0.11		0.15							0.12					0.18		
		TTI	-0.11		0.16							0.11					0.19		
		BTI	-0.13		0.13					0.14		0.19	0.15				0.16		
	Evening peak	ATT	0.2	0.09	0.22	0.11	0.19	0.11	0.18	0.16	0.36	0.18	0.21	0.17		0.12	0.22	0.13	0.15
		PTI	-0.19				0.12		0.09		-0.22	0.2	0.26		-0.09		0.08		-0.15
		TTI	-0.17				0.09		0.1		-0.19	0.19	0.27		-0.09		0.1		-0.13
		BTI	-0.22		0.08		0.16				-0.18	0.16	0.18		-0.09			0.11	-0.17
	Night-time	ATT	0.37	0.14	0.21	0.09	0.2	0.1	0.12	0.13	0.56	0.09	0.08	0.21	0.08	0.12	0.11	0.1	0.24
		PTI	-0.12				0.21		0.09			0.29	0.11						-0.14
		TTI	-0.15		0.09		0.19				-0.08	0.23	0.09				0.09		-0.14
		BTI	-0.13				0.24		0.1	0.11		0.33	0.14						-0.15
Weekend	Morning peak	ATT	0.24	0.09	0.18	0.11	0.18		0.11	0.12	0.5	0.11	0.18	0.12		0.11	0.12	0.11	0.19
		PTI	-0.15									0.08	0.18				0.1		
		TTI	-0.14				0.1					0.09	0.18				0.08		-0.08
		BTI	-0.1		0.09		0.11										0.12		
	Afternoon peak	ATT	0.34	0.12	0.21	0.11	0.17	0.09	0.1	0.1	0.53	0.09		0.18	0.09	0.14	0.16	0.1	0.25
		PTI	-0.11		0.15							0.12					0.18		
		TTI	-0.11		0.16							0.11					0.19		
		BTI		0.11	0.1		0.09			0.12							0.12		
	Evening peak	ATT	0.2	0.09	0.22	0.11	0.19	0.11	0.18	0.16	0.36	0.18	0.21	0.17		0.12	0.22	0.13	0.15
		PTI	-0.19				0.12		0.09		-0.22	0.2	0.26		-0.09		0.08		-0.15
		TTI	-0.17				0.09		0.1		-0.19	0.19	0.27		-0.09		0.1		-0.13
		BTI	-0.08		0.09		0.12										0.14		
	Night-time	ATT	0.37	0.14	0.21	0.09	0.2	0.1	0.12	0.13	0.56	0.09	0.08	0.21	0.08	0.12	0.11	0.1	0.24
		PTI	-0.12				0.21		0.09			0.29	0.11						-0.14
		TTI	-0.15		0.09		0.19				-0.08	0.23	0.09				0.09		-0.14
		BTI	-0.09				0.23					0.13	0.18						-0.09

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table B4. Pearson Correlation Coefficients between the Selected Truck Travel Time Performance Measures and Demographic Characteristics (0.25-mile buffer)

		Performance Measure	Population Estimates	Household Units	Population Density	Employment Density
Weekday	Morning peak	ATT	0.55	0.53		
		PTI	-0.09	-0.09	0.1	0.18
		TTI	-0.1	-0.1	0.1	0.18
		BTI			0.94	0.18
	Afternoon peak	ATT	0.63	0.62	-0.1	-0.12
		PTI			0.1	0.13
		TTI			0.13	0.14
		BTI			0.11	0.17
	Evening peak	ATT	0.5	0.5		
		PTI	-0.11	-0.09	0.28	0.45
		TTI	-0.1	-0.09	0.18	0.4
		BTI	-0.12		0.34	0.4
	Night-time	ATT	0.66	0.65	-0.12	-0.14
		PTI	-0.11	-0.11		
		TTI	-0.11	-0.11	0.12	0.11
		BTI	-0.11	-0.11		
Weekend	Morning peak	ATT	0.67	0.65	-0.12	-0.15
		PTI			0.08	
		TTI			0.11	
		BTI			0.91	
	Afternoon peak	ATT	0.64	0.63	-0.11	-0.14
		PTI				
		TTI				
		BTI				
	Evening peak	ATT	0.64	0.63	-0.11	-0.14
		PTI			0.13	0.09
		TTI			0.15	0.11
		BTI			0.14	0.1
	Night-time	ATT	0.66	0.65	-0.13	-0.15
		PTI	-0.12	-0.12		0.12
		TTI	-0.12	-0.12	0.1	0.12
		BTI	-0.12	-0.12		0.13

Color scale						
	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Table B5. Pearson Correlation Coefficients between the Selected Truck Travel Time Performance Measures and Demographic Characteristics (0.50-mile buffer)

		Performance Measure	Population Estimates	Household Units	Population Density	Employment Density
Weekday	Morning peak	ATT	0.53	0.52		-0.09
		PTI	-0.08		0.15	
		TTI	-0.08	-0.09	0.14	0.09
		BTI			0.13	
	Afternoon peak	ATT	0.61	0.6	-0.11	-0.14
		PTI			0.14	0.08
		TTI			0.16	0.1
		BTI			0.17	0.11
	Evening peak	ATT	0.49	0.49		
		PTI	-0.1	-0.08	0.31	0.42
		TTI	-0.09		0.21	0.31
		BTI	-0.11	-0.08	0.37	0.46
	Night-time	ATT	0.64	0.62	-0.14	-0.15
		PTI	-0.11	-0.11	0.11	
		TTI	-0.11	-0.11	0.17	0.08
		BTI	-0.11	-0.11	0.09	
Weekend	Morning peak	ATT	0.53	0.52		-0.09
		PTI	-0.08		0.15	
		TTI	-0.08	-0.09	0.14	0.09
		BTI			0.12	
	Afternoon peak	ATT	0.61	0.6	-0.11	-0.14
		PTI			0.14	0.08
		TTI			0.16	0.1
		BTI				
	Evening peak	ATT	0.49	0.49		
		PTI	-0.1	-0.08	0.31	0.42
		TTI	-0.09		0.21	0.31
		BTI			0.17	0.09
	Night-time	ATT	0.64	0.62	-0.14	-0.15
		PTI	-0.11	-0.11	0.11	
		TTI	-0.11	-0.11	0.17	0.08
		BTI	-0.12	-0.12		

Color scale	<(-0.5)	-0.5 to -0.3	-0.3 to 0	0 to 0.3	0.3 to 0.5	>0.5

Abbreviations and Acronyms

AADT	Annual Average Daily Traffic
ATA	American Trucking Association
ATT	Average Travel Time
BT	Buffer Time
BTI	Buffer Time Index
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GPS	Global Positioning Systems
HCM	Highway Capacity Manual
LOS	Level of Service
MAP-21	Moving Ahead for Progress in 21st Century
MPO	Metropolitan Planning Organization
NPMRDS	National Performance Management Research Dataset
PCE	Passenger Car Equivalent
PCU	Passenger Car Unit
PT	Planning Time
PTI	Planning Time Index
TAZ	Traffic Analysis Zones
TMC	Traffic Message Channel
TTI	Travel Time Index
WIM	Weigh-in-Motion

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