EXAMINING ASSOCIATIONS, IDENTIFYING CHOKEPOINTS, AND MODELING TRUCK TRAVEL TIME PERFORMANCE MEASURES

by

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ABSTRACT

SARVANI V. DUVVURI. Examining Associations, Identifying Chokepoints, and Modeling Truck Travel Time Performance Measures. (Under the direction of DR. SRINIVAS S. PULUGURTHA)

Trucks transport a 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 an important 'highway' problem, delays in truck travel result in loss of revenue to the freight trucking companies. There is significant research on traffic congestion mitigation, but not many studies focused on data exclusive to trucks. This research is aimed at a link-level truck travel time data analysis to identify roads for improving truck traffic mobility and reducing congestion. The objectives of this dissertation research are to:

1. compute and evaluate the truck travel time performance measures (by time of the day and day of the week),
2. use selected truck travel time performance measures to examine their correlation with on-network and off-network characteristics,
3. generate geospatial maps to visualize truck travel time performance measures, and,
4. develop truck travel time estimation models using on-network and off-network variables as independent variables.

Truck travel time data for the year 2019 were obtained and processed at the link level for Mecklenburg County, Buncombe County, and Wake County in North Carolina. 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 characteristics in the near vicinity of each selected link were captured using 0.25 miles, 0.50 miles and 1-mile buffer widths. The relationships between the selected truck travel time performance measures and on-network and off-network characteristics were analyzed using Pearson correlation coefficient analysis. The results indicate that urban areas, high-volume roads, and roads with through lanes <= 6 are positively correlated with the truck travel time performance measures. Further, the presence of agriculture, 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).

Using the selected four performance measures, geospatial mapping was performed to visualize variations and identify potential chokepoints. The maps were generated across the study area and visualized for various times of the day and days of the week. Selected maps were used to interpret and identify "truck-exclusive" chokepoints.

Truck travel time estimation models were developed using generalized estimating equations (GEE) with the average truck travel time per mile (ATTPM) as the dependent variable and the on-network and off-network characteristics as independent variables. The influence of the off-network characteristics was incorporated based on spatial proximity (buffers) and spatial weights (distance decay function, $1/d$, $1/d^2$, $1/d^3$) to check the best approach for modeling.

A longitudinal dataset was created using time of the day and day of the week as variables. Modeling was performed using data for 75% of the links while data for the remaining 25% of the links was used for validation. Linear and gamma log link models were developed to estimate the ATTPM using all variables from multiple buffer widths, all variables with specific buffer widths (individually), and all variables from the spatial weights.

All the model results indicated significant influence of time of the day, day of the week, and on-network characteristics like AADT, speed limit and number of through lanes on truck travel time. The model results indicate that office, transportation, heavy commercial, and light industrial land uses, population and employment density of the surrounding areas have a significant increasing influence on the ATTPM (i.e., an increase in these land use areas/demographic estimates result in an increase in the ATTPM). Contrarily, some of the variables like government land use and number of household units have a decreasing influence on the ATTPM (i.e., an increase in these land use areas/demographic estimates result in a decrease in the ATTPM). The model results including the goodness of fit and validation indicated that using data from individual buffer widths performs better compared to the spatial weights.

The data was segregated based on the speed limit and county to estimate the ATTPM. The data was classified into three categories based on the speed limit; (1) <= 50 mph; (2) > 50 mph & <= 60 mph; and (3) > 60 mph. In all the models developed (the three datasets), variables like time of the day, day of the week, and on-network characteristics like AADT and number of through lanes were found to be significant. The model results indicate that the ATTPM for the evening peak is the highest followed by the morning peak and afternoon peak hours. Similarly, the results indicate that the ATTPM decreases as the number of through lanes increase. The model results also indicate a significant increasing influence of institutional, light commercial, and light industrial land uses and population on the ATTPM. Contrarily, the heavy industrial land use and population have a significant decreasing influence on the ATTPM.

The data was classified into three categories based on the county. The results from the models indicate the dependency of local spatial parameters on the ATTPM. For example, heavy commercial land use and employment density had a significant decreasing influence on the ATTPM in the case of Mecklenburg County, whereas model results indicate a significant increasing influence on the ATTPM in the case of Buncombe and Wake Counties. This can be attributed to the county development patterns and demographic characteristics.

Overall, the model results suggest a buffer width of 0.25-mile and gamma log link models being ideal to capture the off-network characteristics to estimate truck travel times. The research demonstrated the potential influence of the on-network and off-network characteristics on truck travel time performance and related models. The ATTPM was considered as the dependent variable. The research can be extended to estimate the 95th percentile travel time (or PT) accounting for factors that results in recurring and non-recurring congestion. Additionally, supervised machine learning techniques could be explored to model travel time performance measures.

DEDICATION

To my Father – who never saw this adventure

To my Mother and Sister – for being my biggest support throughout

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LIST OF ABBREVIATIONS

AADT	Annual Average Daily Traffic
ATT	Average Travel Time
ATTPM	Average Travel Time per Mile
BT	Buffer Time
BTI	Buffer Time Index
DOT	Department of Transportation
FHWA	Federal Highway Administration
GEE	Generalized Estimating Equations
GIS	Geographic Information Systems
GPS	Global Positioning System
HCM	Highway Capacity Manual
LOS	Level of Service
MAP-21	Moving Ahead for Progress in the 21st Century Act
MPO	Metropolitan Planning Organization
NCDOT	North Carolina Department of Transportation
NPMRDS	National Performance Management Research Dataset
PCE	Passenger Car Equivalent
PCU	Passenger Car Unit
PT	Planning Time
PTI	Planning Time Index
QIC	Quasilikelihood Under Independence Model Criterion
QICC	Quasilikelihood Under Independence Model Criterion Corrected
RITIS	Regional Integrated Transportation System

TAZ	Traffic Analysis Zone
TMC	Traffic Message Channel
TTI	Travel Time Index

CHAPTER 1: INTRODUCTION

Trucks are used to transport nearly 71% of the freight tonnage through highways. Despite the low percentage of trucks in the traffic stream, they are susceptible to traffic congestion due to their size and weight characteristics. Truck traffic is governed by the road network type, demographics, and land use developments ranging from manufacturing amenities, commercial centers, business parks to the residential properties in an area. Truck travel delays affect the supply chains and lead to revenue losses to truck-dependent shipping companies. With the increasing demand for trucking due to emerging freight operations, there is a need to emphasize better planning and truck routing strategies. Hence, a clear understanding of truck travel performance across the region and its dependence on surrounding area characteristics like demographics, and land use will help in developing sound transportation policy decisions for truck network management. Therefore, this dissertation focuses on identifying performance indicators of truck traffic and understanding their association with on-network (road) and surrounding off-network characteristics (land use and demographics). This chapter summarizes the motivation for this research, problem statement, and research objectives. Further, the organization of this dissertation report is summarized at the end of this chapter.

1.1 Motivation and Background

Trucking is the predominant and preferred mode for freight transportation. Trucks are used to transport nearly 71% of the total tonnage (ATA, 2020a). Activities like online shopping of physical goods and groceries amplified significantly in recent years, resulting in increased freight demand and corresponding trucking activity (Visser and Nemoto, 2003).

Based on the current trends in trade and e-commerce with physical movement of goods, the freight tonnage by truck is expected to increase by 44% by the year 2045 compared to 2015 (Visser and Nemoto, 2003; BTS, 2019). In the recent "Freight Transportation Forecast" report by the American Trucking Association (ATA), it was estimated that a 36% growth in freight volume could be expected by 2031 despite the global pandemic (ATA, 2020b). Further, the revenue in freight is expected to jump from $870 billion in 2020 to $1.435 trillion in 2031 (ATA, 2020b).

Trucks on most of the urban roads are susceptible to congestion and delays, ultimately costing the shippers an extra amount by 50% to 250% (Mallett et al., 2006). An analysis by the American Transportation Research Institute (ATRI) on trip times by motor carriers indicated a delay of 1.2 billion hours due to congestion, which adds to an increased cost of $6,478 per truck (Hooper, 2018). Trucking companies, therefore, thrive on just-in-time management to ensure on-time deliveries (Mallett et al., 2006). The increasing demand for freight transportation is expected to trigger significant growth in trucking, warehousing, and distribution centers for last-mile deliveries.

Trucks carrying freight also have a pronounced influence on the traffic stream and the road operational performance due to their enormous size and braking abilities (Yang et al., 2015). Large trucks in the traffic stream influence the sight distance of following vehicles resulting in higher gaps between the vehicles and a fluctuation in the overall operational performance (Kong et al., 2016). Hence, higher congestion rates are anticipated to occur with the presence of trucks in high road density conditions. To ensure the timely delivery of goods, there is a need to evaluate the operational performance of trucks exclusively in the traffic stream.

In general, traffic stream operational performance is assessed using measures like travel speed, vehicle delay, traffic density, and volume-to-capacity ratio. Nowadays, due to the increased availability of traffic data from various sources, researchers and practitioners have expanded the metrics for road operational performance from static measures to the inclusion of travel time-based measures. Moreover, travel time is considered as a robust performance measure to identify and mitigate congestion in an area (Mallett et al., 2006). Travel time data of vehicles on road not only addresses the information on average estimation of time taken to traverse the road, but also helps understand possible variations and reliability of a particular road (or system) from a road user perspective (Chen et al., 2003). Various state and federal transportation agencies use vehicle travel time data to assess and measure the operational performance of a road facility. Furthermore, the availability of travel time data at almost all times of the day and for all days of the week adds value and opens avenues for computation and comparison of the operational performance.

On-network and off-network characteristics influence trucking and freight demand in an area (Niles, 2003; FMCSA, 2017). The on-network characteristics include traffic volume, number of lanes, functional class, and the speed limit. The off-network characteristics reflect the surrounding area and infrastructure, developments, demographic and socioeconomic parameters.

The association between on-network/off-network characteristics and truck travel is important to understand truck travel performance and congestion in a region. The on-network and off-network characteristics could be used to predict selected travel time performance measures. The geospatial variations in truck performance measures help identify chokepoints, thereby aiding in better routing strategies.

1.2 Problem Statement

Travel time performance and reliability are widely explored comprehensive research areas in the field of traffic engineering. Various measures, concepts, and models are currently in use to understand the travel time reliability of a road, corridor, or system. However, majority of the research on the reliability or performance measures are conducted based on passenger car travel data or mixed traffic conditions such as a traffic stream.

Trucks carrying freight vary significantly from passenger cars in terms of their size, braking abilities, power, and weight characteristics. Further, road characteristics (like functional class, speed limit, and traffic volume) and surrounding area characteristics (land use and demographics) have a distinctive influence on these trucks, which makes the applicability of passenger car performance measures debatable. Identifying suitable measures to define truck travel performance will assist in prioritizing areas for truck travel improvement and potential resource allocation. Further, these measures can also be used to geospatially visualize the performance and aids in identifying chokepoints in a region.

Regional travel demand models consider the land use, socioeconomic and demographic characteristics to estimate travel demand and anticipated operational performance on major roads. A conscious effort is made by the planners to define zones for travel demand modeling and to improve personal mobility and transit. Similar to the passenger car travel, truck traffic also depends on the type of development (distribution centers, warehouses, and industries) and area demographics. Hence, there is a need to incorporate these independent variables to estimate the truck travel time in a particular area or road. Identifying the independent variables which significantly influence the truck travel time helps develop better planning strategies to improve reliability of truck transportation system.

While there is a significant amount of research on travel time estimation, very limited studies examined the influence of on-network and off-network characteristics on traffic stream or passenger car travel times, and even fewer on truck travel times. The availability of comprehensive data associated with truck travel, on-network, and off-network characteristics enables the possibility of exploring the data using statistical tools, examining spatiotemporal aspects, and identifying areas susceptible to freight truck congestion for the implementation of "truck priority zones."

1.3 Research Objectives

The goal of this dissertation is to understand, model, and better account for the effect of trucks on transportation system operational performance. The objectives of this research are:

1. to examine the level of association between various truck travel time performance measures to select suitable performance measure(s) for assessment;
2. to examine the level of association between the selected truck travel time performance measures and on-network (road) and off-network (land use and demographic) characteristics;
3. to generate geospatial maps and visualize variations in truck travel time performance measures to identify vulnerable areas (chokepoints); and,
4. to develop the truck travel time estimation models using on-network characteristics

(such as the speed limit and functional class) and off-network characteristics (demographic and land use characteristics).

The term “truck” used in this research refers to a large vehicle used to transport freight (NPMRDS, 2018). It could be a tractor-semitrailer-trailer combination (minimum of 28 feet long trailing unit), automobile and boat transporter (minimum of 65 feet in length), maxi-cube vehicle (34-65 feet in length), or a straight truck (10-26 feet in length) and typically transports 20,000 pounds or more (FHWA, 2003; USDOT, 2015).

1.4 Organization of the Report

The rest of the dissertation report is organized as follows. Chapter 2 presents a review of past studies on the travel time performance and reliability measures, practices by various state departments of transportation (DOTs), and their initiatives to measure freight/truck performance. In addition, a literature review on the travel time estimation models is also presented in Chapter 2. Chapter 3 outlines the methodological approach used in this research. Chapter 4 provides the discussion on study area and data processing. Chapter 5 summarizes the results from the correlation analysis of truck travel time measures and their association with on-network and off-network characteristics. Chapter 6 illustrates the geospatial visualization of the identified truck travel performance measures. Chapters 7, 8 and 9 discuss the truck travel time estimation model development and validation results. Chapter 10 summarizes the conclusions from this research.

CHAPTER 2: LITERATURE REVIEW

This chapter presents the literature synthesis of five prime areas related to this research study. Firstly, a review of the freight performance measurement and the role of the trucking industry is summarized. Secondly, the concept of passenger car equivalent (PCE), which quantifies the involvement of trucks to measure the operational performance of a facility is reviewed. Various PCE estimation methods are reviewed to understand the role of prime variables like travel time to define the truck performance. The concept of travel time reliability and research on suitable performance measures and their association with each other are then reviewed and summarized. The final part of the chapter comprises the research synthesis of truck performance measurement and a review of travel time estimation models.

2.1 Freight Performance Measurement

Freight infrastructure and mobility has been a priority to the United states, especially, with the emergence of Moving Ahead for Progress in the 21st Century Act (MAP-21) and Fixing America's Surface Transportation (FAST) Act (Margiotta et al., 2015). Particularly, Section 1115 of the MAP-21 requires evaluation of the freight-specific projects to invest and improve performance of the system (Margiotta et al., 2015). Many state agencies have initiated and implemented projects focusing on freight mobility and bottleneck identification/assessment (Systematics, 2005; Jansuwan et al., 2010; Systematics, 2011; Margiotta et al., 2015), freight planning models (Systematics, 2008; Systematics, 2013), intermodal plans (Systematics, 2002; Ahanotu and Grenzeback, 2017; TxDOT, 2018), and freight transportation improvement (GDOT, 2010). The Federal Highway Administration

(FHWA) recommends the average speed, travel time reliability, travel time variance, and crash rates to be classified as the measures of freight performance (Easley et al., 2017). The freight performance is defined considering multiple modes in the system. However, highways being the major contributor of freight transportation, an emphasis on performance measures carried by freight trucks is considered significant in identifying roads that are congested (exclusive to trucks) and also assist in better planning strategies.

2.2 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 (Roess and Prassas, 2014). 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 performance measures like travel time, density, delay, queue length, and percent time spent following.

Apart from the conventional performance measures, the HCM emphasizes incorporating the significance of user perceptions in determining the overall performance measure of any road facility type (Roess and Prassas, 2014). These additional variables include driver experience, traffic composition, scenery or aesthetics of the area, and pavement condition (Roess and Prassas, 2014).

Trucks on freeways and at signalized intersections contribute indirectly to the overall LOS when user perceptions are taken into account (Roess and Prassas, 2014). Especially, the presence of trucks in the traffic stream result in a “psychological and practical” influence, which are quantified by additional spacing with heavy vehicles and speed differences in a traffic stream (Roess and Prassas, 2014).

2.3 Passenger Car Equivalent (PCE) Estimation Methods

The operational performance of a road is expressed as a combination of performance by all the vehicles and users in the traffic stream. The HCM proposed a unit named "passenger car equivalent (PCE)" to account for the variations in traffic stream compositions (Raj et al., 2019). The PCE indicates the number of passenger cars which will result in the same operational condition as a single heavy vehicle considering similar traffic, control and road conditions (Highway Research Board, 1965). The PCE for trucks vary with variables like grade, length of the section, vehicle speed, and facility type (Highway Research Board, 1965; Raj et al., 2019). The PCE estimation aids in determining the LOS measures (Raj et al., 2019). The HCM estimates PCE of trucks to analyze capacity, delay, and LOS of a facility (Dowling et al., 2014).

The heavy vehicles in the HCM are defined as buses, recreational vehicles and trucks. However, one of the main drawbacks of the PCE estimation lies in the lack of consideration of "weight to horsepower ratios" which significantly distinguish trucks from passenger cars (Dowling et al., 2014). At present, there is no concept of truck LOS in the HCM. Further, the service measures used in the HCM do not account for travel time reliability measures (Dowling et al., 2014).

Traffic stream characteristics are highly distinct and complex in nature (Highway Research Board, 1965; Raj et al., 2019). Considering the far-reaching impact of trucks on the overall traffic stream, the PCE values would be highly beneficial in evaluating overall traffic flow. Researchers in the past proposed various PCE estimation methods by employing characteristics such as headway (Greenshields et al., 1947; Krammes and Crowley, 1986), delay (Craus et al., 1980), speed (Van Aerde and Yagar, 1984), queue discharge flow (Al-Kaisy et al., 2002), density (Huber, 1982), and travel time (Keller and Saklas, 1984).

The truck performance in a traffic stream is majorly attributed to the prevailing surrounding traffic conditions. Majority of the past studies proposing PCE estimation methods considered variables (like density, delay, headway, etc.) which are not captured in the real-world on a regular basis. The travel time was used in the PCE estimation in some of the research studies. However, the analysis/scenarios were simulation-based with various study assumptions making them unsuitable for real-world applications.

Measures such as travel times of a road are highly beneficial considering their role in PCE estimation as well as a performance measure. Various travel time measures are used to assess the congestion, reliability and variability of the transportation system (Chen et al., 2003; Lomax et al., 2003; Dowling et al., 2015). The concept of travel time reliability mainly focuses on assessing the performance and the degree of reliability of a route using the travel time measures. This concept was recently explored to assess PCE from a travel time perspective (Jain, 2019; Jain and Pulugurtha 2019).

2.4 Travel Time Reliability and Performance

Travel time reliability is one of the commonly used terms to indicate the consistency of a service, mode, trip or corridor in a particular time period (Lomax et al., 2003; FMCSA, 2017). Travel time reliability, in other words, is an indicator of the user perspective, which indicates how reliable the system is (Lomax et al., 2001; Lomax et al., 2003; FMCSA, 2017). Data from probe sources are majorly used to compute the travel time reliability due to their higher frequency in sample sizes and accuracy of the samples collected (Dowling et al., 2015). Travel time reliability in case of trucks plays a major role mainly aiming to avoid disruptions or inconsistencies in travel times attributing to fluctuation in service patterns (Dowling et al., 2015).

One of the main steps in assessing the performance using the travel time measures is to identify the appropriate measure. The United States Department of Transportation (USDOT) proposed planning time (PT), buffer time (BT), planning time index (PTI) and buffer time index (BTI) to compute the travel time reliability (FHWA, 2006). Some of these are used for congestion management (Dowling et al., 2015). The measures selected are typically confined to the study purpose, type of problem, and data.

Yazici et al. (2012) 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 better captured using the coefficient of variance, indices of skewness and variance (λ^{skew} and λ^{var}). However, each measure indicated variability based on the specific time period considered for the analysis. Based on the travel time trends, off-peak periods such as mid-night and early morning (until 7 AM) indicated unreliability mainly due to the lack of traffic volumes compared to other time periods and also the signal timing patterns (Yazici et al., 2012). By considering the variations in the travel time, Franklin and Karlstorm (2009) 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 characteristics like core urban area, outer area, etc. The instability in congestion rates during the peak periods is better captured by the lateness factor (Franklin and Karlstorm, 2009).

Carrion and Levinson (2012) conducted a meta-analysis of travel time to research on the differences among travel time reliability measure estimates. Their results indicated that mean and variance are better indicators of travel time variability based on the temporal aspects (Carrion and Levinson, 2012). Chen et al. (2003) computed the travel time reliability measures for I-5 corridor in the city of Los Angeles to examine the LOS. Their results indicated that the mean, median and the 90th percentile travel time had shown similar trends in the variability over various times of the day.

2.5 Relationship Between Travel Time Reliability Measures

Travel time data is available through private data sources which are collected using a wide range of technologies. Travel time reliability and performance measurement is conducted using different measures. However, these measures may be related to each other and result in different outcomes when applied for various kinds of analysis. Hence, a better understanding of relationships between these variables is needed before using these measures in any study. The relationship between these travel time reliability measures is of great significance, especially when choosing a single or limited number of performance measures to define operational performance of a system. Further, understanding the level of relationships between these travel time measures help in identifying suitable performance measures to assess the transportation problems.

Pu (2011) explored relationships within travel time reliability measures (variance, BTI, PTI, standard deviation, frequency of congestion, etc.) 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 (Pu, 2011). However, the consideration of standard deviation for computing the coefficient of variance is a concern as it is termed as “unstable” (Pu, 2011). In a study by Chase et al. (2013), semi-standard deviation travel time was chosen as an appropriate measure to analyze the freeway segments. Their results indicated that the majority of the measures are correlated to the average travel rate (Chase et al., 2013).

Inter-relationships between the travel time measures were explored in the past to understand the degree of relationships between the measures and also to select suitable performance measures (Pulugurtha et al., 2015; Pulugurtha et al., 2016; Pulugurtha and Koilada, 2020). The average travel time (ATT), BT, and BTI were found to be appropriate to assess the performance or quantify reliability of a transportation facility (Pulugurtha et al., 2015; Pulugurtha and Koilada, 2020).

While many researchers recommended the use of the variance-based travel time measures such as the standard deviation, covariance, etc., some of the studies contradict the usage of such variance-based measures (Van Lint et al., 2008). Van Lint et al. (2008) conducted travel time reliability analysis to establish a comparison between the classical measures (like standard deviation, covariance, etc.) 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).

2.6 Truck 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 included the usage of Global Positioning Systems

(GPS) (McCormack et al., 2010; Ma et al., 2011; Liao, 2014; Wang et al., 2016), probe data sources (Bluetooth or Wi-Fi data) (Kaushik et al., 2015; Karimpour et al., 2019), or sensors near weigh-in-motion stations (McCormack and Hallenbeck, 2006; Monsere et al., 2009; Samandar et al., 2018). Some of the potential challenges of these data collection strategies include the data cleaning difficulties and inaccuracies (McCormack et al., 2010), loss of signals while collection (McCormack et al., 2010), data security/privacy (Monsere et al., 2009; Ma et al., 2011), resource constraints (Monsere et al., 2009) and also the presence of a large number of outliers in the data (Kaushik et al., 2015).

A few studies were conducted on truck travel time-based performance measures using data captured by GPS units. They include the number of trips in a traffic analysis zone (TAZ) (McCormack et al., 2010; Ma et al., 2011), travel time reliability measure (Ma et al., 2011; Wang et al., 2016), sample size (Ma et al., 2011), vehicle speed (McCormack et al., 2010; Ma et al., 2011), daily truck delay and delay cost (Liao, 2014), and reliability index (80^{th} percentile travel time/travel time at specified threshold speed) (Liao, 2014; Wang et al., 2016). Considering the Intelligent Transportation System (ITS)-based approaches like the weigh-in-motion stations, researchers used performance measures like standard deviation of travel time (Monsere et al., 2009; Samandar et al., 2018), ATT (Monsere et al., 2009; McCormack et al., 2010; Samandar et al., 2018), 80^{th} and 95^{th} percentile travel times (McCormack and Hallenbeck, 2006), TTI (Samandar et al., 2018), PTI (Samandar et al., 2018), reliability rating (Samandar et al., 2018) and misery index (Samandar et al., 2018). Probe vehicle data-based travel time measures like the percentiles were also used to measure truck reliability and performance (Kaushik et al., 2015).

2.7 Travel Time Estimation

Travel time on a road depends on its surrounding traffic environment, type of traffic control devices, and facility type. Further, these travel times depend on the corresponding spatial and temporal aspects. Travel time prediction assists various stakeholders and the travelers to estimate the expected travel time, allocate resources, proactively plan improvements and/or plan a trip.

In terms of freight, the travel time indicates an opportunity to better plan and implement quicker delivery rates by avoiding potential congested areas. Travel times can be assessed using historical travel time patterns (Li and McDonald, 2002). They vary with the vehicle type (Li and McDonald, 2002), road facility type (Li and McDonald, 2002), driving condition (Li and McDonald, 2002), traffic flow condition (Lum et al., 1998), signal characteristics (Lum et al., 1998; Wu, 2001), weather condition (Chien and Kuchipudi, 2003), and in case of road construction or incidents (Pulugurtha and Mahanthi, 2016; Kukkapalli and Pulugurtha, 2020). Various research efforts were expended to predict the travel times on a road segment. They include the use of statistical models and artificial intelligence techniques.

Some of the most common short-term forecasting methods include the time-series estimation (D'Angelo et al., 1999; Reza et al., 2015; Reza and Pulugurtha, 2019) and regression-based statistical analysis (Zhang and Rice, 2003; Rice and Van Zwet, 2004). Other methods like the artificial intelligence techniques (neural network) have been explored in the past to predict the travel time (Anderson and Bell, 1997; Ishak and Al-Deek, 2002; Kisgyörgy and Rilett, 2002; Wei et al., 2003; Van Lint, 2004; Van Lint et al., 2005; Wei and Lee, 2007; Mane and Pulugurtha, 2018).

Travel patterns are governed by its area type, socioeconomic and surrounding land use categories (Badoe and Miller, 2000; Stead, 2001; Handy, 2005; Mane and Pulugurtha, 2018; Mane and Pulugurtha, 2020). These components of the cities assist potential planning strategies to construct new facilities or incorporation of transportation projects.

While many previous studies emphasized the importance of surrounding land use on the travel patterns, there is also a debatable need to include the socioeconomic characteristics in an area (Stead, 2001). Regression analysis of the travel survey data was conducted by Stead (2001) to identify variables influencing the travel distance. The results from their study indicate that socioeconomic variables account up to 50% of the variation in travel distance while the land use alone explain around 25% of the variation in travel distance (Stead, 2001).

Similar to the travel demand in an area, travel time patterns of a road vary based on the facility type, surrounding conditions and also the area type. Further, the performance in terms of the travel times at road link-level are influenced by the surrounding land use and socioeconomic characteristics (Mane and Pulugurtha, 2018; Mane and Pulugurtha, 2020). The complex interactions between the surrounding area characteristics and the travel patterns requires a research design which considers the spatial approach. Incorporating a Geographic Information System (GIS)-based approach enables to capture associated data for analysis and modeling (Handy, 2005).

Spatial modeling approach accounts for the characteristics in the surrounding area into the prediction framework. Studies in the past on the travel time prediction incorporated the spatial modeling frameworks to capture and quantify the surrounding variables (Mane and Pulugurtha, 2020). Further, some of the research studies in the past incorporated the use of spatial modeling approaches like Kriging to predict the link-level travel times (Aultman-Hall and Du, 2006; Miura, 2010).

2.8 Limitations of Past Research

It is important to study the operational performance of the trucks due to their profound influence on the traffic streams and plan for better routing strategies to account for future demand. The availability of probe data by the vehicle type enables researchers understand truck travel performance computed based on real-world travel time information. 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. Further, many studies also explored the relationships between these measures to better understand the travel time patterns. As truck travel are significantly different from passenger cars, the applicability of passenger cars or mixed traffic stream-based performance evaluation is debatable. Further, research on truck performance and management using travel time data is currently very limited.

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

The trucking activity in a region is also influenced by characteristics in the near vicinity (on-network and off-network characteristics). Majority of the previous studies did not account or examine the association of trucking activity with on-network and off-network characteristics. The association of the truck travel time performance measures with the on-network and off-network characteristics in the near vicinity would provide valuable insights to not only understand the influence of trucks on traffic stream but also to proactively plan, design, and build land use and transportation systems.

CHAPTER 3: METHODOLOGY

This chapter provides an overview of the methodological framework adopted for this research. The framework includes the following steps.

1. Identifying the truck travel time performance measures
2. Understanding the association of truck travel time performance with on-network and off-network characteristics
3. Geospatial mapping of truck travel time performance measures
4. Development of the truck travel time estimation models
    - Statistical modeling approach
    - Model development mechanism
5. Model validation

3.1 Identifying the Truck Travel Time Performance Measures

Truck travel times vary with 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 mixed traffic streams. The past research on truck traffic and their operational performance is fairly limited. Hence, there are no defined or widely acceptable truck travel time performance measures available at the time of this research.

Examining relationships between the link-level travel time performance measures enables to identify the appropriate measure based on the study purpose. The applicability of these performance measures for trucks is examined using the Pearson correlation analysis.

The Pearson correlation analysis is used to examine the degree of linear association between two variables (De Sá, 2007). The Pearson correlation coefficient can be equal to 0 (indicating no association), equal to ±1 (indicating a strong positive or negative association), 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 significant at a 95% confidence level are considered to define the association between any two selected travel time performance measures.

Various link-level truck travel time measures are used and segregated by the time of the day and day of the week. The travel time performance measures 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, ranking segments, etc.

3.2 Understanding the Association of Truck Travel Time Performance with On-network and Off-network characteristics

Truck travel patterns are influenced by the on-network and proximal off-network characteristics. Pearson correlation analysis was used to assess the linear association and understand the relationship between the truck travel time performance with these variables. The truck travel time performance measures (identified in the previous step) for various times of the day and days of the week were considered with the corresponding on-network (road) and off-network (land use and demographic) characteristics for the analysis.

3.3 Geospatial Mapping of the Truck Travel Time Performance Measures

Truck travel time performance measures assist in understanding travel patterns of individual links. Visualizing the link-level performance measures (from the previous steps) geospatially allows identifying the links that are susceptible to truck congestion. In addition, the temporal variations in truck travel times/travel time reliability can be identified by comparing the maps for various times of the day and days of the week.

3.4 Development of the Truck Travel Time Estimation Models

Traffic congestion is a prevailing problem emphasizing the need to research on estimating the travel times for various times of the day and days of the week. Particularly, in the case of trucks, potential data sources offer less coverage area, i.e., the data is available for a limited number of roads with fewer sample sizes. While many passenger car or mixed traffic stream travel time estimation models exist, their applicability for trucks is uncertain as they are significantly different in terms of travel times and their reliability measures (Duvvuri et al., 2021). Hence, this research aims to fill the gap to understand truck travel data and recommend a suitable model and corresponding methodology to be adopted to estimate link-level truck travel times.

The Pearson correlation analysis in the previous step provides an understanding of the bivariate relationship between the truck travel time performance and on-/off-network characteristics. Reinforcing this analysis with travel time estimation models using statistical modeling enables better understanding of the multivariate relationship between the truck travel time and on-/off-network characteristics. In addition, truck travel time data is not available for all the roads making it difficult to understand truck travel behavior on each road. Hence, it is practical to estimate the truck travel using the set of on-network and off-network characteristics.

3.4.1 Statistical Models for Estimating Truck Travel Times

Regression models have gained popularity in the field of transportation to understand the relationship between two entities. In the case of linear regression models, multiple assumptions on the linearity, normality, homoscedasticity, and multicollinearity exist, making their applicability in estimating truck travel times questionable. Some of these assumptions are addressed in the extension of the standard linear regression model by introducing the generalized linear modeling (GLM) method, where the normality and the constant variance of the errors are not required. However, in the case of GLMs, the variables are assumed to be independently and identically distributed, which may not be applicable for truck travel time data. Further, GLM is not suitable for longitudinal datasets and also result in inaccurate estimates if the independent variables are correlated.

To overcome these challenges, generalized estimating equations (GEE) was considered for analysis to estimate the truck travel times. GEE is an extension of the GLM developed by Liang and Zeger (1986). GEE is applicable in cases where the dependent variable is not normally distributed. GEE models are also applicable for longitudinal datasets and is based on the Quasilikelihood theory (Wedderburn, 1974).

Multiple models can be developed using the link function and distribution of the dependent variable. Distributions like the Poisson, Gamma, linear, multinomial, etc. can be selected with varying link functions like the identity, natural log, square, square root, etc. For this research, linear (with identity link function), gamma log link, Poisson log linear and negative binomial log link were used for modeling using GENMOD procedure in Statistical Analysis Software. In the case of linear distribution-based method, two models were developed: with and without intercept.

The Quasilikelihood under independence model criterion (QIC) and corrected Quasi-likelihood under Independence Model Criterion (QICC) are used to examine the goodness of fit of the model (Pan, 2001). Typically, lower values of QIC and QICC are suggested along with low difference between QIC and QICC.

Multiple GEE models were developed to estimate the truck travel times (normalized based on the link length) using the temporal, and spatial (on-network and off-network) characteristics as independent variables.

Models with multiple independent variables are susceptible to being insignificant in the model leading to complexity, making the interpretation of these variables difficult. In order to overcome this, stepwise backward elimination was used to remove variables (one at a time) by checking their significance value in each step. This step of removing each variable was performed until all the variables in the model are significant.

3.4.2 Model Development Mechanism

Two main questions are investigated in the first step of modeling. Firstly, the model to be chosen in the GEE method and, secondly, the extent of the off-network characteristics which are useful to estimate the truck travel times.

Various off-network characteristics like the demographics and land use influence truck travel times. However, there is a lack of evidence on up to what extent these off-network characteristics may influence the truck travel times. Spatial proximity and spatial weights were considered for the model development. Buffers (proximity toolset) was used to capture data around the link within 0.25-, 0.50-mile and 1-mile, respectively. The spatial weights account for spatially varying patterns and are computed by assigning relatively higher weight to the nearest objects than the far objects. A total of three distance decay functions ($1/d$, $1/d^2$, $1/d^3$) were used to compute the spatial weights of the off-network characteristics. A detailed discussion on the data processing of spatial proximity and spatial weights is presented in Chapter 4. Three possibilities to capture the surrounding off-network characteristics in the truck travel time estimation models are inspected using the framework shown in Figure 1.

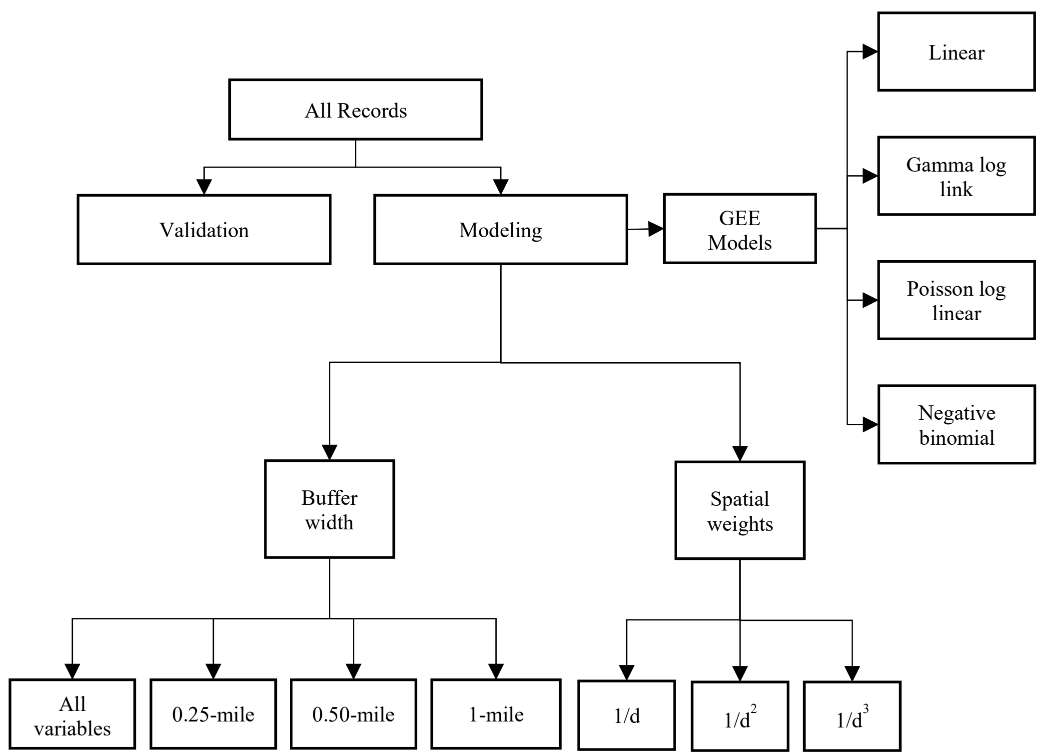

Figure 1 Methodology for model development

There are multiple land use and demographic characteristics around a link that may not have a similar effect on the truck travel times. For example, the residential land use within a 0.25-mile buffer to the subject link may significantly influence the truck travel times. Contrarily, heavy commercial areas within a 1-mile buffer to the subject link may significantly influence truck travel times. To understand such complex interactions, the truck travel time estimation modeling was conducted using all the variables from all the buffer widths.

The second approach comprises modeling truck travel times using individual buffer widths, separately, to identify ideal spatial proximity that significantly influences truck travel times. Lastly, the third approach included integration of off-network characteristics using spatial weights.

Truck travel time data for 75% of the links in the analysis were used for modeling, while data for the remaining 25% of the links was used for validation. The links for modeling and validation were selected randomly.

The goodness of fit and model validation was performed to check which model/approach works better. The disaggregate level models were also developed based on the speed limit and area type to account for varying link patterns. A detailed description on the study area and data processing is presented in Chapter 4.

3.5 Model Validation

Model validation plays an important role in understanding the efficiency of the model used for truck travel time estimation. The validation dataset was considered for validating the truck travel time estimation models. They are validated using the mean percentage error (MPE), mean absolute percentage error (MAPE), and root mean square error (RMSE). These are mathematically represented using the equations 1-3. The MPE and MAPE are expressed in percentages whereas the RMSE is expressed in minutes per mile in this case.

$$MPE = \frac{100\%}{n} \sum \left(\frac{Actual\ truck\ travel\ time - Predicted\ truck\ travel\ time}{Actual\ truck\ travel\ time} \right) \quad (1)$$

$$MAPE = \frac{100\%}{n} \sum \left| \frac{Actual\ truck\ travel\ time - Predicted\ truck\ travel\ time}{Actual\ truck\ travel\ time} \right| \quad (2)$$

$$RMSE = \sqrt{\frac{\sum (Actual\ truck\ travel\ time - Predicted\ truck\ travel\ time)^2}{n}} \quad (3)$$

where n is the number of records for validation.

CHAPTER 4: STUDY AREA AND DATA

This chapter provides an overview of the study area, data, data processing, and variables considered in this research.

4.1 Study Area and Data Collection

Three counties in North Carolina were selected based on their geographic location, development type, data availability and quality. They are Mecklenburg County, Buncombe County, and Wake County. These counties are spatially distributed in North Carolina. They represent the piedmont region and the mountainous region in the state.

Mecklenburg County is an urban county with around 1 million population, with a growth rate of around 1.9% per annum (as of 2018). Buncombe County is considered as a rural county with approximately 0.2 million population and reported a growth rate of 0.9% .Similarly, Wake County is an urban county with a population of 1 million and the corresponding growth rate of 2.2% per annum (as of 2018) (NCDOC, 2020a; NCDOC, 2020b).

Travel time data was obtained from a private data source for the year 2019 from National Performance Management Research Dataset (NPMRDS) at 5-minute intervals. NPMRDS is part of the INRIX with a coverage of over 400,000 links across the United States with high accuracy in travel time data. Each link is identified with a unique Traffic Message Channel (TMC) Code - a 9-digit code. The raw truck travel time dataset for each link consists of the variables such as the date-time stamp of the record, average speed, truck travel time, reference speed, and data density. They indicate the time and date of data collection, corresponding speed and travel time information, reference speed, and the data density condition. The reference speed variable is an indicator of the free-flow speed of the corresponding link. This measure is computed using the 85^{th} percentile speed amongst all the time periods. Data density is the representative of the number of possible reporting vehicles in the corresponding time interval (an indicator of traffic volume / condition). It is classified into three groups with density condition “A” indicating 1 to 4 vehicles, density condition “B” indicating 5 to 9 vehicles, and the density condition “C” indicating 10 or more vehicles. The network characteristics present include the variables such as the length of the segment, route characteristics, and other traffic characteristics (such as the traffic volume).

The on-network characteristics mainly comprised of the information associated with the links (variables such as functional class, number of lanes, etc.). The dataset for the raw travel time data consists of supporting data associated with location referencing metadata and the shapefiles. The on-network characteristics such as the annual average daily traffic (AADT), functional class, and number of through lanes are collected from the shapefiles. The speed limit was manually captured using Google Maps street view.

The off-network characteristics like land use, demographic and socioeconomic data were also considered. The demographic and socioeconomic data are obtained from the metropolitan planning organizations (MPOs) in GIS-shapefile format, represented at TAZ level. The 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 was obtained from the open-source data platform (“nconemap” platform) in GIS-shapefile format with information represented at a parcel-level.

4.2 Data Processing

Data processing involved the travel time processing and filtering, followed by the extraction of on-network and off-network characteristics. The travel time was processed using Microsoft SQL and GIS-based processing was used for capturing the on- and off-network variables (Microsoft, 2017).

4.2.1 Travel Time Data and On-network Characteristics

Link-level truck travel times are extracted for selected days of the week, weekday and weekend traffic. A total of four times of the day are 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). Travel time percentiles, descriptive measures and reliability measures are computed. In addition to the travel time measures, the reference speed and data density were also processed. The percentage of samples falling in each category are computed to quantify the data density. The processed data was joined with the link characteristics to extract selected information (length of the link and AADT). The AADT variable was scaled to thousands for the analysis. The final dataset after joining included travel time measures and other variables such as time of the day, day of the week, reference speed, total number of samples involved, AADT (in thousands), and percentages of samples in each data density condition.

The links with lower samples of probe data and smaller segment-lengths were excluded from the research. The data filtering was performed by excluding the links with sample size less than 52, and the length of the segment less than 0.06 miles (approximately 300 feet). The travel time filtered data was divided into eight individual datasets (representing each category of time of the day and day of the week) to extract the links present in common. This step was performed to ensure that the links for the study contained travel time data associated with all considered times of the day and days of the week. Figures 2, 3, and 4 show the links considered for analysis.

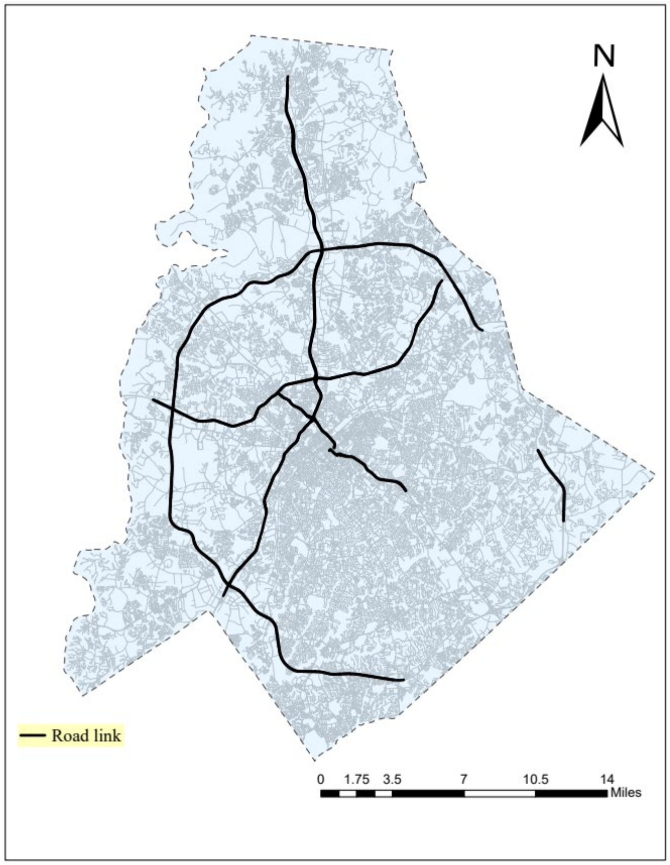

Figure 2 Links considered for the study (Mecklenburg County)

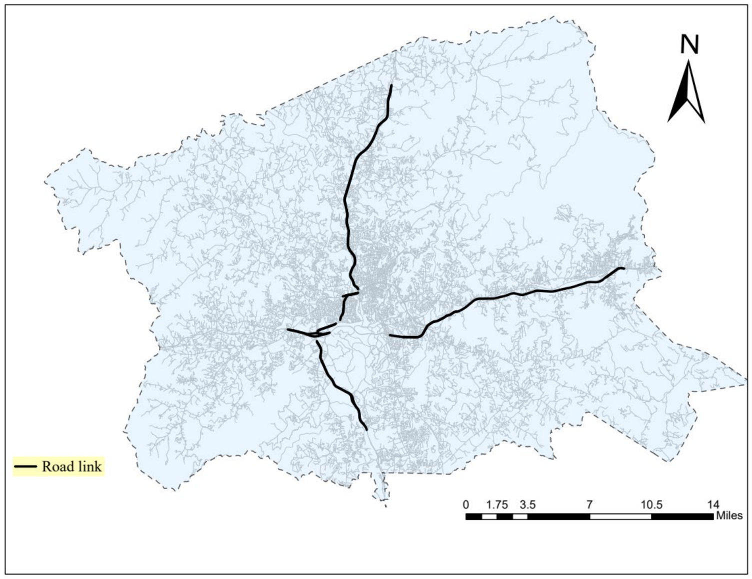

Figure 3 Links considered for the study (Buncombe County)

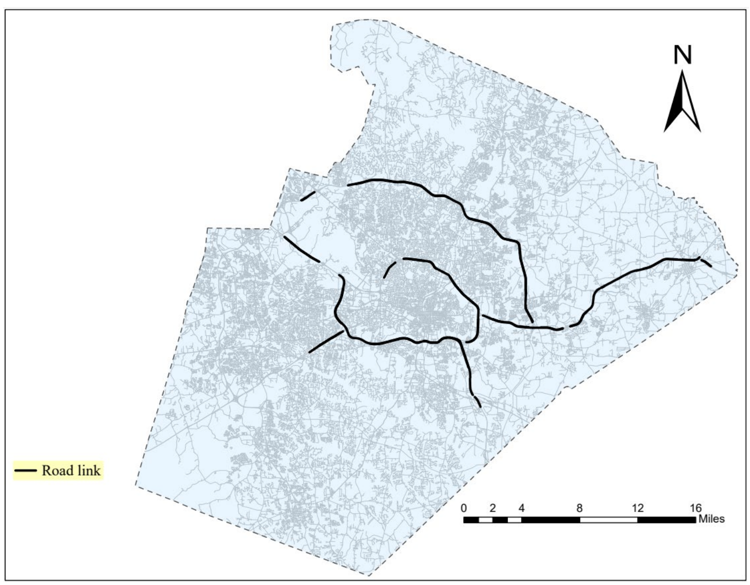

Figure 4 Links considered for the study (Wake County)

The final dataset consists of a total of 501 links with 275 links in Mecklenburg County, 80 links in Buncombe County, and 146 links in Wake County. The on-network characteristics data extraction for the links was performed using ArcGIS Pro (ESRI, 2018).

Various travel time performance measures were computed for the analysis. The travel time measures are divided into three categories: the descriptive measures, percentile travel times, and travel time reliability measures.

The descriptive measures considered include the minimum travel time (MinTT), maximum travel time (MaxTT), ATT, and the standard deviation of the travel time. The percentile travel time measures considered include 5^{th}, 10^{th}, 15^{th}, 25^{th}, 50^{th}, 75^{th}, 85^{th}, 90^{th}, and 95^{th} percentile travel times. The travel time reliability measures considered include the PT, PTI, BT, BTI, travel time index (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.

PT is defined as the 95th percentile travel time (Lomax et al., 2003). It is an indicator of travel time during congested conditions. PTI is defined as the ratio of the PT to the free-flow travel time (Equation 4) (Lomax et al., 2003).

$$PTI = \frac{PT}{Free-flow\ travel\ time} \tag{4}$$

BT is defined as the difference between the PT and the ATT (Equation 5) (Lomax et al., 2003). BT is an indicator of extra time the motorists consider to plan for reaching their destination on time. BTI is defined as the ratio of the BT to the ATT (Equation 6) (Lomax et al., 2003). BTI represents the percentage of extra time the motorists consider to plan for reaching their destination on time.

TTI is defined as the ratio of the ATT to the free-flow travel time (Equation 7) (Lomax et al., 2003). TTI represents the extra time the motorists consider than the free-flow time for reaching their destination on time.

$$BT = PT - ATT \tag{5}$$

$$BTI = \frac{BT}{ATT} \quad (6)$$

$$TTI = \frac{ATT}{Free\text{-}flow\ travel\ time} \quad (7)$$

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 of the 90th and the 10th percentile travel times to the 50th percentile travel time. Higher λ^{Skew} indicates higher probability of extreme travel times (high variation) while higher λ^{Var} indicates 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 8 and 9 (Van Lint and Van Zuylen, 2005).

$$\lambda^{Skew} = \frac{(90th\ percentile\ travel\ time - 50th\ percentile\ travel\ time)}{(50th\ percentile\ travel\ time - 10th\ percentile\ travel\ time)} \quad (8)$$

$$\lambda^{Var} = \frac{90th\ percentile\ travel\ time - 10th\ percentile\ travel\ time}{50th\ percentile\ travel\ time} \quad (9)$$

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

4.2.2 Land Use and Demographic Data

Land use data obtained in the GIS-shapefile format contains information of each parcel such as the development/construction year, type of land use, land use code, land use description and area of the parcel. Missing, abrupt values, and duplicate data points were removed in the county-wide parcel data. The raw data consisted of multiple categories of the land use description. Hence, these categories are reclassified for each county separately for the research. A total of 18 reclassified categories were considered for the analysis and modeling. The categories and their descriptions are shown in Table 1.

Table 1 Land use categories with description

Land use variable	Description
Agriculture	Land use parcels such as farms, commercial forestry, pasture, tree farms, etc.
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, church, etc.
Medical	Hospitals, pharmacy, and medical-based parcels
Light commercial	Constrained to community-based services such as fast-food centers, commercial stores (like laundry), service stations, etc.
Heavy commercial	Commercial land use parcels such as shopping mall, furniture stores, etc.
Light industrial	Light manufacturing-based industries and warehouse-based land use parcels
Heavy industrial	Involves industry-based land use parcels involving small manufacturing services, wastewater treatment plans, etc.
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, etc.
Resource	Resource land use parcels include wetlands, creeks, etc.
Retail	Parcels allocated for retail purposes; include convenient/department store, supermarket, etc.
Transportation	Parcels such as trucking rest areas, right of way, or transportation/parking services
Unknown/vacant	Unknown parcels, or no land use category is allocated

Socioeconomic and demographic data at the TAZ-level are obtained from the corresponding MPOs in GIS-shapefile format. Selected variables considered for the research include the numbers of household units, population density, and employment density. The raw data consists of the population and employee estimates in the TAZs. Hence, the population and employment density are computed using the equations 10 and 11.

$$Population\ density = \frac{Number\ of\ people\ in\ the\ TAZ}{Area\ of\ the\ TAZ\ (in\ square\ miles)} \tag{10}$$

$$Employement\ density = \frac{Number\ of\ people\ employed\ in\ the\ TAZ}{Area\ of\ the\ TAZ\ (in\ square\ miles)} \tag{11}$$

The off-network characteristics in the vicinity are captured using spatial proximity and spatial weights. Buffers are classified under the proximity toolset to capture the area of influence under the proximity. Buffer around an entity creates a border with specified buffer width indicating the influence area. As the links are represented in the form of links, network buffers are created using ArcGIS Pro (ESRI, 2018). Three buffer widths were considered for this research (0.25 miles, 0.50 miles, and 1 mile).

Land use data, and demographic data was overlaid on the generated buffers and "intersect" feature was used in the ArcGIS Pro to extract the data in the buffer. Hence, the area of influence was computed for each land use category. Figures 5 and 6 indicate the representation of a sample network buffer considered along with the TAZ and land use data overlaid on that.

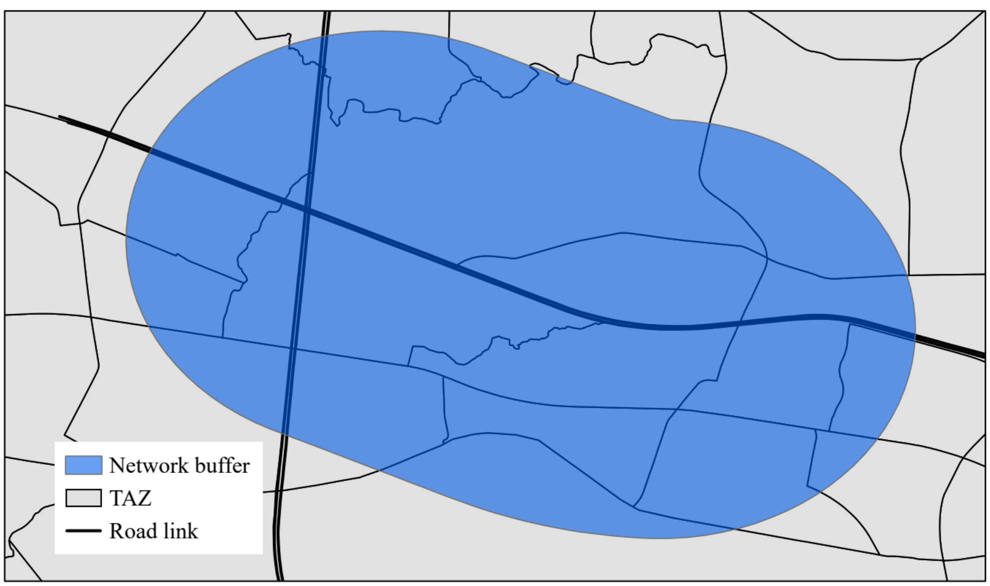

Figure 5 Buffer overlaid on the TAZ data

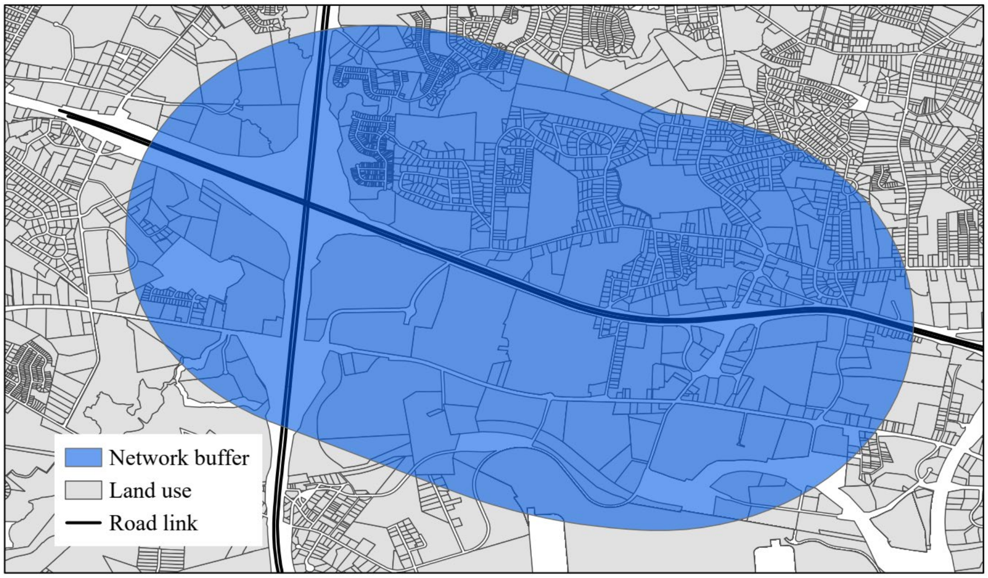

Figure 6 Buffer overlaid on the land use data

The population, number of household units, population density and employment density are computed using the equations 12 and 13.

$$P_i = \sum_j \frac{A_{j,i}}{A_j} \times P_j \quad (12)$$

where P_i is the population or 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 or number of household units of the TAZ "j", and A_j is the total area of the TAZ "j".

$$PD_i = \frac{\sum_j A_{j,i} \times PD_j}{A_i} \quad (13)$$

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".

In addition to the individual effects of land uses and socioeconomic variables, there is also an effect of the overall developed area. According to Environmental Protection Agency (EPA), the percent of developed area represents the areas or developments where “people live, work, and play…” (EPA, 2015). Hence, a variable named “percent of developed area” was computed within the buffer in order to capture the effect of developed area. The value of the developed area is computed using equation 14.

$$Percent\ of\ developed\ area =$$

$$\frac{\sum(Land\ uses\ in\ the\ buffer\ except - resource,\ \ unknown,\ \ agriculture\ and\ vacant)}{Area\ of\ buffer} \qquad (14)$$

4.3 Data Preparation for Truck Travel Time Estimation

Data preparation is an important step prior to developing a model and estimating the truck travel times efficiently. Travel times are susceptible to temporal and spatial variations. Hence, the estimation models must consider temporal aspects (time of the day and day of the week) while developing the model. Longitudinal (or panel) data preparation considers the subject (links in this case) having multiple values at multiple time frames (travel times for various times of the day and days of the week). The data was prepared in the form of a longitudinal dataset.

Some of the off-network variables like the population, number of household units, population density and employment density were scaled to 1000 to match the range of truck travel times and other variables. In addition, the AADT variable was transformed to natural log by computing ln(AADT).

Modeling based on spatial proximity and spatial weights requires separate datasets for the analysis. For spatial proximity-based models, the dataset was segregated based on buffer width for model development.

The spatial weights account for spatially varying patterns (off-network characteristics in this case) and are computed by assigning relatively higher weight to the nearest objects than the far objects. The spatial weights method was used in the past studies to identify the critical buffer width and its corresponding weight to capture the off-network characteristics (Kusam, 2011; Pulugurtha and Agurla, 2012a,b; Pulugurtha and Kusam, 2012; Pulugurtha and Maradapudi, 2013). The data preparation and processing for the spatial proximity and weights is discussed in the next section.

In preparing data for developing spatial weights based models, one of the most important step is to compute the weighted values for each off-network variable. Three spatially decreasing functions were considered for analysis: 1/d, $1/d^2$, and $1/d^3$. The data from 0.25-mile, 0.50-mile and 1-mile buffer widths were used for computing the weights for 0-0.25, 0.25-0.50 and 0.50-1-mile using the equations 15-17.

$$Spatial\ Weight\ for\ i-j\ of\left(\frac{1}{j}\right) = W_j = \frac{1/j}{\sum 1/j} \tag{15}$$

$$Spatial\ Weight\ for\ i-j\ of\ \left(\frac{1}{j^2}\right) = W_{j^2} = \frac{1/j^2}{\sum 1/j^2} \tag{16}$$

$$Spatial\ Weight\ for\ i-j\ of\left(\frac{1}{j^3}\right) = W_{j^3} = \frac{1/j^3}{\sum 1/j^3} \tag{17}$$

where j is the buffer width (0.25, 0.50 mile and 1 miles).

The bandwidth weights are computed as shown in Table 2.

Table 2 Spatial weights for bandwidths

Bandwidth					**Function**					
i	**j**	**1/j**	**W_j**	**W_{i-j}**	**$1/j^2$**	**W_j^2**	**W_{i-j}**	**$1/j^3$**	**W_j^3**	**W_{i-j}**
0.00	0.25	1/0.25	4.00	0.57	$1/0.25^2$	16.00	0.76	$1/0.25^3$	64.00	0.88
0.25	0.50	1/0.50	2.00	0.29	$1/0.50^2$	4.00	0.19	$1/0.50^3$	8.00	0.11
0.50	1.00	1/1.00	1.00	0.14	$1/1.00^2$	1.00	0.05	$1/1.00^3$	1.00	0.01
		Total	7.00		Total	21.00		Total	73.00	

The spatial weights computation gives rise to a value based on the equations. They were converted to percentages to ensure the sum of weights remain "1". For example, in Table 2, for the spatial weight of 1/j, the weights for each bandwidth range from 1 to 4. Based on the total, the percentage contribution of each buffer width was computed as: for 0-0.25 mile: $W_{i\text{-}j}$ = 4/7=0.57 (or 57%); for 0.25-0.50 mile: $W_{i\text{-}j}$ = 2/7=0.29 and for 0.50-1.00 mile: $W_{i\text{-}j}$ = 1/7 = 0.14.

Figure 7 shows the spatial weights used for the analysis of the three distance decaying functions. It can be observed that the weight towards the 1-mile buffer decreases significantly as the power increases while the weight for the 0.25-mile buffer increases.

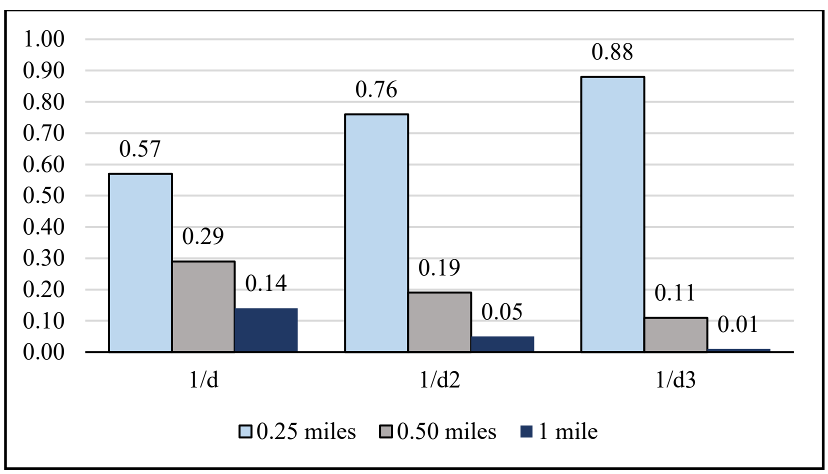

Figure 7 Spatial weights for varying decaying functions

CHAPTER 5: TRUCK TRAVEL TIME PERFORMANCE MEASURES AND THEIR ASSOCIATION WITH ON-NETWORK AND OFF-NETWORK CHARACTERISTICS

This chapter presents the descriptive statistics of the data (truck travel time measures, on-network and off-network characteristics) and results of the truck travel time performance measures' identification, and their association with the on-network and off-network characteristics. The Pearson correlation analysis was performed with the computed truck travel time measures to identify possible performance measures. Further, these performance measures are used to conduct Pearson correlation analysis with the on-network and off-network characteristics.

5.1 Descriptive Statistics of Truck Travel Time Measures, On-network and Off-network Characteristics

Prior to the analysis, the descriptive statistics of the data considered for the study are examined to identify possible outliers and any anomalies in the data. Table 3 summarizes the descriptive statistics of the filtered links travel time measures. The minimum, maximum, median, average and standard deviation values are presented in the table.

Tables 4 and 5 summarize the frequency distribution and descriptive statistics of on-network variables considered for this research.

Table 3 Descriptive statistics of the truck travel time measures

		Minimum		Median		Mean		Maximum		Standard Deviation	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Morning peak hour	ATT in minutes	0.08	0.07	0.66	0.54	0.95	0.73	13.12	4.47	1.01	0.63
	PT	0.10	0.08	0.89	0.60	1.49	0.81	30.67	5.11	2.13	0.69
	BT	0.00	0.01	0.12	0.06	0.54	0.08	17.55	0.65	1.23	0.08
	BTI	0.14	1.20	17.59	10.32	43.17	12.68	251.81	103.12	47.35	9.26
	PTI	1.11	1.11	1.40	1.20	2.29	1.25	13.20	3.05	1.85	0.18
	TTI	1.05	1.05	1.19	1.09	1.46	1.11	7.35	1.87	0.68	0.07
	λ^{Skew}	0.25	0.20	1.72	1.14	3.05	1.27	42.44	5.20	3.88	0.67
	λ^{Var}	0.07	0.08	0.21	0.15	0.51	0.17	5.27	1.20	0.63	0.09
Afternoon peak hour	ATT in minutes	0.07	0.07	0.55	0.54	0.75	0.75	4.81	5.65	0.65	0.68
	PT	0.09	0.09	0.61	0.62	0.85	0.90	5.70	11.38	0.76	1.02
	BT	0.00	0.00	0.05	0.06	0.10	0.15	2.06	5.75	0.17	0.47
	BTI	0.48	0.30	9.64	11.06	13.92	16.37	122.48	218.13	15.08	20.23
	PTI	1.09	1.13	1.21	1.22	1.31	1.34	4.83	7.25	0.32	0.47
	TTI	1.04	1.05	1.10	1.10	1.14	1.14	2.17	2.50	0.10	0.12
	λ^{Skew}	0.25	0.25	1.33	1.25	1.62	1.59	29.34	21.82	1.71	1.86
	λ^{Var}	0.06	0.10	0.13	0.15	0.17	0.20	1.42	3.91	0.14	0.23
Evening peak hour	ATT in minutes	0.11	0.07	0.72	0.55	1.14	0.74	8.41	4.89	1.16	0.65
	PT	0.13	0.09	1.09	0.63	1.93	0.87	18.67	6.42	2.39	0.77
	BT	0.00	0.01	0.23	0.07	0.80	0.12	11.24	1.97	1.34	0.19
	BTI	0.33	1.33	38.67	12.56	57.54	17.30	272.02	152.55	55.06	18.22
	PTI	1.13	1.13	1.84	1.24	3.23	1.35	17.75	5.27	3.02	0.37
	TTI	1.06	1.05	1.31	1.11	1.82	1.14	9.47	2.10	1.20	0.11
	λ^{Skew}	0.33	0.50	1.88	1.43	3.00	1.57	24.79	8.82	3.06	0.85
	λ^{Var}	0.07	0.09	0.35	0.16	0.69	0.20	3.71	1.73	0.71	0.13
Night-time	ATT in minutes	0.07	0.07	0.55	0.55	0.76	0.75	4.72	4.69	0.67	0.64
	PT	0.09	0.09	0.65	0.64	0.97	0.90	7.35	6.59	1.00	0.82
	BT	0.00	0.01	0.08	0.08	0.21	0.16	5.25	5.22	0.52	0.36
	BTI	0.29	1.34	13.26	13.52	24.24	21.33	304.31	381.39	39.41	35.91
	PTI	1.13	1.13	1.27	1.26	1.49	1.42	9.29	9.29	0.82	0.71
	TTI	1.05	1.05	1.12	1.11	1.16	1.14	2.35	1.97	0.13	0.11
	λ^{Skew}	0.25	0.33	1.46	1.50	2.14	1.87	68.58	28.12	3.97	2.08
	λ^{Var}	0.09	0.09	0.17	0.17	0.23	0.22	5.52	2.23	0.32	0.18

Table 4 Frequency distribution for on-network characteristics

Variable	Category	Frequency (percentage)
Number of through lanes	4	143 (28.54)
	6	195 (38.92)
	8	154 (30.74)
	10	9 (1.80)
Functional class	Interstates	423 (84.43)
	Principal Arterials (Freeways and expressways)	78 (15.57)
Speed limit	45 mph	8 (1.6)
	50 mph	26 (5.19)
	55 mph	73 (14.57)
	60 mph	128 (25.55)
	65 mph	101 (20.16)
	70 mph	165 (32.93)

Table 5 Summary statistics of the on-network characteristics

		Minimum (%)		Median (%)		Mean (%)		Maximum (%)		Standard Deviation (%)	
		Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend	Weekday	Weekend
Morning peak hour	A	14.93	83.72	92.76	100.00	81.25	98.97	100.00	100.00	21.99	2.15
	B	0.00	0.00	7.21	0.00	17.49	1.03	64.19	16.28	19.69	2.15
	C	0.00	0.00	0.00	0.00	1.26	0.00	34.83	0.19	3.32	0.01
Afternoon peak hour	A	6.13	69.93	87.28	99.46	74.14	97.47	100.00	100.00	27.14	4.53
	B	0.00	0.00	12.65	0.54	22.86	2.52	65.58	29.22	22.56	4.49
	C	0.00	0.00	0.17	0.00	3.00	0.01	59.35	0.84	6.47	0.06
Evening peak hour	A	15.32	64.49	96.66	99.67	87.77	97.94	100.00	100.00	16.82	4.12
	B	0.00	0.00	3.34	0.33	11.74	2.05	71.45	33.50	15.60	4.05
	C	0.00	0.00	0.00	0.00	0.49	0.01	20.88	2.01	1.84	0.12
Night-time	A	62.84	86.47	99.46	100.00	96.89	99.36	100.00	100.00	5.50	1.40
	B	0.00	0.00	0.54	0.00	3.09	0.64	35.98	13.53	5.42	1.40
	C	0.00	0.00	0.00	0.00	0.02	0.00	1.36	0.00	0.12	0.00

Land use, socio-economic and demographic variables captured using buffer analysis are considered as off-network characteristics. Land use data statistics are inspected by representing the total area in each category for the considered buffer widths (0.25, 0.50 and 1 miles). Table 6 summarizes the land use variables for each considered buffer width.

Table 6 Summary statistics of the land use characteristics

	Sum of land use in the buffers (in sq. mi.)		
	0.25-mile	**0.50-mile**	**1.00-mile**
Agriculture	55.92	155.52	567.60
College	22.08	87.36	310.96
Government	21.20	59.60	186.72
Heavy commercial	37.60	109.68	326.32
Heavy industrial	49.76	132.64	337.52
Institutional	32.08	104.24	350.80
Light commercial	141.52	399.36	1064.88
Light industrial	193.04	554.88	1687.60
Medical	5.20	10.00	35.36
Multifamily residential	123.76	382.08	1324.64
Office	72.96	206.64	586.48
Recreational	24.00	85.52	339.04
Resource	26.48	72.56	214.32
Retail	27.36	78.16	209.28
Single family residential	536.72	1722.72	6045.20
Transportation	1.92	6.80	29.92
Unknown/Vacant	220.72	578.16	1679.52

Weighted values for population, number of household units, population density and employment density are computed for the corresponding buffer widths to capture the demographic and socioeconomic characteristics. Table 7 summarizes the descriptive statistics of the demographic characteristics for the corresponding buffer widths.

Table 7 Summary statistics of the demographic and socioeconomic variables

Variable	Buffer width (in miles)	Minimum	Maximum	Median	Average	Standard deviation
Population (population count)	0.25	0	314	453	2649	417
	0.50	1	994	1254	6209	940
	1.00	17	3547	4079	15125	2394
Household units (# of units)	0.25	0	125	182	1153	173
	0.50	1	382	501	2660	390
	1.00	8	1339	1622	6515	1006
Population density (population per sq. mi.)	0.25	0.17	1325.98	1712.57	9241.37	1507.28
	0.50	0.18	1502.48	1777.22	7710.48	1367.16
	1.00	7.41	1626.99	1853.44	12856.87	1395.7
Employment density (Employees per sq. mi.)	0.25	10.62	1264.25	1963.93	9830.88	1974.38
	0.50	9.89	1322.48	2351.88	27556.99	3636.66
	1.00	2.02	1332.63	2296.99	35336.75	3557.43

5.2 Truck Travel Time Performance Measures

A total of eight datasets (by time of the day and day of the week) were generated leading to a total of eight correlation tables. The Pearson correlation coefficients are explored to understand the multicollinearity between the variables.

Typically, the performance measures are selected based on the multicollinearity of the variables. The travel time performance measure which shows multicollinearity with majority of other travel time measures was considered to be suitable as the performance indicator. The correlation coefficients which are significant at a 95% confidence level are considered for assessment. The Pearson correlation coefficients are classified into six categories and represented in the table 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)

The Pearson correlation table results between truck travel time measures are shown in Appendix A. Tables 8-15 summarize sample Pearson correlation matrices with coefficients color-coded and labeled accordingly. Multicollinearity patterns are inspected among the travel time measures. All the percentile measures indicate similar trends (i.e., high positive correlation coefficient with the other travel time measures) leaving no specific measure amongst them to be chosen.

Trip patterns and their associated travel times are influenced by the variability and reliability in travel time measures (Dowling et al., 2015). Descriptive measures like the minimum, maximum and variance indicate inconsistencies by the selected time of the day. For example, in the case of peak hours, the variance is correlated to minimum / maximum travel times. However, a moderate or low correlation is observed in the case of the off-peak periods such as the night-time. Variance and standard deviation indicate a high positive correlation with all other variables (including λ^{Skew} and λ^{Var}). The ATT remains as a consistent indicator among the descriptive travel time measures.

Variables such as the λ^{Skew} and λ^{Var} cannot be chosen due to their low correlation trends with other travel time measures. Further, the trends are a mix of low to moderate correlations in the case of the considered time of the day and day of the week scenarios. Measures such as the PTI and TTI are recommended by the FHWA for the congestion management process (Dowling et al., 2015). Hence, from the correlation results, the ATT, PTI, BTI and TTI were considered as better performance measures in all the selected time of the day and day of the week datasets. These measures are used to assess the relationship between on-network and off-network characteristics.

Table 8 Correlations between the truck travel time measures (morning peak, weekday)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	HN	MN	LN	LP	MP	HP

Table 9 Correlations between the truck travel time measures (morning peak, weekend)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	HN	MN	LN	LP	MP	HP

Table 10 Correlations between the truck travel time measures (afternoon peak, weekday)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	HN	MN	LN	LP	MP	HP

Table 11 Correlations between the truck travel time measures (afternoon peak, weekend)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	HN	MN	LN	LP	MP	HP

Table 12 Correlations between the truck travel time measures (evening peak, weekday)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	HN	MN	LN	LP	MP	HP

Table 13 Correlations between the truck travel time measures (evening peak, weekend)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	HN	MN	LN	LP	MP	HP

Table 14 Correlations between the truck travel time measures (night-time, weekday)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	HN	MN	LN	LP	MP	HP

Table 15 Correlations between the truck travel time measures (night-time, weekend)

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

Note: Cells with blank values on the lower diagonal of the table indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	HN	MN	LN	LP	MP	HP

The correlation results indicate variations 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 is categorized as the off-peak hour.

The results for the weekday datasets indicate a high positive correlation (>0.5) among descriptive truck travel time and truck travel time percentile measures. The results for the weekend datasets 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.

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

The PTI is an indicator of how much the total travel time varies from the free-flow time, while the 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, the results from weekday datasets indicate high positive correlation with the standard deviation.

The 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 (>50th 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 results in 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

The sum of scores was calculated initially. As there are eight Pearson correlation coefficient matrices, the maximum score would be $8 \times 3 = 24$. 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 16. A higher percentage 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 the 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.

Table 16 Scores indicating correlation between the truck travel time performance measures

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	100																			
ATT	100	100																		
Var	63	100	71																	
Std	88	100	92	100																
TT5	100	100	100	63	88															
TT10	100	100	100	63	88	100														
TT15	100	100	100	63	88	100	100													
TT25	100	100	100	67	88	100	100	100												
TT50	100	100	100	67	88	100	100	100	100											
TT75	100	100	100	67	92	100	100	100	100	100										
TT85	100	100	100	71	92	100	100	100	100	100	100									
TT90	100	100	100	75	92	100	100	100	100	100	100	100								
TT95	100	100	100	83	96	100	100	100	100	100	100	100	100							
PT	100	100	100	83	96	100	100	100	100	100	100	100	100	100						
BT	67	83	88	79	96	71	75	75	75	79	88	88	96	100	100					
BTI	13	46	17	42	63	8	8	8	13	13	17	25	33	54	54	96				
PTI	17	46	25	50	75	17	21	21	17	21	29	29	38	50	50	96	100			
TTI	17	50	33	54	79	17	21	25	29	33	42	38	33	42	42	88	100	100		
λ^{Skew}	8	33	17	29	50	8	8	13	13	13	13	17	21	38	38	75	100	83	71	
λ^{Var}	17	29	25	33	54	17	17	17	21	21	33	33	33	46	46	83	100	100	100	100

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

Selecting performance measures for the trucks involved two criteria, correlation results and findings from the past research. Trip patterns and their associated travel times are influenced by the variability and reliability in travel time performance measures (Lomax et al., 2001). Measures such as the PTI and TTI were recommended by the FHWA for congestion management (Lomax et al., 2001). 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. (Pulugurtha et al., 2016; Pulugurtha et al., 2017; Duddu et al., 2018)

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

5.3 Association of Truck Travel Time Performance Measures with On-network Characteristics

The results from the Pearson correlation analysis between the truck travel time performance measures and on-network characteristics are discussed in this section. Variables representing the on-network characteristics include the functional class, AADT, reference speed, speed limit, area type (as a binary variable), and data density (A, B and C).

The Pearson correlation coefficients which are significant at a 95% confidence level are considered for assessment. The Pearson correlation coefficients were classified into six categories and represented as color-coded cells. Table 17 summarizes the color-coded Pearson correlation analysis results between the truck tfravel time performance variables and on-network characteristics.

Interstates and principal arterials (freeways and expressways) are negatively correlated with the selected truck travel time performance measures. The correlations are more consistent in the case of weekdays compared to the weekend, mainly attributing to the amount of weekday traffic activity than weekend.

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. However, the association is relatively low. The selected truck travel time performance measures by time of the day and day of the week are positively correlated with the number of through lanes and AADT, in most cases. The selected truck travel time performance measures are negatively correlated with the reference speed and speed limit variables. The PTI, TTI, and BTI are negatively correlated with the speed limit, whereas the ATT showed a positive correlation with the speed limit during weekdays, possibly attributing to the high volumes of truck traffic.

Table 17 Correlation between the selected truck travel time performance measures and on-network characteristics

			Number of through lanes				Functional class		Area type		AADT	Speed limit	Reference speed	Data density		
			4	6	8	10	Interstates	Principal arterials (Freeways and other expressways)	Rural	Urban				A	B	C
Weekday	Morning peak	ATT			LN									LN	LP	
		PTI		LP					LN	LP	LP	LN	LN			
		BTI							LN	LP	LP	LN	LN			
		TTI		LP					LN	LP	LP	LN	LN			
	Afternoon peak	ATT	LP		LN						LN	LP				
		PTI	LP		LN		LN	LP				LN	LN			
		BTI	LP		LN							LN	LN			
		TTI	LP		LN	LN	LN	LP				LN	LN	LP	LN	
	Evening peak	ATT	LP		LN									LN	LP	LP
		PTI		LP			LP	LN	LN	LP	LP	LN	LN			
		BTI					LP	LN	LN	LP	LP	LN	LN			
		TTI		LP	LN		LP	LN	LN	LP	LP	LN	LN			
	Night-time	ATT	LP		LN						LN	LP		LN	LP	
		PTI							LN	LP	LP	LN	LN	LN	LP	LP
		BTI							LN	LP	LP	LN	LN	LN	LP	LP
		TTI									LP	LN	LN	LN	LP	LP
Weekend	Morning peak	ATT	LP		LN						LN	LP		LN	LP	LP
		PTI	LP				LN	LP			LN	LN	LN	LP	LN	
		BTI	LP				LN	LP			LN	LN	LN	LP	LN	
		TTI	LP		LN	LN	LN	LP			LN	LN		LP	LN	
	Afternoon peak	ATT	LP		LN				LP	LN	LN	LP		LN	LP	
		PTI	LP		LN				LP	LN		LN	LN	LN	LP	
		BTI	LP		LN				LP	LN		LN	LN	LN	LP	
		TTI	LP		LN				LP	LN	LN	LN	LN	LN	LP	
	Evening peak	ATT	LP		LN						LN	LP		LN	LP	LP
		PTI										LN	LN			LP
		BTI									LP	LN	LN	LN	LP	LP
		TTI					LN	LP				LN	LN			
	Night-time	ATT	LP		LN						LN	LP				
		PTI									LP	LN	LN			
		BTI									LP	LN	LN	LN	LP	
		TTI									LP	LN	LN			

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	HN	MN	LN	LP	MP	HP

The selected truck travel time performance measures are negatively correlated with the data density condition A during the night-time hours on weekday and majority of the times of the day for weekends. 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, the ATT is positively correlated with the data density condition B during all the selected times of the day.

The TTI and PTI are negatively correlated with the data density condition C during the weekday night-time 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. The ATT is significantly correlated with the data density condition C during all the selected times of the day. The PTI and TTI are positively correlated with the data density condition C during the weekday night-time hour.

5.4 Association of Truck Travel Time Performance Measures with Off-network Characteristics

Off-network variables considered included land use categories and demographic estimates for the study area. Land use data was used based on the area of each category in the established buffer. Tables 18-20 summarize the correlation results between the truck travel time measures and the land use categories for 0.25-mile, 0.50-mile and 1-mile buffer widths.

Table 18 Correlation between the truck travel time performance measures and land use characteristics (0.25-mile buffer)

			Agri	Clg	Gov	LCom	HCom	LInd	HInd	Inst	Med	SFam	MFam	Ofc	Rec	Resc	Retl	Transp	Vac/ukn	DevArea
Weekday	Morning peak	ATT	MP	LP	LP	MP		LP	LP	MP	LP	HP	MP	LP	LP			LP	LP	
		PTI	LN			LP								LP						
		BTI	LN			LP								LP						
		TTI	LN											LP					LN	
	Afternoon peak	ATT	MP	LP	LP	MP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		MP	
		PTI	LN			LP						LN		LP		LN			LN	
		BTI				LP					LP	LN		LP		LN			LN	LP
		TTI	LN			LP						LN				LN			LN	
	Evening peak	ATT	LP	LP	LP	MP		LP	LP	LP	LP	MP	MP	LP	LP				LP	LP
		PTI	LN			LP						LN		LP		LN			LN	LP
		BTI	LN			LP						LN		LP		LN			LN	LP
		TTI	LN			LP						LN		LP		LN			LN	LP
	Night-time	ATT	MP	LP	LP	MP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		MP	
		PTI						LP							LP				LN	LP
		BTI	LN			LP		LP							LP	LN			LN	LP
		TTI	LN			LP		LP	LN							LN			LN	LP
Weekend	Morning peak	ATT	HP	LP	LP	MP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		MP	
		PTI											LN	LN						
		BTI										LN	LN	LN						
		TTI				LN		LN					LN	LN						
	Afternoon peak	ATT	HP	LP	LP	MP		LP	LP	MP	LP	HP	HP	LP	LP	LP	LP		MP	
		PTI			LP	LP					LP		LP				LP			
		BTI			LP	LP					LP		LP				LP			
		TTI				LP		LN			LP						LP			
	Evening peak	ATT	HP	LP	LP	MP		LP	LP	MP	LP	HP	HP	LP	LP	LP	LP		MP	
		PTI										LN				LN			LN	
		BTI										LN				LN			LN	
		TTI					LN					LN							LN	
	Night-time	ATT	HP	LP	LP	MP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		MP	
		PTI						LP				LN							LN	LP
		BTI						LP				LN							LN	LP
		TTI										LN							LN	LP

Note 1: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Note 2:

Agri = Agriculture land use
Clg = College land use
Gov = Government land use
LCom = Light commercial land use
HCom = Heavy commercial land use
LInd = Light industrial land use
HInd = Heavy industrial land use
Inst = Institutional land use
Med = Medical land use
SFam = Single family residential land use
MFam = Multifamily residential land use
Ofc = Office land use
Rec = Recreational land use
Resc = Resource land use
Retl = Retail land use
Transp = Transportation land use
Vac/ukn = Vacant or unknown land use
DevArea = Percent of developed area

Color scale						
	HN	MN	LN	LP	MP	HP

Table 19 Correlation between the truck travel time performance measures and land use characteristics (0.50-mile buffer)

			Agri	Clg	Gov	LCom	HCom	LInd	HInd	Inst	Med	SFam	MFam	Ofc	Rec	Resc	Retl	Transp	Vac/ukn	DevArea
Weekday	Morning peak	ATT	MP	LP	LP	MP		LP	LP	MP	LP	MP	MP	LP	LP		LP		LP	
		PTI	LN			LP								LP					LN	
		BTI	LN			LP								LP			LP	LP		
		TTI	LN											LP					LN	
	Afternoon peak	ATT	MP	LP	LP	MP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		LP	
		PTI	LN			LP						LN				LN			LN	
		BTI	LN			LP					LP	LN		LP		LN			LN	
		TTI	LN			LP	LN					LN				LN			LN	
	Evening peak	ATT	LP	LP		MP		LP	LP	MP	LP	MP	MP	LP	LP		LP		LP	
		PTI	LN			LP		LP				LN		LP		LN			LN	LP
		BTI	LN			LP		LP				LN		LP		LN			LN	LP
		TTI	LN			LP						LN		MP		LN			LN	LP
	Night-time	ATT	MP	LP	LP	MP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		LP	
		PTI	LN			LP		LP									LN		LN	LP
		BTI	LN			LP		LP									LN		LN	LP
		TTI	LN			LP		LP	LN							LN			LN	LP
Weekend	Morning peak	ATT	HP	LP	LP	LP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		LP	
		PTI				LN	LN				LN		LN							
		BTI									LN	LN	LN							
		TTI				LN	LN	LN					LN							
	Afternoon peak	ATT	HP	LP	LP	MP		LP	LP	MP	LP	HP	HP	LP	LP	LP	LP		LP	
		PTI			LP	LP					LP		LP							
		BTI			LP	LP					LP		LP			LN			LN	
		TTI			LP	LP		LN					LP			LN			LN	
	Evening peak	ATT	HP	LP	LP	LP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		LP	
		PTI					LN					LN				LN			LN	
		BTI		LP								LN				LN			LN	
		TTI					LN					LN				LN			LN	
	Night-time	ATT	HP	LP	LP	LP		LP	LP	MP	LP	HP	MP	LP	LP	LP	LP		LP	
		PTI						LP				LN							LN	LP
		BTI						LP				LN							LN	LP
		TTI	LN					LP			LN	LN							LN	LP

Note 1: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Note 2:

Agri = Agriculture land use
Clg = College land use
Gov = Government land use
LCom = Light commercial land use
HCom = Heavy commercial land use
LInd = Light industrial land use
HInd = Heavy industrial land use
Inst = Institutional land use
Med = Medical land use
SFam = Single family residential land use
MFam = Multifamily residential land use
Ofc = Office land use
Rec = Recreational land use
Resc = Resource land use
Retl = Retail land use
Transp = Transportation land use
Vac/ukn = Vacant or unknown land use
DevArea = Percent of developed area

Color scale						
	HN	MN	LN	LP	MP	HP

Table 20 Correlation between the truck travel time performance measures and land use characteristics (1-mile buffer)

			Agri	Clg	Gov	LCom	HCom	LInd	HInd	Inst	Med	SFam	MFam	Ofc	Rec	Resc	Retl	Transp	Vac/ukn	DevArea
Weekday	Morning peak	ATT	LP	LP		LP		LP		MP	LP	MP	MP	LP	LP		LP		LP	
		PTI	LN							LP				LP		LN				
		BTI	LN			LP				LP	LP			LP			LP			
		TTI	LN					LP		LP				LP		LN			LN	LP
	Afternoon peak	ATT	MP	LP	LP	LP	LP			MP	LP	HP	MP		LP	LP	LP		LP	
		PTI	LN	LP		LP				LP		LN				LN			LN	
		BTI	LN			LP				LP		LN		LP		LN			LN	
		TTI	LN			LP				LP		LN				LN	LN		LN	
	Evening peak	ATT	LP	LP		LP	LP	LP		LP		MP	MP	LP	LP					
		PTI	LN			LP		LP		LP		LN		MP		LN	LN		LN	LP
		BTI	LN		LP	LP		LP		LP		LN		LP		LN			LN	LP
		TTI	LN			LP		LP				LN		MP		LN	LN		LN	LP
	Night-time	ATT	MP	LP	LP	LP	LP	LP		MP	LP	HP	MP		LP	LP	LP		LP	
		PTI	LN			LP		LP									LN		LN	LP
		BTI	LN	LP		LP		LP								LN	LN		LN	LP
		TTI	LN	LP		LP	LN	LP	LN	LP	LN	LN				LN	LN		LN	LP
Weekend	Morning peak	ATT	MP	LP	LP	LP	LP			MP	LP	HP	MP		LP	LP	LP		LP	
		PTI					LN				LN	LN	LN							
		BTI	LN				LN				LN	LN	LN							
		TTI					LN			LP	LN		LN							
	Afternoon peak	ATT	MP	LP	LP	LP				MP	LP	HP	MP		LP	LP	LP		LP	
		PTI			LP	LP				LP			LP							
		BTI			LP	LP				LP			LP			LN			LN	
		TTI			LP	LP	LN			LP			LP			LN				
	Evening peak	ATT	MP	LP	LP	LP				MP	LP	HP	MP		LP	LP	LP		LP	
		PTI		LP		LP	LN					LN							LN	
		BTI					LN					LN							LN	
		TTI	LN			LP	LN		LN	LP	LN	LN				LN			LN	
	Night-time	ATT	MP	LP	LP	LP		LP		MP	LP	HP	MP		LP	LP	LP		LP	
		PTI	LN		LP			LP				LN							LN	LP
		BTI	LN		LP			LP				LN							LN	LP
		TTI	LN		LP		LN	LP			LN	LN							LN	LP

Note 1: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Note 2:

Agri = Agriculture land use
Clg = College land use
Gov = Government land use
LCom = Light commercial land use
HCom = Heavy commercial land use
LInd = Light industrial land use
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Ofc = Office land use
Rec = Recreational land use
Resc = Resource land use
Retl = Retail land use
Transp = Transportation land use
Vac/ukn = Vacant or unknown land use
DevArea = Percent of developed area

Color scale						
	HN	MN	LN	LP	MP	HP

The correlation results for various buffer widths indicate low to moderate/high correlation of the truck travel time performance characteristics with the land use variables. The land use data are represented as variables within an area (in square miles) for each category. Hence, the correlation results are interpreted using the square area and the travel time performance measures. An increase in 1 square mile of an area in the land use category 'x' is attributed to an increase/decrease in travel time performance by 1 unit.

Agriculture, 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, agriculture, and transportation land uses are significantly correlated with the selected truck travel time performance measures. Agriculture land use is positively correlated with the ATT. However, the presence of agriculture land use in the vicinity has a negative correlation with PTI, BTI, and TTI. Land uses - government, institutional, medical, recreational and retail in the vicinity of 0.25, 0.50 and 1-mile 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, 0.50 and 1 miles are positively correlated with the selected truck travel time performance measures. Contrarily, single-family residential in the vicinity of 0.25, 0.50 and 1 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, the number of household units, the population density, and the employment density were also computed for each dataset. Table 21 summarizes the correlations between the selected truck travel time performance measures and demographic characteristics within 0.25, 0.50 and 1-mile of a link.

Table 21 Correlation between the truck travel time performance measures and demographic characteristics

		Variables →	Population			# of household units			Population density			Employment density		
		Buffer width →	**0.25**	**0.50**	**1.0**	**0.25**	**0.50**	**1.0**	**0.25**	**0.50**	**1.0**	**0.25**	**0.50**	**1.0**
Weekday	**Morning peak**	**ATT**	MP	MP	MP	MP	MP	MP			LN			LN
		PTI	LN	LN		LN	LN		LP	LP		LP		
		BTI								LP		LP		
		TTI	LN	LN	LN	LN	LN	LN		LP		LP	LP	
	Afternoon peak	**ATT**	HP	HP	HP	HP	HP	HP	LN	LN	LN	LN	LN	LN
		PTI	LN	LN		LN			LP	LP	LP	LP	LP	
		BTI	LN			LN			LP	LP	LP	LP	LP	
		TTI	LN	LN	LN	LN	LN	LN	MP	MP	LP	LP	MP	
	Evening peak	**ATT**	MP	MP	MP	MP	MP	MP			LN			
		PTI	LN	LN	LN	LN	LN		LP	MP	LP	MP	MP	
		BTI	LN	LN	LN	LN	LN	LN	MP	MP		MP	MP	
		TTI	LN			LN			LP	LP	LP	MP	MP	LP
	Night-time	**ATT**	HP	HP	HP	HP	HP	HP	LN	LN	LN	LN	LN	LN
		PTI	LN	LN	LN	LN	LN	LN		LP	LP			LP
		BTI	LN	LN	LN	LN	LN	LN			LP			LP
		TTI	LN	LN	LN	LN	LN	LN	LP	LP	LP	LP	LP	LP
Weekend	**Morning peak**	**ATT**	HP	HP	HP	HP	HP	HP	LN	LN	LN	LN	LN	LN
		PTI	LN	LN	LN	LN	LN	LN	LP	LP	LP		LP	
		BTI	LN	LN	LN	LN	LN	LN	LP	LP	LP		LP	
		TTI	LN	LN	LN	LN	LN	LN	LP	LP	LP		LP	
	Afternoon peak	**ATT**	HP	HP	HP	HP	HP	HP	LN	LN	LN	LN	LN	LN
		PTI												
		BTI												
		TTI							LP	LP	LP	LP	LP	
	Evening peak	**ATT**	HP	HP	HP	HP	HP	HP	LN	LN	LN	LN	LN	LN
		PTI	LN	LN	LN	LN	LN	LN	LP	LP	LP	LP	LP	LP
		BTI	LN	LN	LN	LN	LN	LN	LP	LP	LP	LP	LP	LP
		TTI	LN	LN	LN	LN	LN	LN	MP	MP	LP	LP	MP	LP
	Night-time	**ATT**	HP	HP	HP	HP	HP	HP	LN	LN	LN	LN	LN	LN
		PTI	LN	LN	LN	LN	LN	LN			LP	LP		LP
		BTI	LN	LN	LN	LN	LN	LN				LP		LP
		TTI	LN	LN	LN	LN	LN	LN	LP	LP	LP	LP	LP	LP

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	HN	MN	LN	LP	MP	HP

The results indicate that the ATT is positively correlated with the population and number of household units. Significant correlation was observed when analyzed using the weekday datasets with 0.25-, 0.50- and 1-mile buffer widths. In the case of the weekend data, significant high positive correlations were observed between the population, number of household units, and ATT. A strong significant negative correlation was observed between the BTI, and population and number of household units, while a low negative correlation was observed between the PTI, and population and number of household units. Likewise, a negative correlation was observed between the TTI, and population and number of household units. The BTI is positively correlated (low correlation) with population and employment estimates in the vicinity of 0.25 miles, 0.50 and 1 miles. However, the PTI and TTI are negatively correlated with the population and number of household units in the vicinity of 0.25 miles, 0.50 and 1 miles. The population and employment densities are positively correlated (low to moderate correlation) with the BTI, PTI, and TTI but negatively correlated with the ATT.

CHAPTER 6: GEOSPATIAL MAPPING OF TRUCK TRAVEL TIME PERFORMANCE MEASURES

Geospatial mapping of the truck travel time performance measures helps to visualize and understand the region-wide truck travel patterns. This chapter presents the geospatial maps of the selected performance measures: ATT, PTI, BTI and TTI.

Two aspects related to the variables were checked before mapping the truck travel time performance measures. Firstly, the study area comprises links of varying lengths, which arises the need to normalize the travel time values. Hence, ATT per mile (ATTPM) was computed, expressed in minutes per mile. Secondly, the performance measures were classified into multiple categories using the mean and standard deviation to rank links based on low-high variability.

The descriptive analysis was first performed to assess the variations in truck travel time performance measures. Table 22 summarizes the descriptive statistics of ATTPM, PTI, BTI and TTI for various times of the day and days of the week.

The descriptive statistics of the truck travel time performance measures show varying patterns based on time of the day and day of the week. Weekday and weekend traffic patterns of truck travel are different for various times of the day. In the case of both morning and evening peak hours on a weekday, the mean ATTPM were higher than the night-time and afternoon peak hour mean ATTPM. During the weekend, the mean ATTPM values showed almost persistent patterns for all times of the day.

Table 22 Descriptive statistics of truck travel time performance measures

Day of the week	Time of the day	Travel time measure	Minimum	Median	Mean	Maximum	Standard deviation
Weekday	Morning peak hour	ATTPM (minute per mile)	0.89	1.05	1.29	6.68	0.62
		BTI	0.14	17.59	43.17	251.81	47.35
		PTI	1.11	1.4	2.29	13.2	1.85
		TTI	1.05	1.19	1.46	7.35	0.68
	Afternoon peak hour	ATTPM (minute per mile)	0.89	0.96	1.01	2.25	0.14
		BTI	0.48	9.64	13.92	122.48	15.08
		PTI	1.09	1.21	1.31	4.83	0.32
		TTI	1.04	1.1	1.14	2.17	0.1
	Evening peak hour	ATTPM (minute per mile)	0.9	1.16	1.62	7.99	1.09
		BTI	0.33	38.67	57.54	272.02	55.06
		PTI	1.13	1.84	3.23	17.75	3.02
		TTI	1.06	1.31	1.82	9.47	1.2
	Night-time hour	ATTPM (minute per mile)	0.89	0.98	1.03	2.17	0.16
		BTI	0.29	13.26	24.24	304.31	39.41
		PTI	1.13	1.27	1.49	9.29	0.82
		TTI	1.05	1.12	1.16	2.35	0.13
Weekend	Morning peak hour	ATTPM (minute per mile)	0.89	0.95	0.98	1.61	0.1
		BTI	1.2	10.32	12.68	103.12	9.26
		PTI	1.11	1.2	1.25	3.05	0.18
		TTI	1.05	1.09	1.11	1.87	0.07
	Afternoon peak hour	ATTPM (minute per mile)	0.89	0.96	1.01	2.29	0.15
		BTI	0.3	11.06	16.37	218.13	20.23
		PTI	1.13	1.22	1.34	7.25	0.47
		TTI	1.05	1.1	1.14	2.5	0.12
	Evening peak hour	ATTPM (minute per mile)	0.89	0.96	1.01	2.18	0.14
		BTI	1.33	12.56	17.3	152.55	18.22
		PTI	1.13	1.24	1.35	5.27	0.37
		TTI	1.05	1.11	1.14	2.1	0.11
	Night-time hour	ATTPM (minute per mile)	0.89	0.97	1.01	2.04	0.14
		BTI	1.34	13.52	21.33	381.39	35.91
		PTI	1.13	1.26	1.42	9.29	0.71
		TTI	1.05	1.11	1.14	1.97	0.11

In the case of BTI, they are represented in percentages. A higher value indicates higher cushion time, indicating high travel time variability on the corresponding link. During morning and evening peak hours of a weekday, the mean BTI values were higher than other times of the day and days of the week. In the case of weekend, the maximum BTI values were higher than the weekday.

The PTI for trucks indicates the amount of extra time that truckers need to add to free-flow (or posted speed limit based) travel time in order to arrive on-time at their destination. It accounts for both recurring and nonrecurring congestion. The mean, maximum, and standard deviation values for the weekend were significantly lower than that of the weekday from the descriptive statistics of the PTI. Especially, the mean, maximum, and standard deviation are higher during the evening peak hour on a weekday.

The TTI value represents the degree of congestion for a particular time of the day. From the descriptive statistics of the TTI values, marginal differences were observed for weekdays and weekends. In the case of weekend, the TTI values remain persistent with similar mean values and low standard deviation for all the times of the day. Relatively higher values of the standard deviation and mean were observed in the case of weekday.

The geospatial maps were generated using four categories of the travel time measures based on mean and standard deviation. The four categories are: (1) <= mean; (2) > mean and <= mean + standard deviation; (3) > mean + standard deviation and <= mean + 2 × standard deviation; and, (4) > mean + 2 × standard deviation.

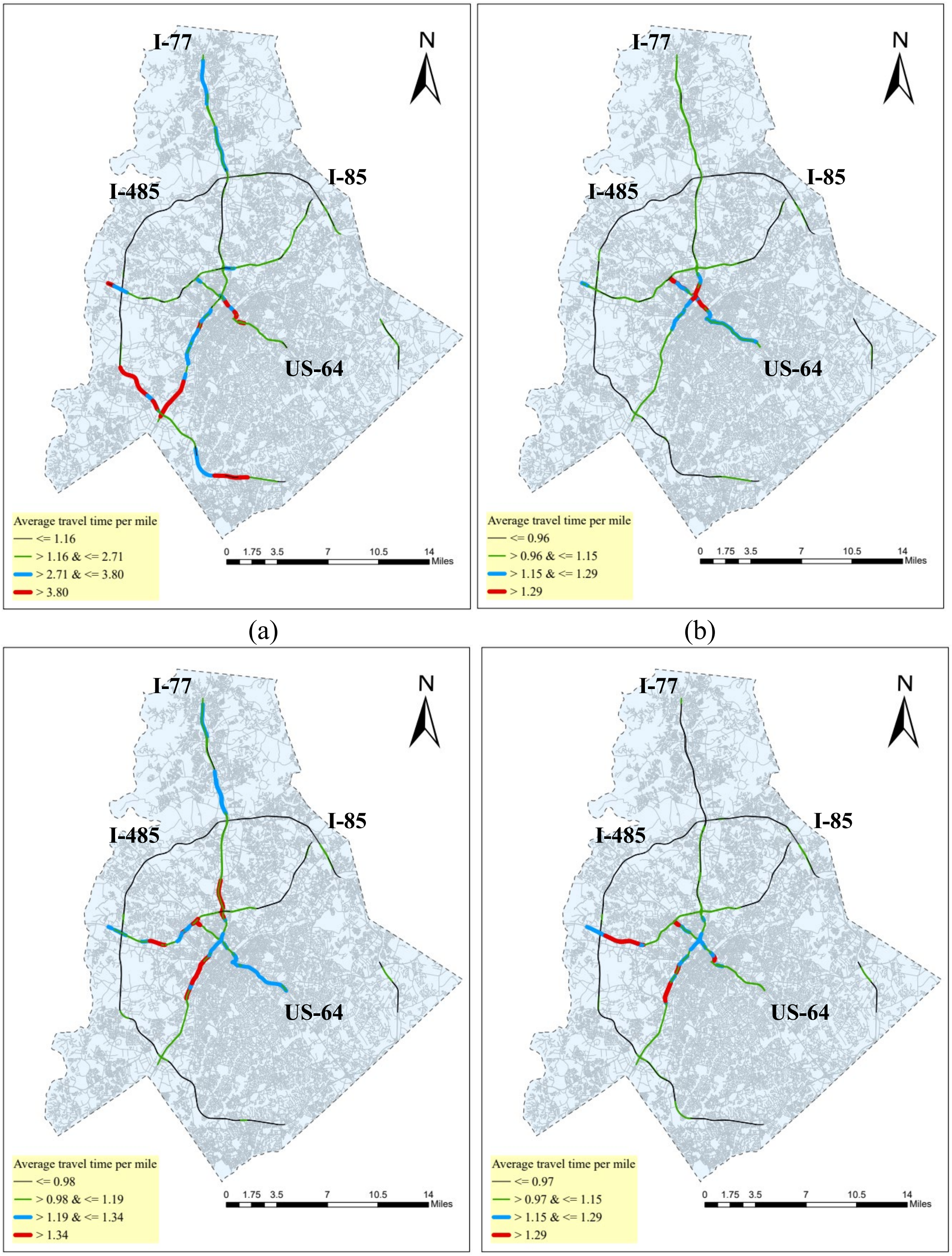
The geospatial maps were generated for the three counties, separately, based on the categories of mean and standard deviation for all the times of the day and days of the week. A total of 96 maps were generated in total (4 times of the day × 2 days of the week × 3 counties × 4 travel time measures). To maintain consistency, similar symbology was used to represent the values in the maps. Links with solid black line was used to represent values "<= mean" while the green line (which is slightly thicker than the previous) was used to represent values falling under the category of "> mean and <= mean + standard deviation". Light blue line with slightly higher thickness was used to represent links with values falling under the category of "> mean + standard deviation and <= mean + 2 × standard deviation" and the final category of "> mean + 2 × standard deviation" was represented using a dark red color line with higher thickness compared to the light blue line.

The geospatial maps for the Mecklenburg County for the evening peak and night-times (weekday and weekend) are shown and discussed in the following sections.

6.1 Average Travel Time (ATT)

Figure 8 (a-d) shows the geospatial maps representing ATTPM for evening peak and night-time hours (weekday and weekend) for Mecklenburg County. The maps show Mecklenburg County border with light-colored lines in the background representing the street network. Major roads involving significant truck travel were considered for assessment. The links in Mecklenburg County represent four major freeway and principal arterial corridors. The road on the outer part of the county (resembling a closed loop) is the Interstate 485 corridor and the road passing vertically (north-south) is the Interstate 77. The road passing East-West as shown in maps represent the Interstate 85 corridor. The road passing in the core urban area includes the Interstate 277.

From Figures 8 (a-d), the two maps show distinctive patterns of links vulnerable to larger values of ATTPM. The evening peak hour is susceptible to large volumes of trips than the night-time period. In the case of evening peak hour maps, links in the southern part of the area show higher values of ATTPM (parts of Interstate 485 and Interstate 77).



(a) (b) (c) (d)

Figure 8 Maps depicting ATTPM during the evening peak and night-time hours for links in Mecklenburg County

(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)

(c) Night time hour (weekday); (d) Night time hour (weekend)

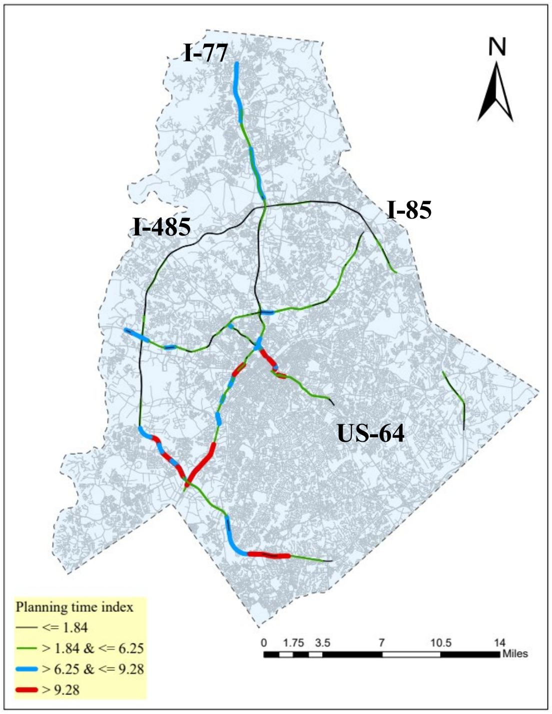
The maps show some of the links susceptible to high travel times in the south-western part of the city during the evening peak hours. Specifically, the links that are located towards the outer part of the county/ county border. In the case of night-time hours, the roads diverging from the core urban area show higher ATTPM values.

Interstate 77 in the northern-most part of the county showed almost similar trends in ATTPM in the case of evening peak hours (weekday and weekend) and night-time hours on a weekday. While the ATTPM values for a weekday show variation in the patterns, the majority of the roads have ATTPM values lower than mean on a weekend, possibly due to low trucking trips within the county along with lower traffic volumes on the road.

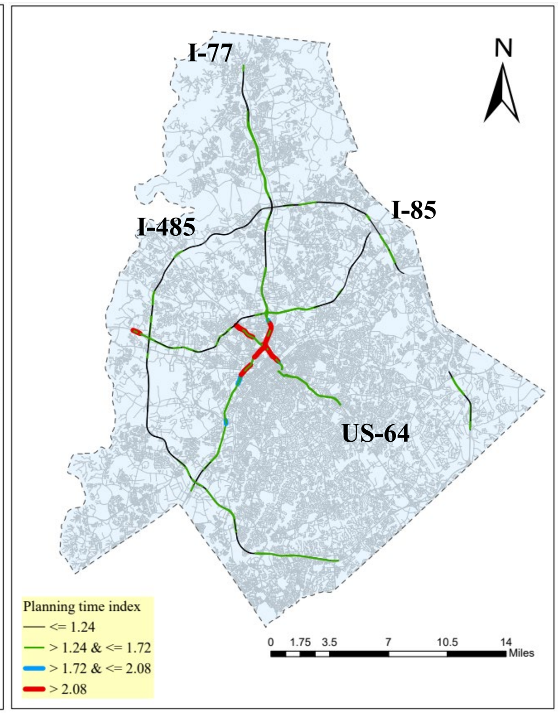
6.2 Planning Time index (PTI)

The PTI is one of the most commonly used travel time reliability metrics to measure congestion and the level of reliability of a road. A value of 1.30 for a road indicates that the truckers should plan on allocating 30% more time during the peak hour than the free-flow traffic conditions. From the descriptive statistics, it can be observed that during peak hours like the evening times, the PTI values can go up to 17.75. Even in the case of night-time hours, the PTI values go up to 9.29 (on a weekday or weekend).

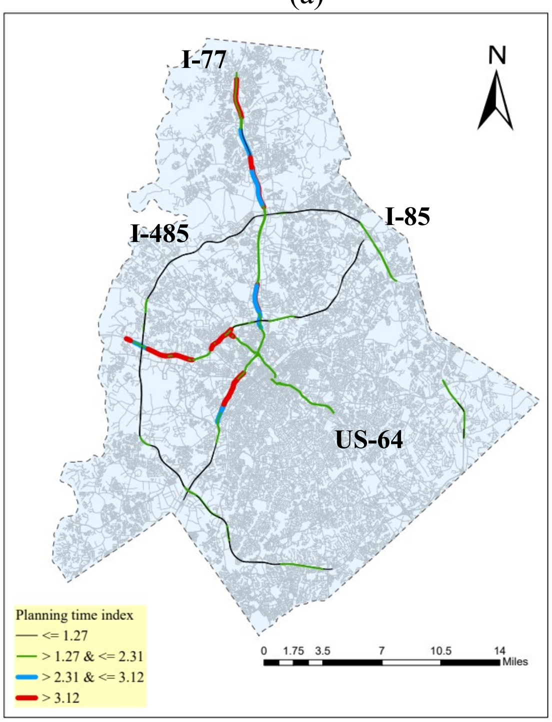
Figures 9 (a-d) represent the geospatial maps of Mecklenburg County representing the PTI for the evening peak and night-time hours of weekdays and weekends. Out of the four maps, the evening peak hour on a weekday has the highest PTI values, followed by the night-time weekday period.



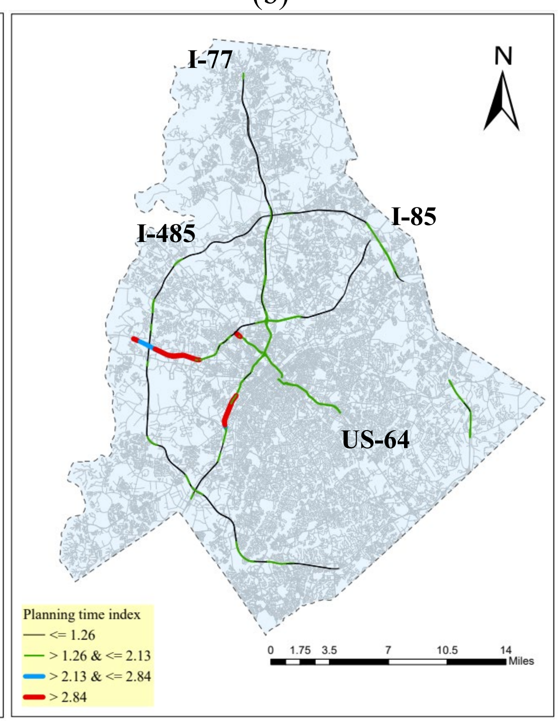
(a)



(b)



(c)



(d)

Figure 9 Maps depicting PTI during the evening peak and night-time hours for links in Mecklenburg County

(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)

(c) Night-time hour (weekday); (d) Night-time hour (weekend)

Similar to the ATTPM, the PTI values for the links in the south-western part (where Interstate 485 and Interstate 77 meet) have higher values and are more susceptible to higher degrees of congestion. However, in the case of weekend evening peak hours, links in the core urban area showed higher values of the PTI.

During the night-time hours on a weekday, Interstate 77 in the northern-most part of the county showed higher PTI values, followed by some of the links on Interstate 85 (western part of the county). In addition, Interstate 77 corridor in the southern part of the county also showed higher PTI values. Similar patterns of links susceptible to higher PTI values were observed during the weekend night-time hours.

Considering both the ATTPM and PTI, some of the links which show similar patterns of higher travel times are Interstate 485 and Interstate 77 in the south-western part of the county.

6.3 Buffer Time Index (BTI)

The BTI emphasizes on the extra cushion time truckers need to consider for on-time arrival for 95% of the trips. The BTI is expressed in percentages. In the case of morning peak, afternoon peak, and evening peak hours, the BTI on a weekday is higher than on a weekend. However, for night-time hours, higher values for a weekend were observed compared to a weekday. Figures 10 (a-d) represent the geospatial maps of Mecklenburg County representing BTI for evening peak and night-time hours on a weekday and weekend.

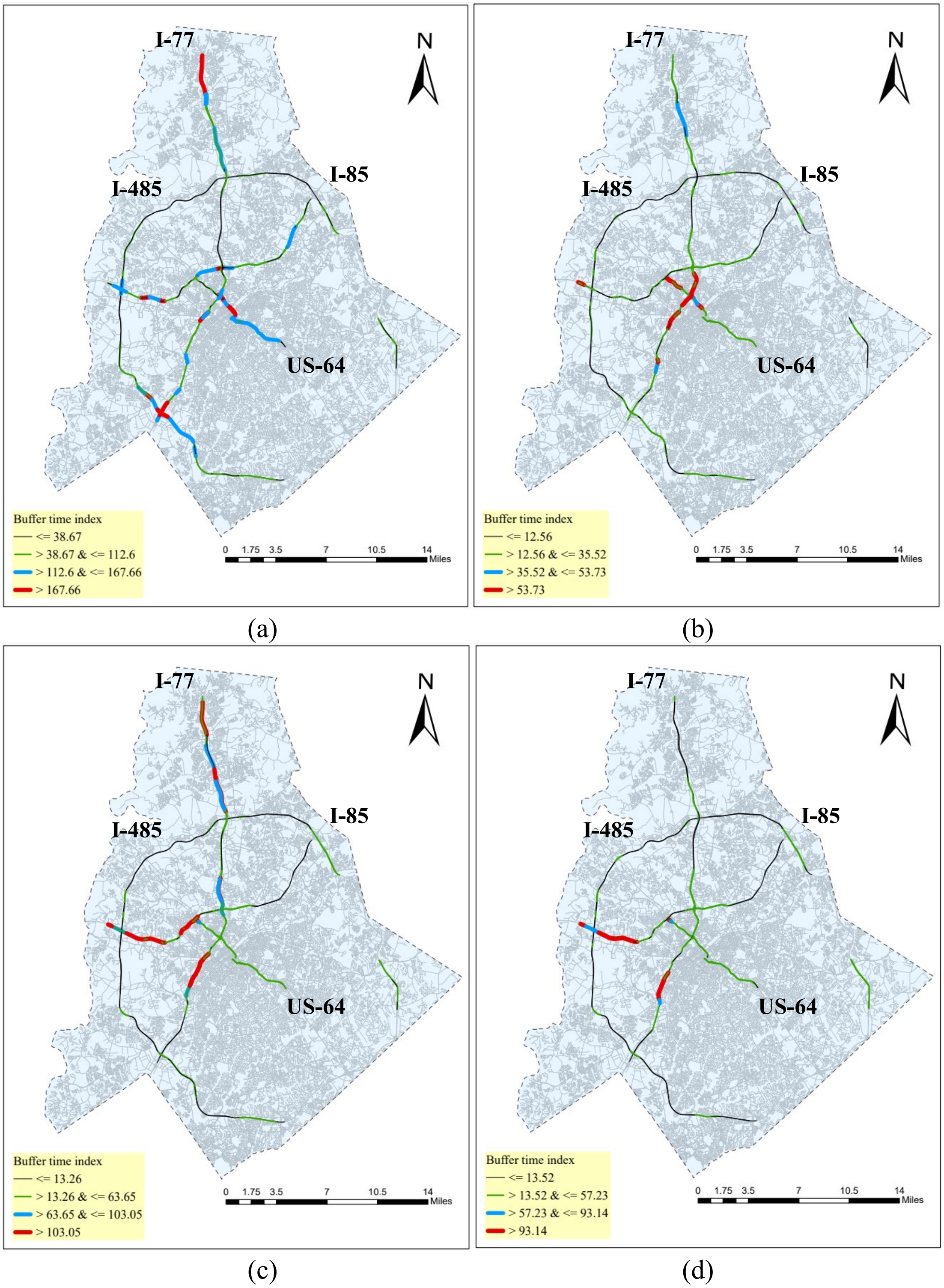


Figure 10 Maps depicting BTI during the evening peak and night-time hours for links in Mecklenburg County

(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)

(c) Night-time hour (weekday); (d) Night-time hour (weekend)

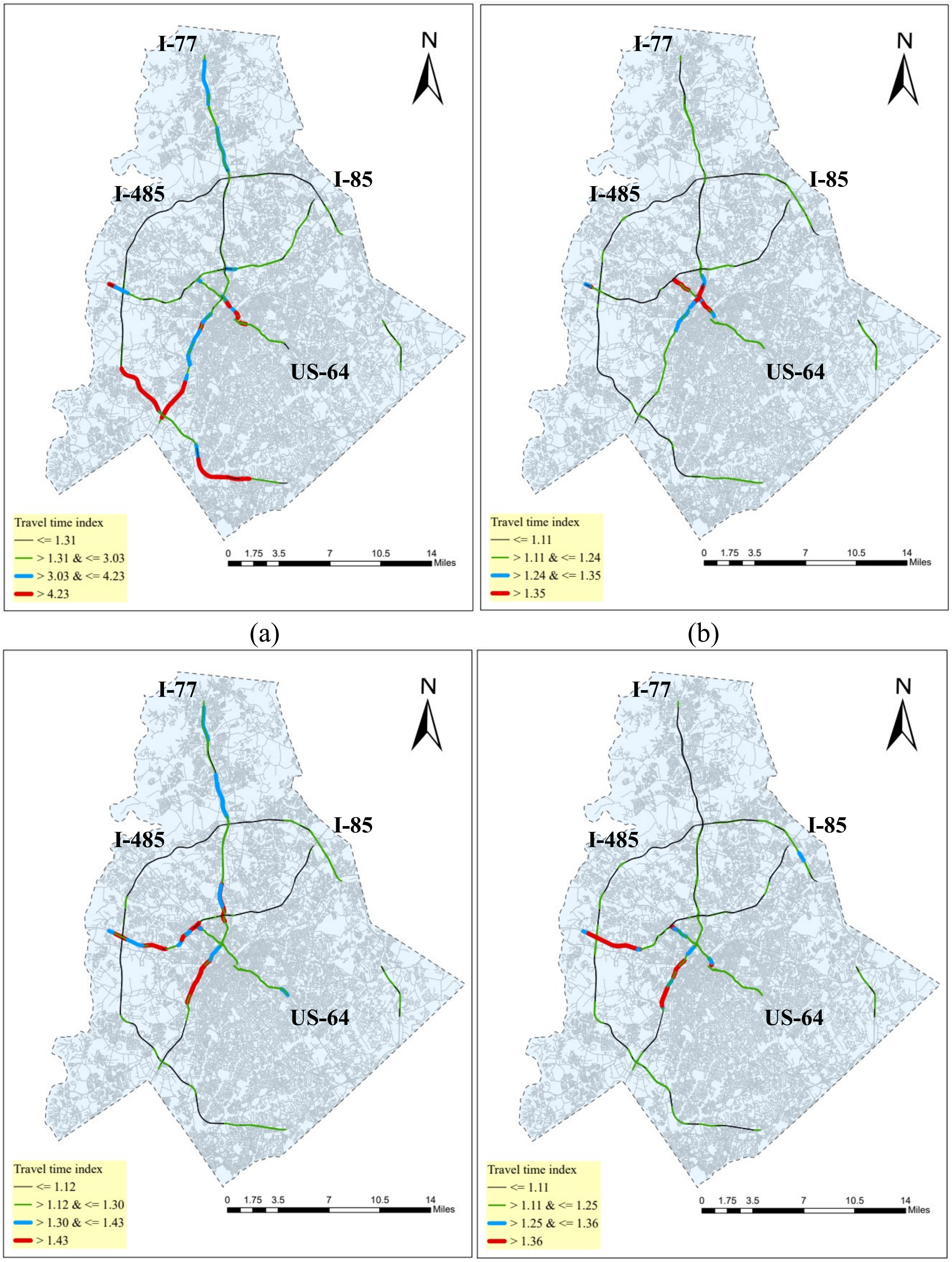
During the evening peak hour on a weekday, majority of the links showed BTI of at least 100%. Some of the links on Interstate 77 (in northern and southern parts) and Interstate 85 (in the western part) have higher values (>167%). In the case of evening peak hour on a weekend, some of the links in the core urban area have BTI >53%.

During the night-time hours on a weekday, links on Interstate 77 (in northern and southern parts) and Interstate 85 (in the western part) have higher values, similar to trends during a weekday evening peak hour. However, in the case of weekend, links on Interstate 77 (in the southern part) and Interstate 85 (in the western part) have higher values of BTI (>93%).

6.4 Travel Time Index (TTI)

From the descriptive statistics tables, out of all the times of the day and days of the week considered in this research, the TTI values are higher during morning and evening peak hours on a weekday. However, in the case of weekend and other times of the day, the values are marginally similar.

Figures 9 (a-d) represent the geospatial maps of Mecklenburg County representing TTI for evening peak and night-time hours of a weekday and weekend. Similar to the ATTPM and PTI maps, the links in the south-western part (where Interstate 485 and Interstate 77 meet) have higher values of TTI (>4.23) during evening peak hour on a weekday. In addition, some of the links in the core urban area have higher TTI values. In the case of evening peak hour on a weekend, links in the core urban area have higher PTI values followed by the Interstate 77 in the core urban part of the county (blue-colored).



(a) (b)

(c) (d)

Figure 11 Maps depicting TTI during the evening peak and night-time hours for links in Mecklenburg County

(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)

(c) Night time hour (weekday); (d) Night time hour (weekend)

During the night-time hours on a weekday and weekend, Interstate 77 (in the southern part of the county) have higher PTI values followed by some of the links in Interstate 85 (western part of the county).

6.5 Discussion related to the Geospatial Maps

This chapter comprises of selected maps of Mecklenburg County (evening peak and night-time hours for weekday and weekend) to interpret and explain the travel time patterns. Additional maps for other peak hours and days of the week (and also for Buncombe and Wake Counties) are shown in Appendix B.

From the four truck travel time performance measures illustrated in the previous sections, some of the links showed consistent patterns of higher truck travel times and their reliability values. One such area is the southern part of Mecklenburg County where the Interstate 77 and Interstate 485 meet. All the measures (ATTPM, PTI, BTI and TTI) are higher in this area suggesting possibility of a truck-exclusive chokepoint. Interstate 77 in the northern part of the county is another area to be looked at where some of the measures have higher values (even during an off-peak hour like the night-time) indicating possibility of a chokepoint or area susceptible to higher truck travel delays.

The descriptive statistics of truck travel time reliability measures and the geospatial maps help in identifying potential patterns in truck travel. At the same time, the research on truck chokepoints is not limited to understanding the truck travel time performance measures but also the surrounding network characteristics that have potential influence on truck travel times.

CHAPTER 7: TRUCK TRAVEL TIME ESTIMATION MODELS

This chapter presents the results associated with the truck travel time estimation models illustrating the relationship between on-network and off-network characteristics with link-level truck travel times.

A total of 376 links were considered for modeling. The dataset comprises travel times for four times of the day and two days of the week, resulting in a total of eight values for each link. Hence, the panel (or longitudinal) dataset for modeling comprises 3008 records. On-network and off-network characteristics were used as the independent variables to model the ATTPM (dependent variable).

The truck ATTPM estimation models were developed at three levels: using all variables from multiple buffer widths, using all variables of selected buffer widths (say, 0.25 mile), and by assigning spatial weights to the variables based on distance decay function. The results from the aforementioned modeling approaches are discussed in this chapter.

7.1 Descriptive Statistics Based on Buffer Widths and Spatial Weights

Descriptive analysis was performed prior to modeling truck ATTPM to understand the travel patterns and variations. Tables 25-28 provide the descriptive statistics of the data considered for modeling. Table 25 provides the frequency distribution of the number of through lanes, functional class, and speed limit of the links. Tables 26-28 summarize descriptive statistics of the continuous variables like ATTPM, reference speed, AADT and off-network characteristics.

Table 23 Frequency distribution of selected on-network variables

Variable	Category	Frequency (percentage)
Number of through lanes	4	143 (28.54)
	6	195 (38.92)
	8	154 (30.74)
	10	9 (1.80)
Functional class	Interstates	423 (84.43)
	Principal Arterials (Freeways and expressways)	78 (15.57)
Speed limit	45 mph	8 (1.6)
	50 mph	26 (5.19)
	55 mph	73 (14.57)
	60 mph	128 (25.55)
	65 mph	101 (20.16)
	70 mph	165 (32.93)

Table 24 Descriptive statistics of on-network and travel time variables

Variable	Minimum	Median	Mean	Maximum	Standard deviation
ATTPM	0.89	0.98	1.12	7.99	0.51
Reference speed	55.00	71.00	70.64	81.00	3.88
Ln(AADT)	10.17	11.53	11.47	12.12	0.41

Note: ATTPM is expressed in minutes per mile, and reference speed is expressed in miles per hour.

Table 25 Descriptive statistics of off-network variables for multiple buffer widths

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
Buffer width→	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**
Agriculture	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.04	0.14	0.43	0.85	2.37	0.05	0.12	0.32
College	0.00	0.00	0.00	0.00	0.00	0.06	0.01	0.02	0.08	0.12	0.21	0.41	0.01	0.04	0.07
Government	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.05	0.21	0.41	0.86	0.02	0.05	0.12
Heavy commercial	0.00	0.00	0.00	0.00	0.01	0.04	0.01	0.03	0.08	0.15	0.27	0.76	0.02	0.05	0.12
Heavy industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.46	1.06	2.13	0.04	0.11	0.26
Institutional	0.00	0.00	0.00	0.00	0.02	0.08	0.01	0.03	0.09	0.15	0.32	0.62	0.02	0.03	0.07
Light commercial	0.00	0.00	0.00	0.02	0.08	0.22	0.04	0.10	0.27	0.40	0.73	1.36	0.05	0.11	0.25
Light industrial	0.00	0.00	0.00	0.01	0.05	0.22	0.05	0.14	0.42	0.71	1.69	4.27	0.10	0.23	0.57
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.08	0.28	0.01	0.01	0.03
Multifamily residential	0.00	0.00	0.00	0.02	0.06	0.25	0.03	0.10	0.33	0.75	1.80	4.11	0.06	0.14	0.35
Office	0.00	0.00	0.00	0.00	0.02	0.08	0.02	0.05	0.15	0.16	0.41	1.23	0.03	0.07	0.18
Recreational	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.02	0.08	0.25	0.69	1.61	0.02	0.06	0.18
Resource	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.22	0.38	1.02	0.03	0.06	0.14
Retail	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05	0.18	0.39	0.89	0.02	0.04	0.10
Single family residential	0.00	0.00	0.06	0.09	0.35	1.41	0.13	0.43	1.51	0.96	2.29	5.68	0.15	0.35	0.89
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.29	0.47	0.00	0.01	0.04
Unknown/vacant	0.00	0.00	0.01	0.02	0.05	0.16	0.06	0.14	0.42	0.60	1.19	2.50	0.09	0.20	0.51
Developed area	0.44	6.53	13.84	59.12	66.34	73.12	56.03	62.46	69.03	85.21	85.42	93.62	15.50	14.89	14.02
Population	0.00	0.00	0.02	0.31	0.99	3.55	0.45	1.25	4.08	2.65	6.21	15.13	0.42	0.94	2.39
# of household units	0.00	0.00	0.01	0.13	0.38	1.34	0.18	0.50	1.62	1.15	2.66	6.51	0.17	0.39	1.01
Population density	0.00	0.00	0.01	1.33	1.50	1.63	1.71	1.78	1.85	9.24	7.71	12.86	1.51	1.37	1.40
Employment density	0.01	0.01	0.00	1.26	1.32	1.33	1.96	2.35	2.30	9.83	27.56	35.34	1.97	3.64	3.56

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

Table 26 Descriptive statistics of spatially weighted off-network variables

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
Spatial weights→	**1/d**	**$1/d^2$**	**$1/d^3$**	**1/d**	**$1/d^2$**	**$1/d^3$**	**1/d**	**$1/d^2$**	**$1/d^3$**	**1/d**	**$1/d^2$**	**$1/d^3$**	**1/d**	**$1/d^2$**	**$1/d^3$**
Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02	0.02	0.57	0.47	0.44	0.08	0.06	0.05
College	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.01	0.11	0.10	0.11	0.02	0.01	0.01
Government	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.20	0.20	0.21	0.03	0.02	0.02
Heavy commercial	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.01	0.18	0.16	0.15	0.03	0.02	0.02
Heavy industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.01	0.55	0.50	0.48	0.06	0.05	0.05
Institutional	0.00	0.00	0.00	0.02	0.01	0.00	0.02	0.01	0.01	0.18	0.16	0.15	0.02	0.02	0.02
Light commercial	0.00	0.00	0.00	0.05	0.04	0.03	0.06	0.05	0.04	0.39	0.38	0.39	0.06	0.05	0.05
Light industrial	0.00	0.00	0.00	0.04	0.02	0.02	0.09	0.07	0.06	1.05	0.85	0.76	0.14	0.11	0.10
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.05	0.01	0.01	0.01
Multifamily residential	0.00	0.00	0.00	0.05	0.03	0.02	0.07	0.05	0.04	1.06	0.89	0.80	0.08	0.07	0.06
Office	0.00	0.00	0.00	0.02	0.01	0.01	0.03	0.02	0.02	0.24	0.19	0.17	0.04	0.03	0.03
Recreational	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.40	0.32	0.28	0.04	0.03	0.02
Resource	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.22	0.20	0.21	0.03	0.03	0.03
Retail	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.23	0.20	0.19	0.02	0.02	0.02
Single family residential	0.01	0.00	0.00	0.28	0.17	0.12	0.31	0.21	0.16	1.41	1.15	1.03	0.21	0.17	0.16
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.10	0.08	0.01	0.01	0.00
Unknown/vacant	0.00	0.00	0.00	0.03	0.02	0.02	0.10	0.07	0.06	0.69	0.62	0.59	0.12	0.10	0.09
Developed area	3.43	1.99	1.16	36.89	46.72	53.01	34.72	44.13	50.08	47.76	64.33	74.78	8.18	11.34	13.40
Population	0.00	0.00	0.00	0.74	0.49	0.38	0.89	0.64	0.52	3.79	3.13	2.81	0.58	0.48	0.44
# of household units	0.00	0.00	0.00	0.28	0.19	0.15	0.35	0.25	0.21	1.63	1.36	1.22	0.24	0.20	0.18
Population density	0.02	0.01	0.00	0.89	1.07	1.18	1.01	1.32	1.51	4.24	6.52	7.92	0.67	1.06	1.30
Employment density	0.02	0.01	0.01	0.83	1.03	1.14	1.22	1.56	1.77	7.32	9.45	10.10	1.18	1.58	1.83

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

All the land use variables (except developed area percentage) were represented in square miles. The frequency distribution of the on-network characteristics imply that majority of the links have 4 to 6 through lanes. In addition, the speed limits of 60 mph and above are predominant in the dataset.

From the descriptive statistics of the land use variables, some of the land use types like light commercial, heavy industrial, single family residential, and multifamily residential are predominant (based on maximum and mean values) in the study areas.

7.2 Model Results Considering All Variables from Multiple Buffer Widths

Three models were developed using the backward elimination. Two linear models were developed (with and without intercept) along with a gamma log link model. Table 27 summarizes the linear (with and without intercept) and gamma log link models. Appendix C (Table C1) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 27 Developed models for all buffer widths

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		1.368	0.502	0.006				0.142	0.304	0.641
Time of the day	Morning peak	0.125	0.016	<.0001	0.127	0.017	<.0001	0.094	0.012	<.0001
Time of the day	Afternoon peak	-0.012	0.005	0.020	-0.010	0.005	0.067	-0.012	0.005	0.009
Time of the day	Evening peak	0.291	0.028	<.0001	0.293	0.028	<.0001	0.209	0.019	<.0001
Day of the week	Weekday	0.239	0.018	<.0001	0.240	0.019	<.0001	0.179	0.012	<.0001
Ln(AADT)		0.084	0.037	0.023	0.180	0.014	<.0001	0.079	0.022	0.001
Number of through lanes	4	0.312	0.049	<.0001	0.439	0.055	<.0001	0.210	0.036	<.0001
Number of through lanes	6	0.283	0.036	<.0001	0.367	0.050	<.0001	0.172	0.029	<.0001
Number of through lanes	8	0.111	0.034	0.001	0.199	0.044	<.0001	0.061	0.028	0.030
Speed limit		-0.021	0.003	<.0001	-0.019	0.002	<.0001	-0.016	0.002	<.0001
Functional class	Interstates									
Reference speed										
Agriculture (0.25 mile)		0.828	0.220	<.0001	0.627	0.206	0.002	0.734	0.154	<.0001
College (0.25 mile)		-1.126	0.507	0.027	-0.996	0.516	0.054	-0.898	0.372	0.016
Government (0.25 mile)										
Heavy commercial (0.25 mile)								0.816	0.468	0.081
Heavy industrial (0.25 mile)										
Institutional (0.25 mile)										
Light commercial (0.25 mile)		0.409	0.186	0.028						
Light industrial (0.25 mile)								-0.457	0.224	0.041
Medical (0.25 mile)		1.972	0.894	0.027				1.537	0.654	0.019
Multifamily residential (0.25 mile)										
Office (0.25 mile)		-1.645	0.791	0.038				-1.088	0.510	0.033
Recreational (0.25 mile)										
Resource (0.25 mile)										
Retail (0.25 mile)		1.862	0.601	0.002				1.279	0.457	0.005
Single family residential (0.25 mile)										
Transportation (0.25 mile)										
Unknown/Vacant (0.25 mile)		0.407	0.131	0.002				0.248	0.096	0.010
Agriculture (0.50 mile)										
College (0.50 mile)										
Government (0.50 mile)		-0.509	0.170	0.003				-0.405	0.102	<.0001
Heavy commercial (0.50 mile)		-0.533	0.225	0.018				-0.618	0.239	0.010
Heavy industrial (0.50 mile)		0.154	0.070	0.028				0.244	0.082	0.003
Institutional (0.50 mile)										
Light commercial (0.50 mile)										
Light industrial (0.50 mile)		0.074	0.033	0.022				0.264	0.106	0.013
Medical (0.50 mile)										
Multifamily residential (0.50 mile)										
Office (0.50 mile)		1.039	0.382	0.007	0.543	0.211	0.010	0.726	0.245	0.003
Recreational (0.50 mile)										
Resource (0.50 mile)										
Retail (0.50 mile)										
Single family residential (0.50 mile)										
Transportation (0.50 mile)		0.713	0.386	0.064				0.500	0.262	0.056
Unknown/Vacant (0.50 mile)					0.391	0.108	<.0001			
Agriculture (1 mile)		-0.177	0.046	<.0001	-0.119	0.050	0.018	-0.165	0.032	<.0001
College (1 mile)					0.268	0.113	0.018			

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Government (1 mile)										
Heavy commercial (1 mile)		0.196	0.114	0.084				0.138	0.081	0.089
Heavy industrial (1 mile)										
Institutional (1 mile)										
Light commercial (1 mile)		-0.104	0.048	0.030				-0.118	0.042	0.005
Light industrial (1 mile)										
Medical (1 mile)		-0.586	0.217	0.007	-0.439	0.172	0.011	-0.389	0.145	0.007
Multifamily residential (1 mile)										
Office (1 mile)										
Recreational (1 mile)										
Resource (1 mile)										
Retail (1 mile)		-0.302	0.112	0.007				-0.222	0.082	0.007
Single family residential (1 mile)										
Transportation (1 mile)										
Unknown/Vacant (1 mile)		-0.213	0.047	<.0001	-0.280	0.064	<.0001	-0.122	0.030	<.0001
Developed area (0.25 mile)		0.003	0.001	0.013	0.001	0.001	0.094	0.003	0.001	<.0001
Developed area (0.50 mile)		-0.007	0.002	<.0001				-0.006	0.001	<.0001
Developed area (1 mile)					-0.005	0.001	<.0001			
Population (0.25 mile)										
Population (0.50 mile)										
Population (1 mile)		0.054	0.024	0.024	0.063	0.026	0.013			
# of household units (0.25 mile)										
# of household units (0.50 mile)										
# of household units (1 mile)		-0.136	0.059	0.022	-0.167	0.063	0.008			
Population density (0.25 mile)										
Population density (0.50 mile)										
Population density (1 mile)										
Employment density (0.25 mile)		0.022	0.010	0.032	0.018	0.009	0.050			
Employment density (0.50 mile)		-0.010	0.004	0.022	-0.009	0.004	0.012			
Employment density (1 mile)										

Note 1: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.
Note 2: Variable with representing off-network characteristics (land use and demographic) showing "(0.25-mile)", "(0.50-mile)" and "(1 mile)" indicate their corresponding their buffer width information.

Some of the variables like time of the day, day of the week and other on-network characteristics like AADT, speed limit, and number of through lanes are statistically significant at a 90% confidence level in all the models (linear and gamma log link). The significance of off-network variables varied based on the buffer width and model type. Some of the land uses like agriculture, college, medical, and office land uses are significant in majority of the developed models. In addition, demographic variables like population and number of household units from 1-mile buffer are significant.

Overall, the models from the backward elimination indicated positive intercept (with exception to linear – no intercept model). Some of the variables like the day of the week, AADT, number of through lanes, light commercial land use, retail land use, heavy industrial land use, and transportation land use have an increasing influence (positive coefficient) on the truck ATTPM, indicating an increase in these land use areas increase truck ATTPM. Contrarily, variables like college land use, office land use, and government land use have a negative influence (negative coefficient) on the truck ATTPM, indicating an increase in these land use areas decrease truck ATTPM. Some of the land use types like the agriculture and heavy commercial showed mixed results for different buffer widths data. The time of the day variable indicated mixed patterns showing high positive coefficient for the evening peak hour followed by the morning peak hour and a negative coefficient for the afternoon peak hour. These coefficients illustrate the effect of time of the day being crucial in the case of evening and morning peak hours than the night-time and afternoon peak hours.

Demographic variables like population (1-mile) and employment density (0.25-mile) have an increasing effect on ATTPM while the number of household units (1-mile) and employment density (0.50-mile) have a decreasing effect on ATTPM .

Specifically, in the case of linear model, when all the independent variables are assumed zero, the ATTPM of trucks is expected to be 1.37 minutes per mile (approximately 44 mph). In the case of gamma log link, when all other variables are assumed to be zero, the ATTPM of trucks is expected to be $e^{0.14}$ i.e., 1.15 minutes per mile (approximately 52 mph).

7.3 Model Results by Specific Buffer Widths

The results from the models developed using individual buffer widths separately are discussed in this section. Similar to the previous section, the results of variables significant in models developed are presented followed by the model results (of backward elimination). Tables 32-34 show the model results from the backward elimination of linear (with and without intercept) and gamma log link models for 0.25-, 0.50- and 1-mile buffer width datasets. Appendix C (Tables C2-C4) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 28 Developed models for 0.25-mile buffer width dataset

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.631	0.450	0.161				-0.354	0.312	0.256
Time of the day	Morning peak	0.125	0.016	<.0001	0.126	0.017	<.0001	0.095	0.013	<.0001
Time of the day	Afternoon peak	-0.012	0.005	0.020	-0.011	0.005	0.038	-0.012	0.005	0.010
Time of the day	Evening peak	0.291	0.028	<.0001	0.292	0.028	<.0001	0.213	0.019	<.0001
Day of the week	Weekday	0.239	0.018	<.0001	0.239	0.018	<.0001	0.182	0.013	<.0001
Ln(AADT)		0.105	0.034	0.002	0.164	0.009	<.0001	0.092	0.023	<.0001
Number of through lanes	4	0.284	0.044	<.0001	0.337	0.041	<.0001	0.224	0.037	<.0001
Number of through lanes	6	0.254	0.032	<.0001	0.287	0.040	<.0001	0.199	0.030	<.0001
Number of through lanes	8	0.129	0.029	<.0001	0.152	0.034	<.0001	0.107	0.028	<0.05
Speed limit		-0.019	0.002	<.0001	-0.020	0.002	<.0001	-0.015	0.002	<.0001
Functional class	Interstates									
Reference speed										
Agriculture										
College										
Government		-0.993	0.447	0.026	-1.125	0.420	0.007	-0.923	0.295	0.002
Heavy commercial										
Heavy industrial		-0.363	0.129	0.005	-0.471	0.131	<.0001	-0.276	0.102	0.007
Institutional										
Light commercial										
Light industrial										
Medical										
Multifamily residential					-0.249	0.160	0.120			
Office		0.874	0.462	0.059	1.084	0.456	0.018	0.514	0.296	0.082
Recreational										
Resource										
Retail										
Single family residential										
Transportation										
Unknown/Vacant		-0.226	0.088	0.011	-0.216	0.083	0.009	-0.152	0.063	0.016
Developed area										
Population		0.251	0.150	0.094						
# of household units		-0.639	0.370	0.085						
Population density										
Employment density		0.014	0.007	0.046				0.009	0.005	0.063

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 29 Developed models for 0.50-mile buffer width dataset

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.765	0.475	0.108				-0.272	0.321	0.397
Time of the day	Morning peak	0.125	0.016	<.0001	0.126	0.017	<.0001	0.094	0.012	<.0001
Time of the day	Afternoon peak	-0.012	0.005	0.020	-0.011	0.005	0.047	-0.012	0.005	0.010
Time of the day	Evening peak	0.291	0.028	<.0001	0.292	0.028	<.0001	0.212	0.019	<.0001
Day of the week	Weekday	0.239	0.018	<.0001	0.240	0.018	<.0001	0.181	0.012	<.0001
Ln(AADT)		0.117	0.037	0.001	0.173	0.010	<.0001	0.099	0.025	<.0001
Number of through lanes	4	0.305	0.041	<.0001	0.370	0.045	<.0001	0.238	0.034	<.0001
Number of through lanes	6	0.255	0.027	<.0001	0.299	0.041	<.0001	0.197	0.026	<.0001
Number of through lanes	8	0.121	0.024	<.0001	0.160	0.037	<.0001	0.101	0.025	<.0001
Speed limit		-0.021	0.002	<.0001	-0.020	0.002	<.0001	-0.016	0.001	<.0001
Functional class	Interstates									
Reference speed										
Agriculture										
College										
Government		-0.587	0.150	<.0001	-0.618	0.149	<.0001	-0.479	0.105	<.0001
Heavy commercial										
Heavy industrial		-0.126	0.068	0.063	-0.159	0.069	0.020	-0.101	0.050	0.043
Institutional										
Light commercial										
Light industrial		0.069	0.035	0.051	0.064	0.034	0.058	0.057	0.026	0.026
Medical										
Multifamily residential										
Office		0.612	0.223	0.006	0.558	0.215	0.010	0.381	0.137	0.005
Recreational										
Resource										
Retail										
Single family residential										
Transportation										
Unknown/Vacant		-0.216	0.059	<.0001	-0.169	0.057	0.003	-0.138	0.042	0.001
Developed area		-0.002	0.001	0.008	-0.002	0.001	0.012	-0.001	0.001	0.006
Population		0.112	0.065	0.086						
# of household units		-0.271	0.161	0.091						
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 30 Developed models for 1-mile buffer width dataset

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.989	0.493	0.045				-0.096	0.325	0.768
Time of the day	Morning peak	0.125	0.016	<.0001	0.126	0.017	<.0001	0.095	0.012	<.0001
Time of the day	Afternoon peak	-0.012	0.005	0.020	-0.011	0.005	0.046	-0.012	0.005	0.012
Time of the day	Evening peak	0.291	0.028	<.0001	0.292	0.028	<.0001	0.211	0.019	<.0001
Day of the week	Weekday	0.239	0.018	<.0001	0.240	0.018	<.0001	0.181	0.012	<.0001
Ln(AADT)		0.108	0.038	0.005	0.175	0.011	<.0001	0.092	0.025	<.0001
Number of through lanes	4	0.321	0.043	<.0001	0.379	0.044	<.0001	0.242	0.034	<.0001
Number of through lanes	6	0.267	0.028	<.0001	0.315	0.040	<.0001	0.202	0.025	<.0001
Number of through lanes	8	0.120	0.024	<.0001	0.157	0.033	<.0001	0.096	0.023	<.0001
Speed limit		-0.021	0.002	<.0001	-0.019	0.002	<.0001	-0.017	0.002	<.0001
Functional class	Interstates									
Reference speed										
Agriculture										
College					0.206	0.106	0.052			
Government		-0.199	0.078	0.011				-0.132	0.057	0.021
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial										
Light industrial		0.034	0.018	0.062				0.027	0.013	0.042
Medical		-0.348	0.177	0.049	-0.425	0.182	0.020			
Multifamily residential										
Office		0.254	0.084	0.002	0.239	0.078	0.002	0.155	0.052	0.003
Recreational										
Resource										
Retail										
Single family residential										
Transportation		0.184	0.138	0.183						
Unknown/Vacant		-0.146	0.032	<.0001	-0.131	0.030	<.0001	-0.099	0.022	<.0001
Developed area		-0.003	0.001	<.0001	-0.003	0.001	0.002	-0.002	0.001	<.0001
Population		0.069	0.027	0.011	0.073	0.027	0.006	0.038	0.017	0.028
# of household units		-0.165	0.066	0.012	-0.185	0.065	0.004	-0.091	0.043	0.033
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

In the case of 0.25-mile buffer width dataset models, some variables like time of the day, day of the week, AADT, speed limit, government land use, heavy industrial land use, and office land use are significant at a 90% confidence levels (backward elimination or not). The demographic variables like the population were found to be significant in the linear model (with intercept). Similarly, employment density was significant in the backward elimination of linear (with intercept) and gamma log link models.

Time of the day, day of the week, AADT, number of through lanes, speed limit, government land use, heavy industrial land use, light industrial land use, office land use, and percent of the developed area were significant in almost all the models developed using 0.50-mile buffer width dataset. The demographic variables such as population and numbers of household units were found to be significant in the linear model with backward elimination (with intercept).

Time of the day, day of the week, AADT, number of through lanes, speed limit, government land use, medical land use, and office land use were significant in all the models developed using 1-mile buffer width dataset. The population and number household units were found to be significant at a 95% confidence level in all the models developed using 1-mile buffer width dataset.

From the model results, office land use, population, and employment density have an increasing influence on the truck ATTPM indicating an increase in the magnitude of office land use or population/employment density within 0.25-mile of a road results in an increase in truck ATTPM. Contrarily, speed limit, government land use, heavy industrial land use and number of household units within a 0.25-mile buffer have a negative influence on the truck ATTPM. Variables such as time of the day, day of the week, AADT, and number of through lanes show trends similar to the models developed using all variables (Section 7.2).

The results from the models developed using 0.50-mile buffer width dataset also show similar patterns as in case of 0.25-mile buffer width dataset. The speed limit, government land use, heavy industrial land use, and number of household units have a decreasing influence on the truck ATTPM. Contrarily, day of the week, AADT, and number of through lanes, light industrial land use, office land use, and population have an increasing influence on the truck ATTPM.

The results from the models developed using 1-mile buffer width dataset show an intercept of 0.98 in the linear model indicating a speed of 67 mph when all the variables are zero. The variables such as day of the week, AADT, number of through lanes, light industrial land use, office land use, transportation land use, and population have an increasing influence on the truck ATTPM, whereas the speed limit, medical land use, percent of the developed area, and number of household units have a decreasing influence on the truck ATTPM.

7.4 Model Results by Spatial Weights

Tables 38-40 show the models developed using spatial weights based on 1/d, $1/d^2$, and $1/d^3$. Appendix C (Tables C5-C7) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 31 Developed models using spatial weights (1/d function)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		1.001	0.492	0.042				-0.107	0.328	0.745
Time of the day	Morning peak	0.125	0.016	<.0001	0.127	0.017	<.0001	0.094	0.012	<.0001
Time of the day	Afternoon peak	-0.012	0.005	0.020	-0.010	0.005	0.060	-0.012	0.005	0.011
Time of the day	Evening peak	0.291	0.028	<.0001	0.293	0.028	<.0001	0.212	0.019	<.0001
Day of the week	Weekday	0.239	0.018	<.0001	0.240	0.018	<.0001	0.181	0.012	<.0001
Ln(AADT)		0.101	0.038	0.008	0.177	0.011	<.0001	0.089	0.025	0.001
Number of through lanes	4	0.313	0.043	<.0001	0.393	0.047	<.0001	0.240	0.033	<.0001
Number of through lanes	6	0.262	0.029	<.0001	0.313	0.041	<.0001	0.198	0.025	<.0001
Number of through lanes	8	0.121	0.026	<.0001	0.162	0.036	<.0001	0.097	0.023	<.0001
Speed limit		-0.021	0.002	<.0001	-0.020	0.002	<.0001	-0.017	0.001	<.0001
Functional class	Interstates									
Reference speed										
Agriculture										
College										
Government		-1.085	0.319	0.001	-0.960	0.323	0.003	-0.781	0.222	<.0001
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial										
Light industrial		0.143	0.069	0.037	0.114	0.068	0.094	0.108	0.050	0.030
Medical										
Multifamily residential										
Office		1.066	0.368	0.004	0.931	0.354	0.009	0.668	0.230	0.004
Recreational										
Resource										
Retail										
Single family residential										
Transportation		0.889	0.788	0.259				0.577	0.513	0.260
Unknown/Vacant		-0.512	0.118	<.0001	-0.437	0.113	<.0001	-0.345	0.082	<.0001
Developed area		-0.005	0.001	0.001	-0.004	0.001	0.003	-0.003	0.001	0.002
Population		0.257	0.118	0.029	0.240	0.114	0.035	0.134	0.077	0.080
# of household units		-0.607	0.288	0.035	-0.564	0.279	0.043	-0.314	0.189	0.096
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 32 Developed models using spatial weights ($1/d^2$ function)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.727	0.480	0.130				-0.242	0.330	0.463
Time of the day	Morning peak	0.125	0.016	<.0001	0.126	0.017	<.0001	0.095	0.012	<.0001
Time of the day	Afternoon peak	-0.012	0.005	0.020	-0.011	0.005	0.041	-0.012	0.005	0.010
Time of the day	Evening peak	0.291	0.028	<.0001	0.292	0.028	<.0001	0.213	0.019	<.0001
Day of the week	Weekday	0.239	0.018	<.0001	0.240	0.018	<.0001	0.182	0.012	<.0001
Ln(AADT)		0.107	0.036	0.003	0.166	0.010	<.0001	0.093	0.025	<.0001
Number of through lanes	4	0.306	0.043	<.0001	0.346	0.040	<.0001	0.241	0.036	<.0001
Number of through lanes	6	0.261	0.031	<.0001	0.282	0.036	<.0001	0.201	0.029	<.0001
Number of through lanes	8	0.133	0.028	<.0001	0.149	0.031	<.0001	0.106	0.027	<.0001
Speed limit		-0.020	0.002	<.0001	-0.020	0.002	<.0001	-0.016	0.001	<.0001
Functional class	Interstates									
Reference speed										
Agriculture					0.253	0.148	0.087			
College										
Government		-1.418	0.381	<.0001	-1.270	0.374	0.001	-1.094	0.264	<.0001
Heavy commercial										
Heavy industrial		-0.383	0.134	0.004	-0.411	0.130	0.002	-0.229	0.100	0.022
Institutional										
Light commercial										
Light industrial		0.115	0.072	0.110				0.111	0.055	0.043
Medical										
Multifamily residential		-0.240	0.163	0.139	-0.359	0.179	0.045			
Office		1.273	0.457	0.005	1.236	0.464	0.008	0.786	0.284	0.006
Recreational										
Resource										
Retail										
Single family residential										
Transportation										
Unknown/Vacant		-0.225	0.084	0.008	-0.266	0.092	0.004	-0.237	0.078	0.002
Developed area								-0.001	0.001	0.073
Population										
# of household units										
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 33 Developed models using spatial weights ($1/d^3$ function)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.667	0.453	0.141				-0.277	0.332	0.405
Time of the day	Morning peak	0.125	0.016	<.0001	0.126	0.017	<.0001	0.095	0.012	<.0001
Time of the day	Afternoon peak	-0.012	0.005	0.020	-0.011	0.005	0.039	-0.012	0.005	0.010
Time of the day	Evening peak	0.291	0.028	<.0001	0.292	0.028	<.0001	0.214	0.019	<.0001
Day of the week	Weekday	0.239	0.018	<.0001	0.239	0.018	<.0001	0.182	0.013	<.0001
Ln(AADT)		0.104	0.034	0.002	0.165	0.010	<.0001	0.092	0.025	<.0001
Number of through lanes	4	0.289	0.043	<.0001	0.340	0.040	<.0001	0.232	0.034	<.0001
Number of through lanes	6	0.250	0.030	<.0001	0.283	0.038	<.0001	0.205	0.027	<.0001
Number of through lanes	8	0.128	0.027	<.0001	0.149	0.032	<.0001	0.107	0.025	<.0001
Speed limit		-0.019	0.002	<.0001	-0.020	0.002	<.0001	-0.016	0.001	<.0001
Functional class	Interstates									
Reference speed										
Agriculture					0.232	0.145	0.110			
College										
Government		-1.095	0.438	0.013	-1.243	0.396	0.002	-1.097	0.282	<.0001
Heavy commercial										
Heavy industrial		-0.366	0.124	0.003	-0.460	0.131	<.0001			
Institutional										
Light commercial										
Light industrial								0.089	0.058	0.125
Medical										
Multifamily residential					-0.349	0.184	0.058			
Office		1.069	0.482	0.027	1.235	0.481	0.010	0.667	0.290	0.022
Recreational										
Resource										
Retail										
Single family residential										
Transportation										
Unknown/Vacant		-0.240	0.090	0.007	-0.254	0.090	0.005	-0.188	0.064	0.003
Developed area										
Population		0.268	0.144	0.062						
# of household units		-0.680	0.355	0.055						
Population density										
Employment density		0.013	0.007	0.092						

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

In the case of models developed using 1/d function-based spatial weights, time of the day, day of the week, AADT, speed limit, number of through lanes, government land use, office land use, population and number of household units were found to be significant at a 90% confidence level in all the models. Light industrial land use and percent of the developed area were significant in the models developed based on backward elimination.

In the case of models developed using $1/d^2$ function-based spatial weights, time of the day, day of the week, AADT, speed limit, number of through lanes, government land use, heavy industrial land use, and office land use were found to be significant in all the models.

In the case of models developed using $1/d^3$ function-based spatial weights, time of the day, day of the week, AADT, speed limit, number of through lanes, government land use, heavy industrial land use, and office land use were found to be significant in all the models. In addition, population, number of household units, and employment density were found to be significant in the linear model with intercept.

In the case of linear model (with intercept) developed using 1/d function-based spatial weights, the ATTPM of trucks is expected to be 1.001 minutes per mile (when all the independent variables are assumed equal to zero). In all the models developed (linear and gamma log link), the variables like speed limit, government land use, percent of the developed area and number of household units have a decreasing effect on ATTPM. Contrarily, day of the week, AADT, number of through lanes, light industrial land use, office land use, transportation land use, and population have an increasing effect on ATTPM.

In the case of models developed using $1/d^2$ function-based spatial weights, the variables like speed limit, government land use, heavy industrial use, and multifamily residential land use, have a decreasing effect on ATTPM . Contrarily, number of through lanes, day of the week, AADT, light industrial land use and office land use have an increasing effect on ATTPM .

In the case of models developed using $1/d^3$ function-based spatial weights, the variables like speed limit, government land use, heavy industrial land use, and office land use, and number of household units have a decreasing effect on ATTPM whereas day of the week, AADT, number of through lanes, office land use, population, and employment density have an increasing effect on ATTPM.

7.5 Goodness of Fit and Validation Results

QIC and QICC are used to assess the goodness of fit of a model. The values with lower magnitude and lower differences of QIC and QICC are chosen to be the best fit. The QIC values of models developed using all the variables and based on the backward elimination, with varying buffer widths and spatial weights are summarized in Table 41.

Table 34 Goodness of fit statistics for models developed using all variables, buffer widths and spatial weights

			Linear				Gamma log link	
			All variables (with intercept)	Backward elimination (with intercept)	All variables (without intercept)	Backward elimination (without intercept)	All variables	Backward elimination
All variables		QIC	3047.38	3028.90	3047.12	3025.36	69068.80	68384.24
		QICC	3086.00	3043.00	3085.00	3031.00	69102.68	68397.28
Buffer width	0.25-mile	QIC	3039.88	3026.36	3036.76	3021.38	63561.19	63190.31
		QICC	3042.00	3025.00	3041.00	3022.00	63562.68	63188.39
	0.50-mile	QIC	3040.99	3026.67	3038.01	3023.71	64901.66	64693.76
		QICC	3042.00	3026.00	3041.00	3023.00	64901.92	64692.80
	1-mile	QIC	3042.45	3025.69	3039.77	3023.31	65219.03	64811.08
		QICC	3042.00	3027.00	3041.00	3024.00	65216.03	64809.99
Spatial weights	1/d	QIC	3044.46	3026.36	3040.86	3024.69	65073.26	64619.58
		QICC	3042.00	3026.00	3041.00	3024.00	65068.97	64620.06
	$1/d^2$	QIC	3042.44	3025.80	3038.92	3022.69	64492.47	63948.90
		QICC	3042.00	3024.00	3041.00	3023.00	64491.08	63948.49
	$1/d^3$	QIC	3040.68	3026.77	3037.39	3021.67	63995.78	62772.64
		QICC	3042.00	3025.00	3041.00	3023.00	63996.41	62770.69

The results from linear models indicate QIC and QICC values in the range of 3000-3050, whereas the models developed using the gamma log link indicate values up to 640000. Initially, the models with all the variables are developed followed by based on the backward elimination. The results from the linear and gamma log link models indicate that the ranges of QIC and QICC values are similar, irrespective of the number of variables in the model. In other words, the models with all the variables have similar/lower QIC and QICC values compared to the model based on the backward elimination.

Based on the models developed using all the variables, multiple buffer widths and spatial weight functions, the QIC and QICC values are in similar range. In other words, the models developed using variables from individual buffer widths perform equally as good as the models using variables from spatial weights or with all the variables.

The validation results were also considered for selecting dataset and model distributions to estimate the truck ATTPM. Table 35 summarizes the MPE, MAPE and RMSE of each model.

Table 35 Validation results for models developed using all variables, buffer widths and spatial weights

			Linear		Gamma log link
			With intercept	Without intercept	
All variables		MPE (%)	-14.52	0.63	-6.67
		MAPE (%)	26.62	18.95	20.87
		RMSE (minutes/mile)	0.53	0.44	0.51
Based on buffer width	0.25-mile	MPE (%)	-5.01	1.72	-6.58
		MAPE (%)	22.76	15.52	20.41
		RMSE (minutes/mile)	0.51	0.44	0.50
	0.50-mile	MPE (%)	-5.56	1.58	-10.83
		MAPE (%)	23.14	15.81	22.79
		RMSE (minutes/mile)	0.51	0.44	0.51
	1-mile	MPE (%)	-9.71	-4.68	-6.29
		MAPE (%)	24.31	17.60	20.77
		RMSE (minutes/mile)	0.52	0.42	0.50
Based on spatial weights	1/d	MPE (%)	-6.68	-5.32	-13.15
		MAPE (%)	23.18	17.52	24.21
		RMSE (minutes/mile)	0.51	0.42	0.51
	$1/d^2$	MPE (%)	-9.00	-4.65	-9.20
		MAPE (%)	23.84	17.30	21.87
		RMSE (minutes/mile)	0.51	0.42	0.50
	$1/d^3$	MPE (%)	-7.04	-5.04	-9.27
		MAPE (%)	23.27	17.28	21.84
		RMSE (minutes/mile)	0.51	0.42	0.50

The MPE and MAPE are expressed in percentages whereas the RMSE is expressed in same units as the ATTPM, i.e., minutes per mile. From the validation results, the values of MAPE and MPE for all the models are in the range of -15 to +25%. Values up to 0.6 are observed in the case of RMSE. In all the models, the MPE values are negative indicating possible overestimation of the models.

The spatial weights and individual buffer width dataset models were developed to inspect if there is any significant difference in QIC and QICC or the model accuracy. While both the approaches yield similar results, the buffer width dataset-based modeling was used to model the clustered data (results in the coming chapters).

7.6 Discussion on Travel Time Estimation Models Using Data for All Links

Several models were developed using all the variables from multiple buffer widths, using all the variables of a buffer width (for 0.25 mile, 0.50 mile and 1 mile), and by assigning spatial weights to the variables based on the distance decay function. Linear and gamma log link models developed using the backward elimination were used to estimate the ATTPM for trucks.

Based on the model results, areas with land uses like office, light industrial agriculture, heavy commercial and employment density have an increasing influence on the truck ATTPM whereas land uses like medical, multifamily residential, and light commercial have a decreasing influence on the truck ATTPM.

The goodness of fit and model validation were inspected to understand which model performs better. The results indicate marginally similar trends in QIC and QICC, indicating similarity in performance trends. Further, the model validation results suggest that models developed using variables from a buffer width dataset perform marginally better than combined or spatial weight-based datasets.

CHAPTER 8: TRUCK TRAVEL TIME ESTIMATION MODELS BY SPEED LIMIT

Speed limits are a crucial part of the road system and influence overall mobility. The data was clustered based on the speed limit of the links to understand the effect of potential on-network and off network characteristics on the truck ATTPM. This chapter presents the results associated with the truck ATTPM estimation models segregated based on the speed limit.

Truck travel time data was segregated into three categories: (1) links with speed limit of 45 mph and 50 mph, (2) links with speed limit of 55 mph and 60 mph, and (3) links with speed limit of 65 mph and 70 mph.

The dataset with speed limit <= 50 mph comprised of 34 links, out of which 26 links were used for modeling and the remaining 8 links were used for validation. Similarly, the dataset with speed limit > 50 mph and <= 60 mph comprised of 201 links, out of which 151 links were used for modeling and the remaining 50 links were used for validation. The final dataset of speed limit > 60 mph comprised of 266 links, out of which 200 links were used for modeling and remaining 66 links were used for validation.

8.1 Descriptive Statistics Based on the Speed Limit

The descriptive statistics of the variables used for analysis based on the speed limit are presented in Tables 36-40. Table 36 summarizes the frequency distribution of the on-network variables based on the speed limit. Tables 37-40 show the descriptive statistics of travel time, on-network and off-network variables segregated based on the speed limit.

Table 36 Frequency distribution of selected on-network variables by the speed limit

Variable	Category	Frequency (percentage)		
		<= 50 mph	> 50 mph & <= 60 mph	> 60 mph
Number of through lanes	4	7 (20.59)	68 (33.83)	68 (25.56)
	6	21 (61.76)	45 (22.39)	129 (48.50)
	8	6 (17.65)	83 (41.29)	65 (24.44)
	10	-	5 (2.49)	4 (1.50)
Functional class	Interstates	24 (70.59)	165 (82.09)	234 (87.97)
	Principal Arterials	10 (29.41)	36 (17.91)	32 (12.03)

Table 37 Descriptive statistics of on-network and travel time variables by the speed limit

	Variable	Minimum	Median	Mean	Maximum	Standard deviation
<= 50 mph	**ATTPM**	1.07	1.26	1.53	5.84	0.73
	Reference speed	55.00	64.00	64.44	80.00	4.79
	Ln(AADT)	10.97	11.47	11.41	11.79	0.26
> 50 mph & <= 60 mph	**ATTPM**	0.92	1.01	1.16	7.94	0.51
	Reference speed	60.00	68.00	68.46	81.00	2.74
	Ln(AADT)	10.17	11.74	11.52	12.12	0.49
> 60 mph	**ATTPM**	0.89	0.94	1.03	7.99	0.44
	Reference speed	66.00	73.00	73.08	77.00	2.30
	Ln(AADT)	10.28	11.49	11.44	12.07	0.35

Note: ATTPM is expressed in minutes per mile, and reference speed is expressed in miles per hour.

Table 38 Descriptive statistics of off-network variables by the buffer width (<= 50 mph)

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00
Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
College	0.00	0.00	0.03	0.00	0.01	0.09	0.01	0.02	0.10	0.04	0.09	0.17	0.01	0.02	0.03
Government	0.00	0.00	0.00	0.01	0.02	0.07	0.01	0.02	0.08	0.01	0.06	0.19	0.00	0.02	0.05
Heavy commercial	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.01	0.04	0.01	0.06	0.12	0.00	0.01	0.03
Heavy industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.04	0.15	0.01	0.02	0.05
Institutional	0.00	0.01	0.09	0.01	0.03	0.13	0.01	0.04	0.15	0.05	0.13	0.38	0.01	0.03	0.07
Light commercial	0.00	0.04	0.11	0.04	0.14	0.48	0.05	0.16	0.47	0.40	0.64	1.32	0.09	0.13	0.24
Light industrial	0.00	0.00	0.03	0.02	0.10	0.39	0.02	0.10	0.34	0.06	0.22	0.83	0.02	0.06	0.21
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.01
Multifamily residential	0.00	0.01	0.10	0.04	0.12	0.37	0.04	0.12	0.38	0.20	0.52	1.44	0.05	0.11	0.29
Office	0.00	0.00	0.01	0.01	0.04	0.18	0.02	0.05	0.19	0.12	0.28	0.74	0.03	0.06	0.17
Recreational	0.00	0.00	0.00	0.00	0.01	0.05	0.00	0.01	0.05	0.00	0.02	0.12	0.00	0.01	0.03
Resource	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.04	0.00	0.00	0.02
Retail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.03	0.07	0.14	0.01	0.02	0.05
Single family residential	0.00	0.02	0.31	0.06	0.13	0.75	0.09	0.28	1.03	0.64	1.43	3.57	0.15	0.33	0.80
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00
Unknown/vacant	0.00	0.00	0.02	0.02	0.05	0.15	0.02	0.04	0.14	0.04	0.08	0.17	0.01	0.02	0.04
Developed area	46.44	50.83	64.76	56.96	63.82	67.61	58.26	63.60	69.97	70.20	74.44	80.52	5.65	5.75	4.58
Population	0.14	0.52	1.71	0.21	0.69	2.30	0.26	0.81	2.74	1.14	2.57	7.47	0.22	0.45	1.27
# of household units	0.04	0.18	0.76	0.11	0.32	1.00	0.12	0.36	1.19	0.53	1.16	3.31	0.10	0.21	0.58
Population density	1.75	1.95	0.42	4.87	4.55	2.44	4.89	4.67	2.43	9.24	7.71	5.66	2.51	2.03	1.22
Employment density	1.42	1.34	0.29	5.36	9.58	2.07	5.07	11.04	3.44	9.83	27.56	20.48	2.64	8.86	4.08

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

Table 39 Descriptive statistics of off-network variables by the buffer width (>50 & <=60 mph)

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00
Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.09	0.43	0.85	2.06	0.04	0.09	0.23
College	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.02	0.08	0.05	0.15	0.31	0.01	0.04	0.07
Government	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.03	0.09	0.21	0.41	0.86	0.03	0.08	0.16
Heavy commercial	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.05	0.06	0.09	0.35	0.01	0.03	0.07
Heavy industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.06	0.20	0.37	0.01	0.03	0.07
Institutional	0.00	0.00	0.00	0.00	0.02	0.09	0.01	0.03	0.09	0.09	0.16	0.21	0.01	0.03	0.04
Light commercial	0.00	0.00	0.01	0.03	0.09	0.29	0.04	0.10	0.30	0.20	0.43	0.97	0.04	0.08	0.20
Light industrial	0.00	0.00	0.00	0.02	0.09	0.38	0.06	0.16	0.50	0.60	1.29	2.26	0.09	0.20	0.49
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.08	0.01	0.01	0.01
Multifamily residential	0.00	0.00	0.02	0.02	0.07	0.28	0.03	0.11	0.38	0.75	1.80	4.11	0.07	0.18	0.44
Office	0.00	0.00	0.00	0.00	0.02	0.07	0.02	0.05	0.14	0.13	0.39	0.73	0.03	0.07	0.17
Recreational	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.03	0.12	0.25	0.69	1.61	0.03	0.08	0.24
Resource	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.09	0.15	0.00	0.01	0.02
Retail	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.08	0.14	0.23	0.01	0.03	0.05
Single family residential	0.00	0.00	0.20	0.08	0.35	1.39	0.10	0.38	1.38	0.54	1.33	3.61	0.09	0.24	0.55
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.00	0.00	0.00
Unknown/vacant	0.00	0.00	0.02	0.01	0.04	0.13	0.03	0.09	0.28	0.26	0.74	1.70	0.05	0.13	0.35
Developed area	24.69	33.05	46.07	62.97	70.21	75.22	60.76	67.20	74.06	85.21	85.23	93.62	11.90	11.17	9.16
Population	0.01	0.10	0.91	0.27	0.84	3.28	0.39	1.12	3.85	2.57	6.10	14.94	0.39	0.85	2.19
# of household units	0.00	0.04	0.37	0.10	0.33	1.26	0.16	0.46	1.57	1.07	2.37	5.96	0.17	0.38	0.99
Population density	0.04	0.11	0.01	1.22	1.48	1.73	1.61	1.75	1.97	6.20	4.96	12.86	1.21	1.13	1.45
Employment density	0.03	0.04	0.01	1.37	1.58	1.46	2.13	2.09	2.60	8.70	7.44	35.34	1.81	1.64	4.12

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

Table 40 Descriptive statistics of off-network variables by the buffer width (> 60 mph)

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
	0.25	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**
Agriculture	0.00	0.00	0.00	0.00	0.00	0.04	0.02	0.06	0.20	0.41	0.83	2.37	0.06	0.14	0.39
College	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.02	0.08	0.12	0.21	0.41	0.02	0.04	0.08
Government	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.05	0.42	0.01	0.01	0.03
Heavy commercial	0.00	0.00	0.00	0.00	0.01	0.06	0.01	0.04	0.11	0.15	0.27	0.76	0.02	0.06	0.14
Heavy industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.12	0.46	1.06	2.13	0.06	0.14	0.35
Institutional	0.00	0.00	0.00	0.00	0.01	0.06	0.01	0.02	0.07	0.15	0.32	0.62	0.02	0.04	0.08
Light commercial	0.00	0.00	0.00	0.00	0.03	0.11	0.03	0.09	0.21	0.34	0.73	1.36	0.06	0.12	0.26
Light industrial	0.00	0.00	0.00	0.00	0.02	0.10	0.05	0.13	0.37	0.71	1.69	4.27	0.11	0.26	0.65
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.06	0.28	0.01	0.01	0.04
Multifamily residential	0.00	0.00	0.00	0.01	0.05	0.21	0.03	0.08	0.29	0.20	0.57	1.50	0.04	0.10	0.26
Office	0.00	0.00	0.00	0.00	0.02	0.08	0.02	0.05	0.15	0.16	0.41	1.23	0.03	0.07	0.18
Recreational	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.06	0.12	0.22	1.19	0.02	0.04	0.11
Resource	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.09	0.22	0.38	1.02	0.03	0.08	0.18
Retail	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.07	0.18	0.39	0.89	0.02	0.05	0.12
Single family residential	0.00	0.00	0.06	0.11	0.38	1.54	0.16	0.49	1.67	0.96	2.29	5.68	0.17	0.41	1.05
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.29	0.47	0.00	0.02	0.05
Unknown/vacant	0.00	0.00	0.01	0.03	0.09	0.27	0.08	0.20	0.56	0.60	1.19	2.50	0.11	0.24	0.59
Developed area	0.44	6.53	13.84	56.45	64.73	70.68	52.16	58.74	65.10	80.54	85.42	89.41	17.58	16.98	16.42
Population	0.00	0.00	0.02	0.40	1.18	3.89	0.52	1.41	4.42	2.65	6.21	15.13	0.44	1.01	2.57
# of household units	0.00	0.00	0.01	0.15	0.44	1.50	0.21	0.55	1.71	1.15	2.66	6.51	0.18	0.41	1.04
Population density	0.00	0.00	0.01	1.24	1.35	1.44	1.38	1.42	1.69	5.17	4.78	11.34	0.98	0.91	1.35
Employment density	0.01	0.01	0.00	0.80	0.79	1.11	1.44	1.44	1.93	6.35	8.25	30.25	1.56	1.52	2.92

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

8.2 Model Results for Speed Limit <= 50 mph Category

The results from the models developed for dataset comprising of links with speed limit <= 50 mph and variables from 0.25, 0.50 and 1-mile buffer widths separately are presented in this section. Tables 41-43 show the results for models developed using variables from 0.25, 0.50 and 1-mile buffer widths. Appendix C (C8-C10) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 41 Developed models for speed limit <= 50 mph (0.25-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-2.505	3.380	0.459				-0.693	1.027	0.500
Time of the day	Morning peak	0.175	0.056	0.002	0.176	0.056	0.002	0.099	0.033	0.003
Time of the day	Afternoon peak	0.061	0.023	0.007	0.062	0.022	0.006	0.043	0.016	0.008
Time of the day	Evening peak	0.733	0.138	<.0001	0.734	0.137	<.0001	0.407	0.068	<.0001
Day of the week	Weekday	0.449	0.061	<.0001	0.449	0.061	<.0001	0.244	0.030	<.0001
Ln(AADT)		0.512	0.280	0.068	0.267	0.022	<.0001	0.184	0.082	0.025
Number of through lanes	4	1.010	0.177	<.0001	0.722	0.114	<.0001	0.414	0.053	<.0001
Number of through lanes	6	0.258	0.100	0.010	0.126	0.071	0.078	0.108	0.049	0.028
Functional class	Interstates									
Agriculture										
College										
Government										
Heavy commercial										
Heavy industrial					-9.456	2.773	0.001	-6.781	1.650	<.0001
Institutional		19.406	4.793	<.0001	12.943	4.773	0.007	7.028	2.080	0.001
Light commercial		5.422	1.963	0.006						
Light industrial										
Medical										
Multifamily residential										
Office		-13.847	3.978	0.001	-14.649	4.128	<.0001	-7.519	1.870	<.0001
Recreational										
Resource										
Retail		-8.139	3.832	0.034						
Single family residential										
Transportation										
Unknown/Vacant										
Developed area		-0.049	0.008	<.0001	-0.038	0.006	<.0001	-0.022	0.004	<.0001
Population										
# of household units										
Population density								-0.025	0.007	<.0001
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 42 Developed models for speed limit <= 50 mph (0.50-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-11.863	7.729	0.125				-5.343	3.536	0.131
Time of the day	Morning peak	0.175	0.056	0.002	0.175	0.056	0.002	0.099	0.034	0.003
Time of the day	Afternoon peak	0.061	0.023	0.007	0.061	0.023	0.007	0.043	0.016	0.009
Time of the day	Evening peak	0.733	0.138	<.0001	0.733	0.138	<.0001	0.406	0.068	<.0001
Day of the week	Weekday	0.449	0.061	<.0001	0.449	0.061	<.0001	0.244	0.029	<.0001
Ln(AADT)		1.040	0.619	0.093	0.355	0.070	<.0001	0.426	0.284	0.133
Number of through lanes	4	-1.539	0.509	0.003	-5.341	0.912	<.0001	-0.765	0.225	0.001
Number of through lanes	6	0.037	0.085	0.664	0.543	0.118	<.0001	0.024	0.040	0.552
Functional class	Interstates									
Agriculture										
College		-9.372	3.648	0.010	-49.925	6.778	<.0001	-4.453	1.611	0.006
Government		-18.288	5.447	0.001	-13.951	4.452	0.002	-9.278	2.393	<.0001
Heavy commercial					-34.335	8.531	<.0001			
Heavy industrial					-278.118	47.870	<.0001			
Institutional					-49.211	12.674	<.0001			
Light commercial					-6.438	1.817	<.0001			
Light industrial		7.237	1.758	<.0001				3.721	0.779	<.0001
Medical										
Multifamily residential		-8.140	2.522	0.001	-9.092	3.152	0.004	-4.327	1.138	<.0001
Office					-28.917	7.053	<.0001			
Recreational		41.472	9.936	<.0001	127.416	21.195	<.0001	21.231	4.114	<.0001
Resource										
Retail					115.866	20.445	<.0001			
Single family residential		-4.527	0.994	<.0001	-17.117	3.022	<.0001	-2.396	0.442	<.0001
Transportation		-115.586	56.870	0.042	-545.917	104.102	<.0001	-49.569	25.394	0.051
Unknown/Vacant					49.540	9.112	<.0001			
Developed area		0.058	0.024	0.017	0.110	0.024	<.0001	0.030	0.011	0.006
Population		12.756	6.107	0.037	51.683	9.704	<.0001	5.787	2.709	0.033
# of household units		-23.920	11.736	0.042	-92.532	18.073	<.0001	-10.700	5.222	0.041
Population density		-0.288	0.147	0.050	-1.325	0.283	<.0001	-0.133	0.066	0.042
Employment density		-0.057	0.017	0.001	-0.127	0.019	<.0001	-0.032	0.008	<.0001

Note: The reference categories of the categorical variables (time of the day, day of the week, number through lanes, and functional class) are not included in the table.

Table 43 Developed models for speed limit <= 50 mph (1-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-57.712	0.066	<.0001				-62.188	0.033	<.0001
Time of the day	Morning peak	0.175	0.056	0.002	0.175	0.056	0.002	0.099	0.034	0.004
Time of the day	Afternoon peak	0.061	0.023	0.007	0.061	0.023	0.007	0.042	0.017	0.012
Time of the day	Evening peak	0.733	0.138	<.0001	0.733	0.138	<.0001	0.395	0.066	<.0001
Day of the week	Weekday	0.449	0.061	<.0001	0.449	0.061	<.0001	0.240	0.029	<.0001
Ln(AADT)		-6.011	<.0001	<.0001	-5.726	<.0001	<.0001	-1.646	<.0001	<.0001
Number of through lanes	4	-7.814	<.0001	<.0001	-5.571	0.003	<.0001	-4.500	<.0001	<.0001
Number of through lanes	6	-24.490	<.0001	<.0001	-20.807	0.004	<.0001	-11.825	<.0001	<.0001
Functional class	Interstates									
Agriculture		3681.358	<.0001	<.0001	3276.207	0.463	<.0001	1670.516	<.0001	<.0001
College		-323.761	<.0001	<.0001	-271.473	0.060	<.0001	-148.707	<.0001	<.0001
Government		967.436	<.0001	<.0001	835.267	0.151	<.0001	479.499	<.0001	<.0001
Heavy commercial		-349.381	<.0001	<.0001	-254.319	0.109	<.0001	-120.853	<.0001	<.0001
Heavy industrial		-1178.680	<.0001	<.0001	-1033.850	0.166	<.0001	-629.170	<.0001	<.0001
Institutional		-115.431	<.0001	<.0001	-122.136	0.008	<.0001	-45.132	<.0001	<.0001
Light commercial		23.047	<.0001	<.0001	21.617	0.002	<.0001	4.317	<.0001	<.0001
Light industrial		237.346	<.0001	<.0001	201.072	0.041	<.0001	112.252	<.0001	<.0001
Medical		-651.877	<.0001	<.0001	-510.910	0.161	<.0001	-101.269	<.0001	<.0001
Multifamily residential		25.311	<.0001	<.0001	16.774	0.010	<.0001	13.396	<.0001	<.0001
Office		315.685	<.0001	<.0001	269.981	0.052	<.0001	131.438	<.0001	<.0001
Recreational		-157.885	<.0001	<.0001	-141.701	0.019	<.0001	-69.946	<.0001	<.0001
Resource		2268.889	<.0001	<.0001	2045.144	0.256	<.0001	1063.181	<.0001	<.0001
Retail		3176.547	<.0001	<.0001	2922.432	0.290	<.0001	1478.971	<.0001	<.0001
Single family residential		-102.594	<.0001	<.0001	-91.175	0.013	<.0001	-50.445	<.0001	<.0001
Transportation		-16911.200	<.0001	<.0001	-16198.600	0.814	<.0001	-7516.580	<.0001	<.0001
Unknown/Vacant		-1593.430	<.0001	<.0001	-1342.210	0.287	<.0001	-749.495	<.0001	<.0001
Developed area		3.464	<.0001	<.0001	2.570	0.001	<.0001	1.871	<.0001	<.0001
Population		449.465	<.0001	<.0001	398.912	0.058	<.0001	202.940	<.0001	<.0001
# of household units		-1008.460	<.0001	<.0001	-898.144	0.126	<.0001	-448.272	<.0001	<.0001
Population density		0.543	<.0001	<.0001	0.453	<.0001	<.0001	0.261	<.0001	<.0001
Employment density		-2.304	<.0001	<.0001	-1.996	<.0001	<.0001	-1.055	<.0001	<.0001

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

In all the models developed using data for links with speed limit <=50 mph, the coefficients of time of the day, day of the week, AADT and number of through lanes are consistent and significant. The results indicate that the ATTPM of truck for weekday is higher than for weekend (when all other variables are held constant). Similarly, the truck ATTPM values are higher for the evening peak, followed by the morning peak and afternoon peak (when all other variables are held constant). The results also indicate that an increase in AADT results in an increase in the truck ATTPM (when all other variables are held constant).

The off-network variables like heavy industrial, light commercial, institutional, office, and retail land uses, and percent of the developed area were found to be significant at a 90% confidence level in the case of 0.25-mile buffer width dataset. Similarly, the results for models developed using 0.50-mile buffer width dataset, all the land use and demographic variables were found to be significant (with an exception to the agriculture land use) at a 90% confidence level. In the case of 1-mile buffer width dataset, all the land use and demographic variables were found to be significant at a 90% confidence level.

The results from the models developed using the data for links with speed limit < =50 mph show mixed patterns of coefficients, intercept and variables significance. The results from the linear models (with/without intercept) for 0.25, 0.50 and 1-mile buffer width datasets show negative coefficients which range from -2 to -57. Considering the negative coefficients and their irrelevance in the truck travel time data, the linear models are not typically considered for the interpretation. The coefficients of the variables for linear models with intercept have values ranging from -1600 to 2300 (from Tables 51-53), possibly resulting in high truck ATTPM estimation errors. Hence, the linear models without intercept and gamma log link are inspected. The linear models without intercept and gamma log link models for 0.50-mile and 1-mile buffer widths high negative coefficients (<-100 or >100). The summary statistics of the truck ATTPM variable show a maximum value of 7.99 (from Table 37). Hence, models with significantly larger coefficients may possibly result in high truck ATTPM estimation errors.

The models from 0.25-mile buffer width dataset, linear (without intercept) and gamma log links have meaningful coefficients and intercept values. The variables like the time of the day, day of the week, AADT, number of through lanes, and institutional land use have an increasing effect on ATTPM while heavy industrial, office and percent of the developed area have a decreasing effect on ATTPM .

8.3 Model Results for Speed Limit > 50 mph & <= 60 mph Category

The results from the models developed for dataset comprising of links with speed limit > 50 mph and <= 60 mph and variables from 0.25, 0.50 and 1-mile buffer widths separately are presented in this section. Tables 44-46 show the results for models developed using variables from 0.25, 0.50 and 1-mile buffer width datasets. Appendix C (Tables C11-C13) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 44 Developed models for speed limit > 50 mph and <=60 mph (0.25-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.433	1.186	0.715				-0.234	0.963	0.808
Time of the day	Morning peak	0.121	0.032	<.0001	0.122	0.032	<.0001	0.088	0.023	<.0001
Time of the day	Afternoon peak	-0.028	0.010	0.005	-0.027	0.010	0.008	-0.024	0.009	0.008
Time of the day	Evening peak	0.292	0.043	<.0001	0.293	0.043	<.0001	0.204	0.027	.
Day of the week	Weekday	0.263	0.034	<.0001	0.264	0.034	<.0001	0.195	0.022	<.0001
Ln(AADT)		0.023	0.099	0.818	0.062	0.006	<.0001	-0.002	0.083	0.979
Number of through lanes	4	0.201	0.111	0.070	0.202	0.048	<.0001	0.140	0.076	0.066
Number of through lanes	6	0.425	0.062	<.0001	0.303	0.066	<.0001	0.280	0.047	<.0001
Number of through lanes	8	0.140	0.036	<.0001	0.090	0.039	0.021	0.075	0.028	0.007
Functional class	Interstates							0.058	0.033	0.078
Agriculture		0.972	0.296	0.001						
College								1.617	0.970	0.095
Government										
Heavy commercial										
Heavy industrial										
Institutional					2.859	0.876	0.001	1.938	0.683	0.005
Light commercial										
Light industrial		0.317	0.185	0.086	0.364	0.183	0.046	0.299	0.137	0.028
Medical										
Multifamily residential					0.445	0.140	0.002	0.402	0.117	0.001
Office					1.664	0.964	0.084			
Recreational										
Resource										
Retail					3.466	1.729	0.045	3.211	1.369	0.019
Single family residential										
Transportation										
Unknown/Vacant		-1.026	0.414	0.013	-1.498	0.435	0.001	-0.929	0.360	0.010
Developed area										
Population										
# of household units		-0.209	0.089	0.019	-0.362	0.092	<.0001	-0.292	0.073	<.0001
Population density		0.033	0.013	0.011	0.028	0.014	0.044	0.027	0.009	0.003
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 45 Developed models for speed limit > 50 mph and <=60 mph (0.50-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-0.593	0.817	0.468				-1.363	0.543	0.012
Time of the day	Morning peak	0.121	0.032	<0.001	0.121	0.032	<.0001	0.084	0.022	<.0001
Time of the day	Afternoon peak	-0.028	0.010	0.005	-0.029	0.010	0.004	-0.025	0.009	0.006
Time of the day	Evening peak	0.292	0.043	<.0001	0.291	0.043	<.0001	0.198	0.026	.
Day of the week	Weekday	0.263	0.034	<.0001	0.263	0.034	<.0001	0.192	0.021	<.0001
Ln(AADT)		0.135	0.075	0.072	0.086	0.010	<.0001	0.121	0.049	0.014
Number of through lanes	4	0.236	0.061	<.0001	0.181	0.028	<.0001	0.198	0.042	<.0001
Number of through lanes	6	0.161	0.048	0.001	0.146	0.047	0.002	0.127	0.032	<.0001
Number of through lanes	8	0.046	0.021	0.031	0.039	0.023	0.094	0.037	0.016	0.024
Functional class	Interstates									
Agriculture										
College										
Government										
Heavy commercial										
Heavy industrial		-1.518	0.519	0.003	-1.550	0.502	0.002	-1.159	0.371	0.002
Institutional		1.742	0.533	0.001	1.752	0.542	0.001	1.351	0.395	0.001
Light commercial										
Light industrial										
Medical										
Multifamily residential										
Office		1.459	0.565	0.010	1.464	0.594	0.014	0.927	0.339	0.006
Recreational					0.168	0.111	0.130			
Resource										
Retail										
Single family residential										
Transportation										
Unknown/Vacant		-0.598	0.171	0.001	-0.603	0.173	0.001	-0.413	0.116	0.000
Developed area		-0.003	0.002	0.087	-0.003	0.001	0.064	-0.003	0.001	0.014
Population										
# of household units		-0.111	0.032	0.001	-0.124	0.037	0.001	-0.086	0.023	<.0001
Population density										
Employment density										

Note:
The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 46 Developed models for speed limit > 50 mph and <=60 mph (1-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		1.201	1.046	0.251				0.138	0.638	0.828
Time of the day	Morning peak	0.121	0.032	0.000	0.105	0.017	<.0001	0.083	0.021	<.0001
Time of the day	Afternoon peak	-0.028	0.010	0.005	-0.010	0.003	0.001	-0.025	0.009	0.005
Time of the day	Evening peak	0.292	0.043	<.0001	0.249	0.038	<.0001	0.195	0.025	.
Day of the week	Weekday	0.263	0.034	<.0001	0.191	0.021	<.0001	0.189	0.020	<.0001
Ln(AADT)		-0.009	0.092	0.922	0.071	0.006	<.0001	0.002	0.056	0.978
Number of through lanes	4	0.256	0.062	<.0001	0.142	0.055	0.010	0.195	0.042	<.0001
Number of through lanes	6	0.165	0.048	0.001	0.048	0.061	0.438	0.106	0.032	0.001
Number of through lanes	8	0.080	0.026	0.002	-0.001	0.059	0.991	0.043	0.022	0.046
Functional class	Interstates							0.067	0.028	0.019
Agriculture					-0.073	0.027	0.007			
College										
Government										
Heavy commercial					-0.139	0.060	0.021			
Heavy industrial		-0.647	0.190	0.001				-0.611	0.114	<.0001
Institutional								0.455	0.205	0.026
Light commercial										
Light industrial		0.065	0.039	0.096				0.063	0.025	0.012
Medical										
Multifamily residential		0.071	0.022	0.002				0.056	0.017	0.001
Office		0.826	0.269	0.002	0.121	0.051	0.019	0.537	0.149	0.000
Recreational										
Resource		2.587	0.715	0.000				1.614	0.479	0.001
Retail					0.197	0.085	0.021	0.609	0.287	0.034
Single family residential					-0.023	0.009	0.008			
Transportation										
Unknown/Vacant		-0.369	0.084	<.0001	-0.044	0.026	0.094	-0.319	0.066	<.0001
Developed area		-0.005	0.002	0.013				-0.005	0.001	0.001
Population		-0.020	0.005	0.000				-0.022	0.005	<.0001
# of household units					0.030	0.010	0.004			
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

The intercept of the gamma log link model developed using variables of 0.50-mile buffer width dataset is negative. When all the variables are zero, the ATTPM of truck is $e^{-1.36}$ i.e., 0.256 minutes per mile.

The variables like the time of the day, day of the week and other network characteristics like AADT, and number of through lanes are statistically significant at a 90% confidence level in all the models (linear and gamma log link). The coefficients of time of the day, day of the week, AADT and number of through lanes are consistent. The results indicate that the ATTPM of truck on a weekday is higher than weekend (when all other variables are held constant). Similarly, the truck ATTPM values are higher for the evening peak, followed by the morning peak and afternoon peak (when all other variables are held constant). The results also indicate that an increase in AADT results in an increase in the truck ATTPM (when all other variables are held constant).

The models developed using variables from 0.25-mile buffer width dataset indicate that agriculture, light industrial, institutional, multifamily residential, and resource, office, land uses, number of household units, and population density have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with agriculture, light industrial, institutional, multifamily residential, resource, and office land uses have an increasing influence on the truck ATTPM. The model results also indicate that population density has an increasing influence on the truck ATTPM whereas the household estimate has a decreasing influence on the truck ATTPM.

The models developed using variables from 0.50-mile buffer width dataset indicate that institutional, office, recreational, heavy industrial, and heavy industrial land uses, percent of the developed area and household estimate have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with institutional, office, and recreational land uses have an increasing influence on the truck ATTPM. Contrarily, areas with heavy industrial land use have a decreasing influence on the truck ATTPM. In addition, percent of the developed area and household estimate also have a decreasing influence on the truck ATTPM.

The model results from 1-mile buffer width dataset indicate agriculture, institutional, light industrial, retail, heavy commercial, heavy industrial, multifamily residential, single family residential, office, and resource land uses, percent of the developed area and population have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with institutional, light industrial, retail, office, resource, and multifamily residential land uses have an increasing influence on the truck ATTPM, while the areas with agriculture, heavy commercial, heavy industrial, and single family residential land uses have a decreasing influence on the truck ATTPM.

8.4 Model Results for Speed Limit > 60 mph Category

The results from the models developed for dataset comprising of links with speed limit > 60 mph and variables from 0.25, 0.50 and 1-mile buffer widths separately are presented in this section. Tables 47-49 show the results for models developed using variables from 0.25, 0.50 and 1-mile buffer width datasets. Appendix C (Tables C14-C16) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Time of the day, day of the week and other network characteristics like AADT, and number of through lanes are statistically significant at a 90% confidence level in all the models and indicate consistent results when models are developed using data for links with speed limit >60 mph. The results indicate that the ATTPM of truck for weekday is higher than on a weekend (when all other variables are held constant). Similarly, the truck ATTPM values are higher for the evening peak, followed by the morning peak and the afternoon peak (when all other variables are held constant). The results also indicate that an increase in AADT results in an increase in the truck ATTPM (when all other variables are held constant).

Off-network variables like employment density, office, agriculture, and resource land uses were found to be significant at a 90% confidence level when models are developed using 0.25-mile buffer dataset. The areas with office land use have an increasing influence on the truck ATTPM whereas the areas with agriculture and resource, office land uses have a decreasing influence on the truck ATTPM. The model results also indicate that employment density has an increasing influence on the truck ATTPM.

Table 47 Developed models for speed limit > 60 mph (0.25-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-0.476	0.408	0.243				-1.298	0.314	<.0001
Time of the day	Morning peak	0.106	0.017	<.0001	0.106	0.017	<.0001	0.093	0.015	<.0001
Time of the day	Afternoon peak	-0.009	0.003	0.002	-0.009	0.003	0.001	-0.009	0.003	0.001
Time of the day	Evening peak	0.250	0.038	<.0001	0.249	0.038	<.0001	0.203	0.028	<.0001
Day of the week	Weekday							0.161	0.016	<.0001
Ln(AADT)		0.099	0.035	0.005	0.060	0.006	<.0001	0.089	0.027	0.001
Number of through lanes	4	0.198	0.046	<.0001	0.137	0.050	0.007	0.160	0.034	<.0001
Number of through lanes	6	0.151	0.031	<.0001	0.108	0.059	0.068	0.120	0.022	<.0001
Number of through lanes	8	0.093	0.027	0.001	0.046	0.058	0.427	0.075	0.020	0.000
Functional class	Interstates									
Agriculture		-0.163	0.062	0.009				-0.148	0.054	0.006
College										
Government										
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial										
Light industrial										
Medical										
Multifamily residential										
Office					0.659	0.419	0.116			
Recreational										
Resource					-0.320	0.160	0.045			
Retail										
Single family residential										
Transportation										
Unknown/Vacant										
Developed area										
Population										
# of household units										
Population density										
Employment density		0.042	0.013	0.001	0.044	0.012	0.000	0.032	0.009	0.000

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 48 Developed models for speed limit > 60 mph (0.50-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-0.649	0.433	0.134				-1.357	0.327	<.0001
Time of the day	Morning peak	0.106	0.017	<.0001	0.106	0.017	<.0001	0.093	0.015	<.0001
Time of the day	Afternoon peak	-0.009	0.003	0.002	-0.009	0.003	0.001	-0.009	0.003	0.001
Time of the day	Evening peak	0.250	0.038	<.0001	0.250	0.039	<.0001	0.203	0.028	<.0001
Day of the week	Weekday							0.160	0.016	<.0001
Ln(AADT)		0.112	0.038	0.003	0.054	0.007	<.0001	0.093	0.029	0.001
Number of through lanes	4	0.231	0.048	<.0001	0.188	0.050	0.000	0.177	0.034	<.0001
Number of through lanes	6	0.175	0.031	<.0001	0.124	0.052	0.018	0.112	0.024	<.0001
Number of through lanes	8	0.114	0.027	<.0001	0.055	0.049	0.266	0.073	0.020	0.000
Functional class	Interstates				0.059	0.027	0.028			
Agriculture								-0.092	0.031	0.003
College										
Government					-2.970	1.136	0.009			
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial										
Light industrial										
Medical										
Multifamily residential										
Office					0.235	0.131	0.074	0.188	0.103	0.067
Recreational										
Resource					-0.249	0.118	0.035			
Retail					0.508	0.213	0.017	0.357	0.155	0.021
Single family residential		-0.051	0.021	0.016	-0.059	0.025	0.020	-0.033	0.017	0.052
Transportation										
Unknown/Vacant										
Developed area										
Population					0.025	0.009	0.005	0.021	0.007	0.004
# of household units		0.062	0.023	0.007						
Population density										
Employment density		0.036	0.015	0.017	0.032	0.013	0.013	0.019	0.011	0.074

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 49 Developed models for speed limit > 60 mph (1 -mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-0.777	0.428	0.069				-1.614	0.308	<.0001
Time of the day	Morning peak	0.106	0.017	<.0001	0.105	0.017	<.0001	0.093	0.015	<.0001
Time of the day	Afternoon peak	-0.009	0.003	0.002	-0.010	0.003	0.001	-0.009	0.003	0.001
Time of the day	Evening peak	0.250	0.038	<.0001	0.249	0.038	<.0001	0.205	0.028	<.0001
Day of the week	Weekday							0.161	0.016	<.0001
Ln(AADT)		0.128	0.036	0.000	0.071	0.006	<.0001	0.121	0.026	<.0001
Number of through lanes	4	0.247	0.051	<.0001	0.142	0.055	0.010	0.186	0.036	<.0001
Number of through lanes	6	0.139	0.029	<.0001	0.048	0.061	0.438	0.089	0.025	0.000
Number of through lanes	8	0.085	0.026	0.001	-0.001	0.059	0.991	0.054	0.020	0.006
Functional class	Interstates									
Agriculture		-0.074	0.018	<.0001	-0.073	0.027	0.007	-0.067	0.015	<.0001
College										
Government										
Heavy commercial					-0.139	0.060	0.021	-0.079	0.040	0.049
Heavy industrial										
Institutional										
Light commercial										
Light industrial										
Medical										
Multifamily residential										
Office		0.081	0.049	0.099	0.121	0.051	0.019			
Recreational										
Resource										
Retail					0.197	0.085	0.021	0.132	0.065	0.042
Single family residential		-0.024	0.008	0.004	-0.023	0.009	0.008	-0.018	0.007	0.008
Transportation										
Unknown/Vacant					-0.044	0.026	0.094			
Developed area										
Population										
# of household units		0.035	0.010	0.000	0.030	0.010	0.004	0.026	0.008	0.001
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

The results of models developed using 0.50-mile buffer width datasets, indicate that agriculture, office, retail, single family residential, resource, and government land uses, population, number of household units and employment density were significant at a 90% confidence level. The areas with office and retail land uses have an increasing influence on the truck ATTPM whereas the areas with single family residential, resource, government and agriculture land uses have a decreasing influence on the truck ATTPM. The model results also indicate that population, number of household units and employment density has an increasing influence on the truck ATTPM.

In the case of 1-mile buffer width dataset based model, agriculture, office, retail, heavy commercial, and single family residential land uses, and number of household units were found to be significant at a 90% confidence level. The areas with agriculture, heavy commercial, and single family residential land use have a decreasing influence on the truck ATTPM whereas the areas with office and retail land uses have an increasing influence on the truck ATTPM. The model results also indicate that the number of household units have an increasing influence on the truck ATTPM.

8.5 Goodness of Fit and Validation Results

Clustering the data based on the speed limit resulted in a decrease of QIC and QICC values overall. Table 50 summarizes the goodness of fit statistics for models of different speed limit categories.

Table 50 Goodness of fit for models by speed limit category

			Linear model (with intercept)		Linear model (without intercept)		Gamma log linear	
			All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
<= 50 mph	0.25-mile	QIC	195.11	195.66	209.04	209.14	7158.31	7271.42
		QICC	235.00	234.00	221.00	219.00	7199.38	7284.90
	0.50-mile	QIC	191.29	192.95	201.30	194.50	7190.50	7147.76
		QICC	236.00	235.00	228.00	233.00	7235.85	7175.32
	1-mile	QIC	184.31	184.31	184.31	184.31	31314.41	7403.24
		QICC	238.00	238.00	238.00	238.00	31331.11	7456.75
> 50 mph & <= 60 mph	0.25-mile	QIC	1236.42	1230.39	1224.44	1223.95	27820.37	27159.72
		QICC	1239.00	1238.00	1222.00	1224.00	27817.14	27156.07
	0.50-mile	QIC	1237.63	1235.48	1229.68	1227.69	29543.71	29933.97
		QICC	1240.00	1239.00	1223.00	1223.00	29539.82	29926.32
	1-mile	QIC	1614.07	1614.15	1226.27	1606.42	31314.41	32416.19
		QICC	1632.00	1631.00	1226.00	1615.00	31331.11	32416.78
> 60 mph	0.25-mile	QIC	1614.77	1614.96	1607.84	1608.13	31853.82	31481.03
		QICC	1632.00	1631.00	1611.00	1611.00	31870.79	31484.51
	0.50-mile	QIC	1612.77	1613.27	1608.45	1607.76	31928.32	31370.50
		QICC	1632.00	1631.00	1612.00	1616.00	31946.91	31377.60
	1-mile	QIC	1614.07	1614.15	1605.36	1606.42	31314.41	30546.99
		QICC	1632.00	1631.00	1613.00	1615.00	31331.11	30555.40

The goodness of fit statistics for models using data for links with speed limit <=50 mph has the lowest values of all the three models (linear with/without intercept and gamma log link). The goodness of fit statistics for models using data for links with speed limit > 60 mph are marginally similar to that of the goodness of fit statistics for models using data for links with speed limit > 50 mph and < 60 mph. The QIC and QICC values are the lowest for linear models with intercept followed by the linear models without intercept.

Despite the low values for the linear models, their applicability to estimate the truck ATTPM would be questionable due to the model results (high magnitudes of the intercepts and coefficients). Out of all the models, the gamma log link performed well, especially, when modeled with 0.25-mile buffer width dataset. Table 51 summarizes the validation results of the models.

Table 51 Model validation results for speed limit category

			Linear model		Gamma log link
			With intercept	Without intercept	
<= 50 mph	0.25-mile	MPE (%)	-17.67	25.89	9.44
		MAPE (%)	20.24	24.33	15.35
		RMSE (minutes/mile)	0.71	1.00	0.76
	0.50-mile	MPE (%)	85.38	455.78	-75.88
		MAPE (%)	34.07	107.66	39.96
		RMSE (minutes/mile)	2.27	9.64	1.56
	1-mile	MPE (%)	635.08	401.30	>1000.00
		MAPE (%)	703.36	646.67	>1000.00
		RMSE (minutes/mile)	35.80	34.11	>1000.00
> 50 mph & <= 60 mph	0.25-mile	MPE (%)	-2.75	-3.17	-3.64
		MAPE (%)	12.10	12.44	9.82
		RMSE (minutes/mile)	0.39	0.40	0.39
	0.50-mile	MPE (%)	-26.36	-0.44	-1.20
		MAPE (%)	20.30	11.28	9.22
		RMSE (minutes/mile)	0.58	0.40	0.39
	1-mile	MPE (%)	-2.44	3.55	-6.79
		MAPE (%)	11.81	9.04	11.16
		RMSE (minutes/mile)	0.40	0.43	0.39
> 60 mph	0.25-mile	MPE (%)	-6.79	1.27	-8.03
		MAPE (%)	10.72	9.04	10.00
		RMSE (minutes/mile)	0.33	0.34	0.33
	0.50-mile	MPE (%)	-6.77	-1.32	-6.19
		MAPE (%)	10.96	9.78	9.27
		RMSE (minutes/mile)	0.33	0.33	0.33
	1-mile	MPE (%)	-5.67	-5.88	2.17
		MAPE (%)	10.04	10.18	7.30
		RMSE (minutes/mile)	0.33	0.33	0.34

The MPE, MAPE, and RMSE for models based on datasets of speed limits ">50 mph and <= 60 mph" and ">60 mph" are consistent. The values of MPE are negative in majority of the cases, indicating potential overestimation of the models. The results from MAPE indicate a value up to 20%.

The model validation results from datasets of speed limits "<=50 mph" indicate an increase in errors with an increase in buffer widths. The model validation results for datasets of speed limits “<=50 mph” using 0.50-mile and 1.00-mile buffer widths indicate significantly higher MPE, MAPE, and RMSE values compared to the results from 0.25-mile buffer width dataset.

The results suggest that linear and gamma log link models based on 0.25-mile buffer width datasets work well in terms of both goodness of fit statistics and validation.

8.6 Discussion on Travel Time Estimation Models by the Speed Limit

Based on the model results, goodness of fit statistics, and model validation results, a buffer width of 0.25 miles is suitable to capture the relationship between the truck ATTPM and on-/off-network characteristics. Time of the day, day of the week, and on-network characteristics (like AADT, number of through lanes and speed limit) were found to be significant in all the models. In the case of off-network characteristics, an increase in areas of land uses like light commercial, institutional and light industrial result in an increase in the truck ATTPM. Contrarily, an increase in areas of land uses like retail land use results in a decrease in the truck ATTPM. Some of the land uses like office, agriculture and resource land uses showed mixed patterns which depend on the speed limit of the link and also corresponding buffer width.

The model results suggest that the effect of off-network characteristics like the land use and demographics vary based on multiple buffer widths and also the speed limit. For example, an increase in the areas of agriculture land use results in an increase in the truck ATTPM for links with speed limits <= 50 mph. However, for roads with speed limits > 60 mph, an increase in agriculture land use results in a decrease in the truck ATTPM.

CHAPTER 9: TRUCK TRAVEL TIME ESTIMATION MODELS BY COUNTY

Three counties with varying characteristics in terms of terrain, region and development were considered in this research. The data was clustered based on the county and modeled to understand the effect of potential on-network and off network characteristics on the truck ATTPM. This chapter presents the results associated with the truck ATTPM estimation models by county.

For the classification based on county, truck travel time data was segregated into three categories: (1) links in Mecklenburg County, (2) links in Buncombe County, and (3) links in Wake County.

Mecklenburg County comprised of 275 links out of which 206 links were used for modeling and the remaining 69 links were used for validation. Buncombe County comprised of 80 links out of which 60 links were used for modeling and the remaining 20 links were used for validation. Wake County comprised of 146 links out of which 110 links were used for modeling and the remaining 36 links were used for validation.

9.1 Descriptive Statistics by County

The descriptive statistics of the variables used for analysis are presented in Tables 52-56. Table 52 indicates the frequency distribution of the on-network variables, and Tables 53-56 show the descriptive statistics of travel time, on-network and off-network variables segregated based on buffer widths for each county.

Table 52 Frequency distribution of selected on-network variables by county

Variable	Category	Frequency (percentage)		
		Mecklenburg	Buncombe	Wake
Number of through lanes	4	54 (19.64)	73 (91.25)	16 (10.96)
	6	102 (37.09)	5 (6.25)	88 (60.27)
	8	110 (40.00)	2 (2.50)	42 (28.77)
	10	9 (3.27)	-	-
Functional class	Interstates	258 (93.82)	48 (60.00)	117 (80.14)
	Principal Arterials	17 (6.18)	32 (40.00)	29 (19.86)
Speed limit	45	6 (2.18)	2 (2.50)	-
	50	21 (7.64)	5 (6.25)	-
	55	57 (20.73)	16 (20.00)	-
	60	54 (19.64)	47 (58.75)	27 (18.49)
	65	36 (13.09)	10 (12.50)	55 (37.67)
	70	101 (36.73)	-	64 (43.84)

Table 53 Descriptive statistics of on-network and travel time variables by county

	Variable	Minimum	Median	Mean	Maximum	Standard deviation
Mecklenburg	ATTPM	0.89	0.99	1.18	7.99	0.62
	Reference speed	57.00	70.00	69.95	81.00	3.74
	Ln(AADT)	10.17	11.70	11.62	12.12	0.33
Buncombe	ATTPM	0.90	0.99	1.08	2.76	0.24
	Reference speed	55.00	68.00	67.41	72.00	3.22
	Ln(AADT)	10.30	11.02	10.95	11.57	0.32
Wake	ATTPM	0.89	0.94	1.03	5.16	0.33
	Reference speed	70.00	74.00	73.71	77.00	1.92
	Ln(AADT)	10.28	11.56	11.47	12.07	0.35

Note: ATTPM is expressed in minutes per mile, and reference speed is expressed in miles per hour.

Table 54 Descriptive statistics of off-network variables - Mecklenburg County

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00
Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.16	0.29	0.39	0.02	0.04	0.08
College	0.00	0.00	0.00	0.00	0.01	0.09	0.01	0.03	0.09	0.09	0.21	0.41	0.01	0.04	0.08
Government	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.05	0.30	0.01	0.01	0.05
Heavy commercial	0.00	0.00	0.00	0.00	0.01	0.06	0.01	0.03	0.11	0.15	0.27	0.76	0.02	0.06	0.14
Heavy industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.10	0.22	0.53	0.01	0.02	0.07
Institutional	0.00	0.00	0.00	0.00	0.02	0.07	0.01	0.02	0.08	0.15	0.32	0.62	0.01	0.03	0.07
Light commercial	0.00	0.00	0.02	0.03	0.11	0.35	0.05	0.14	0.37	0.40	0.73	1.36	0.06	0.12	0.22
Light industrial	0.00	0.00	0.00	0.03	0.14	0.50	0.08	0.22	0.68	0.71	1.69	4.27	0.12	0.28	0.65
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.08	0.01	0.01	0.02
Multifamily residential	0.00	0.00	0.00	0.02	0.07	0.29	0.03	0.10	0.33	0.20	0.52	1.44	0.04	0.09	0.23
Office	0.00	0.00	0.00	0.00	0.03	0.08	0.02	0.05	0.14	0.13	0.39	0.74	0.03	0.07	0.15
Recreational	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.04	0.12	0.18	0.34	0.02	0.03	0.06
Resource	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.29	0.80	0.01	0.03	0.10
Retail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.09	0.09	0.01	0.01	0.02
Single family residential	0.00	0.00	0.11	0.09	0.36	1.43	0.14	0.45	1.58	0.96	2.29	5.68	0.16	0.37	0.93
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00
Unknown/vacant	0.00	0.00	0.01	0.00	0.02	0.08	0.01	0.03	0.09	0.11	0.24	0.32	0.02	0.03	0.06
Developed area	24.69	36.95	57.00	64.76	70.27	76.47	63.25	69.23	76.00	85.21	85.42	89.41	9.84	8.83	6.07
Population	0.00	0.02	0.69	0.28	0.89	3.34	0.41	1.17	3.89	2.15	4.88	13.82	0.37	0.86	2.28
# of household units	0.00	0.01	0.26	0.11	0.35	1.26	0.16	0.46	1.52	0.83	1.90	5.99	0.15	0.35	0.92
Population density	0.02	0.04	0.01	1.84	1.84	1.78	2.08	2.15	2.03	9.24	7.71	12.86	1.77	1.57	1.53
Employment density	0.16	0.17	0.00	1.79	1.88	1.63	2.51	3.27	2.58	9.83	27.56	35.34	2.09	4.55	3.90

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

Table 55 Descriptive statistics of off-network variables - Buncombe County

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
	0.25	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**	**0.25**	**0.50**	**1.00**
Agriculture	0.00	0.00	0.00	0.00	0.02	0.15	0.03	0.07	0.28	0.43	0.85	2.14	0.07	0.16	0.42
College	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.05	0.12	0.16	0.35	0.02	0.03	0.07
Government	0.00	0.00	0.00	0.01	0.03	0.14	0.03	0.08	0.21	0.21	0.41	0.86	0.04	0.11	0.21
Heavy commercial	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.03	0.09	0.12	0.01	0.02	0.03
Heavy industrial	0.00	0.00	0.02	0.01	0.03	0.07	0.02	0.04	0.08	0.15	0.24	0.30	0.02	0.03	0.05
Institutional	0.00	0.00	0.00	0.01	0.02	0.11	0.01	0.03	0.11	0.09	0.16	0.26	0.02	0.03	0.05
Light commercial	0.00	0.00	0.00	0.03	0.10	0.33	0.04	0.13	0.34	0.20	0.43	0.97	0.04	0.09	0.26
Light industrial	0.00	0.00	0.00	0.00	0.02	0.04	0.01	0.02	0.05	0.09	0.16	0.17	0.02	0.03	0.05
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	0.08	0.08	0.01	0.01	0.02
Multifamily residential	0.00	0.01	0.11	0.03	0.10	0.43	0.05	0.17	0.61	0.75	1.80	4.11	0.11	0.27	0.66
Office	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.02	0.05	0.08	0.09	0.01	0.01	0.02
Recreational	0.00	0.00	0.01	0.00	0.02	0.13	0.02	0.06	0.28	0.25	0.69	1.61	0.04	0.12	0.35
Resource	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.01	0.04	0.00	0.00	0.01
Retail	0.00	0.00	0.00	0.01	0.02	0.06	0.01	0.03	0.06	0.06	0.12	0.14	0.01	0.03	0.04
Single family residential	0.01	0.04	0.62	0.13	0.46	1.69	0.16	0.52	1.75	0.60	1.59	4.24	0.13	0.31	0.65
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00
Unknown/vacant	0.00	0.02	0.06	0.03	0.08	0.26	0.04	0.10	0.31	0.23	0.54	0.90	0.04	0.08	0.18
Developed area	31.22	54.96	62.63	62.53	70.30	73.80	60.43	68.98	75.29	76.75	79.70	93.62	8.36	5.98	6.22
Population	0.08	0.27	1.18	0.52	1.36	4.29	0.69	1.82	5.63	2.65	6.21	15.13	0.60	1.31	3.21
# of household units	0.04	0.13	0.57	0.22	0.58	1.86	0.30	0.79	2.46	1.15	2.66	6.51	0.26	0.55	1.38
Population density	0.14	0.18	0.03	0.86	0.80	1.37	1.03	1.04	1.52	3.48	3.32	5.50	0.79	0.75	1.08
Employment density	0.03	0.03	0.01	0.78	0.71	0.86	1.00	0.94	1.88	4.11	3.65	21.33	0.85	0.77	3.51

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

Table 56 Descriptive statistics of off-network variables - Wake County

Variable	Minimum			Median			Mean			Maximum			Standard deviation		
	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00	0.25	0.50	1.00
Agriculture	0.00	0.00	0.00	0.00	0.01	0.08	0.03	0.08	0.27	0.41	0.83	2.37	0.07	0.16	0.45
College	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.01	0.06	0.07	0.12	0.23	0.01	0.03	0.05
Government	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Heavy commercial	0.00	0.00	0.00	0.00	0.01	0.05	0.01	0.03	0.06	0.10	0.16	0.24	0.02	0.04	0.06
Heavy industrial	0.00	0.00	0.00	0.00	0.01	0.04	0.03	0.09	0.22	0.46	1.06	2.13	0.07	0.19	0.44
Institutional	0.00	0.00	0.00	0.00	0.01	0.08	0.01	0.03	0.08	0.07	0.15	0.29	0.02	0.03	0.06
Light commercial	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.03	0.07	0.11	0.19	0.01	0.02	0.04
Light industrial	0.00	0.00	0.00	0.00	0.02	0.09	0.01	0.04	0.14	0.11	0.21	0.60	0.02	0.06	0.15
Medical	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.05	0.28	0.01	0.01	0.05
Multifamily residential	0.00	0.00	0.00	0.00	0.03	0.15	0.02	0.05	0.19	0.17	0.34	0.83	0.03	0.07	0.16
Office	0.00	0.00	0.00	0.01	0.05	0.19	0.02	0.08	0.23	0.16	0.41	1.23	0.03	0.09	0.22
Recreational	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.02	0.07	0.12	0.22	0.31	0.02	0.04	0.08
Resource	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.05	0.14	0.22	0.38	1.02	0.04	0.09	0.20
Retail	0.00	0.00	0.00	0.00	0.02	0.10	0.01	0.04	0.13	0.18	0.39	0.89	0.02	0.07	0.14
Single family residential	0.00	0.00	0.06	0.07	0.23	0.89	0.10	0.34	1.25	0.64	1.63	4.10	0.12	0.32	0.85
Transportation	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.29	0.47	0.01	0.02	0.07
Unknown/vacant	0.02	0.06	0.37	0.13	0.33	1.01	0.15	0.39	1.10	0.60	1.19	2.50	0.11	0.22	0.44
Developed area	0.44	6.53	13.84	40.72	46.44	56.51	39.99	46.15	52.46	73.52	76.36	72.21	15.42	14.80	14.01
Population	0.00	0.00	0.02	0.31	1.00	3.45	0.40	1.10	3.58	1.39	3.18	7.42	0.32	0.70	1.61
# of household units	0.00	0.00	0.01	0.12	0.38	1.27	0.15	0.42	1.36	0.52	1.18	2.74	0.12	0.26	0.62
Population density	0.00	0.00	0.01	1.22	1.34	1.51	1.40	1.49	1.71	5.09	4.02	6.20	0.99	0.92	1.23
Employment density	0.01	0.01	0.00	0.82	0.90	1.15	1.46	1.40	2.00	8.70	7.44	17.65	1.85	1.57	2.77

Note 1: Land use variables in the table are expressed in square miles (agriculture to unknown/vacant).
Note 2: Developed area is expressed in percentages.
Note 3: Population, and # of household units are expressed in count. The population and employment density are expressed in population per square mile and employees per square mile.

9.2 Model Results for Mecklenburg County

The results from the models developed for dataset comprising of links in Mecklenburg County with variables from 0.25, 0.50 and 1-mile buffer widths separately are presented in this section. Tables 57-59 show the results for models developed using variables from 0.25, 0.50 and 1-mile buffer width datasets. Appendix C (Tables C17-C19) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 57 Developed models for Mecklenburg County (0.25-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.982	0.623	0.115				0.223	0.387	0.564
Time of the day	Morning peak	0.109	0.022	<.0001	0.111	0.022	<.0001	0.074	0.017	<.0001
Time of the day	Afternoon peak	-0.038	0.009	<.0001	-0.036	0.009	<.0001	-0.037	0.007	<.0001
Time of the day	Evening peak	0.377	0.043	<.0001	0.379	0.042	<.0001	0.253	0.027	<.0001
Day of the week	Weekday	0.307	0.025	<.0001	0.308	0.025	<.0001	0.222	0.016	<.0001
Ln(AADT)		0.095	0.047	0.046	0.173	0.012	<.0001	0.055	0.030	0.069
Number of through lanes	4	0.438	0.045	<.0001	0.484	0.047	<.0001	0.328	0.032	<.0001
Number of through lanes	6	0.343	0.050	<.0001	0.369	0.049	<.0001	0.248	0.035	<.0001
Number of through lanes	8	0.177	0.037	<.0001	0.191	0.038	<.0001	0.138	0.027	<.0001
Number of through lanes	10									
Speed limit		-0.024	0.002	<.0001	-0.023	0.002	<.0001	-0.018	0.001	<.0001
Functional class	Interstates									
Reference speed										
Agriculture								-1.211	0.514	0.018
College										
Government								-2.095	0.964	0.030
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial										
Light industrial										
Medical										
Multifamily residential										
Office										
Recreational										
Resource										
Retail										
Single family residential		-0.247	0.088	0.005	-0.206	0.091	0.024	-0.176	0.063	0.005
Transportation		-6.139	2.211	0.006	-6.704	2.227	0.003	-4.856	1.769	0.006
Unknown/Vacant										
Developed area										
Population										
# of household units		0.231	0.092	0.012	0.211	0.095	0.027	0.155	0.065	0.017
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 58 Developed models for Mecklenburg County (0.50-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.948	0.635	0.135				0.315	0.410	0.442
Time of the day	Morning peak	0.109	0.022	<.0001	0.111	0.022	<.0001	0.074	0.017	<.0001
Time of the day	Afternoon peak	-0.038	0.009	<.0001	-0.035	0.009	<.0001	-0.037	0.007	<.0001
Time of the day	Evening peak	0.377	0.043	<.0001	0.379	0.042	<.0001	0.253	0.026	<.0001
Day of the week	Weekday	0.307	0.025	<.0001	0.308	0.025	<.0001	0.221	0.016	<.0001
Ln(AADT)		0.095	0.048	0.050	0.181	0.015	<.0001	0.052	0.031	0.097
Number of through lanes	4	0.420	0.039	<.0001	0.505	0.048	<.0001	0.311	0.027	<.0001
Number of through lanes	6	0.309	0.038	<.0001	0.403	0.044	<.0001	0.257	0.029	<.0001
Number of through lanes	8	0.140	0.028	<.0001	0.187	0.031	<.0001	0.128	0.021	<.0001
Speed limit		-0.022	0.002	<.0001	-0.024	0.003	<.0001	-0.018	0.002	<.0001
Functional class	Interstates									
Reference speed										
Agriculture										
College										
Government										
Heavy commercial					-0.369	0.179	0.039	-0.296	0.123	0.016
Heavy industrial										
Institutional										
Light commercial										
Light industrial										
Medical					-1.805	0.964	0.061			
Multifamily residential		0.223	0.129	0.083						
Office										
Recreational										
Resource										
Retail					1.226	0.681	0.072	0.606	0.419	0.148
Single family residential		-0.069	0.027	0.012	-0.137	0.037	<.0001	-0.110	0.026	<.0001
Transportation										
Unknown/Vacant					0.840	0.249	0.001			
Developed area										
Population										
# of household units					0.120	0.034	0.001	0.086	0.022	<.0001
Population density										
Employment density					-0.009	0.004	0.026	-0.006	0.002	0.013

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 59 Developed models for Mecklenburg County (1-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		1.304	0.625	0.037				0.171	0.396	0.666
Time of the day	Morning peak	0.109	0.022	<.0001	0.110	0.022	<.0001	0.074	0.017	<.0001
Time of the day	Afternoon peak	-0.038	0.009	<.0001	-0.036	0.009	<.0001	-0.036	0.007	<.0001
Time of the day	Evening peak	0.377	0.043	<.0001	0.379	0.042	<.0001	0.254	0.027	<.0001
Day of the week	Weekday	0.307	0.025	<.0001	0.308	0.025	<.0001	0.222	0.016	<.0001
Ln(AADT)		0.057	0.047	0.226	0.177	0.013	<.0001	0.055	0.031	0.075
Number of through lanes	4	0.394	0.044	<.0001	0.444	0.042	<.0001	0.295	0.028	<.0001
Number of through lanes	6	0.277	0.032	<.0001	0.335	0.036	<.0001	0.202	0.021	<.0001
Number of through lanes	8	0.132	0.027	<.0001	0.154	0.027	<.0001	0.091	0.015	<.0001
Speed limit		-0.021	0.003	<.0001	-0.023	0.002	<.0001	-0.016	0.002	<.0001
Functional class	Interstates									
Reference speed										
Agriculture		-0.319	0.154	0.039				-0.278	0.108	0.010
College										
Government										
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial					-0.141	0.076	0.064			
Light industrial										
Medical										
Multifamily residential										
Office		0.239	0.136	0.079						
Recreational										
Resource										
Retail										
Single family residential		-0.023	0.012	0.056	-0.037	0.014	0.007	-0.023	0.008	0.004
Transportation										
Unknown/Vacant					0.356	0.176	0.042			
Developed area										
Population										
# of household units					0.052	0.017	0.003			
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

The variables like the time of the day, day of the week and other network characteristics like AADT, speed limit and number of through lanes are statistically significant at a 90% confidence level in all the models (linear and gamma log link). The coefficients of time of the day, day of the week, speed limit, AADT and number of through lanes are consistent. The results indicate that the ATTPM of truck for weekday is higher than on a weekend (when all other variables are held constant). Similarly, the truck ATTPM values are higher for the evening peak, followed by the morning peak and the afternoon peak (when all other variables are held constant). The results also indicate that an increase in AADT results in an increase in the truck ATTPM (when all other variables are held constant). The speed limit of the link has a decreasing effect on the truck ATTPM i.e., an increase in the speed limit results in a decrease in the truck ATTPM. Both, linear and gamma log link models have an increasing effect on ATTPM.

The models developed using variables from 0.25-mile buffer width dataset indicate that agriculture, single family residential, transportation, and government land uses have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with single family residential, transportation, and government land uses have a decreasing influence on the truck ATTPM. The model results also indicate that the number of household units have an increasing influence on the truck ATTPM.

The models developed using variables from 0.50-mile buffer width dataset indicate that multifamily residential, retail, heavy commercial, medical, and single family residential land uses, employment density and number of household units have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with multifamily residential, and retail land uses have an increasing influence on the truck ATTPM. Contrarily, the areas with heavy commercial, medical, and single family residential land uses have a decreasing influence on the truck ATTPM. The number of household units has an increasing influence on the truck ATTPM while the employment density has a decreasing influence on the ATTPM.

The model results from 1-mile buffer width dataset indicate agriculture, light commercial, single family residential, and office land uses, and number of household units have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with agriculture, light commercial, and single family residential land uses have an increasing influence on the truck ATTPM while the areas with office land use have a decreasing influence on the truck ATTPM. The number of household units has an increasing influence on the truck ATTPM.

9.3 Model Results for Buncombe County

The results from the models developed for dataset comprising of links in Buncombe County with variables from 0.25, 0.50 and 1-mile buffer widths separately are presented in this section. Tables 60-62 show the results for models developed using variables from 0.25, 0.50 and 1-mile buffer widths. Appendix C (Tables C20-C22) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 60 Developed models for Buncombe County (0.25-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		0.965	0.744	0.194				-0.329	0.686	0.631
Time of the day	Morning peak	0.041	0.013	0.001	0.041	0.012	0.001	0.032	0.010	0.002
Time of the day	Afternoon peak	0.030	0.015	0.039	0.031	0.014	0.030	0.025	0.013	0.058
Time of the day	Evening peak	0.094	0.019	<.0001	0.094	0.019	<.0001	0.073	0.013	<.0001
Day of the week	Weekday	0.060	0.014	<.0001	0.060	0.014	<.0001	0.046	0.010	<.0001
Ln(AADT)		0.100	0.056	0.076	0.185	0.028	<.0001	0.135	0.051	0.008
Number of through lanes	4									
Number of through lanes	6									
Number of through lanes	8									
Speed limit		-0.019	0.006	0.001	-0.018	0.005	<.0001	-0.019	0.005	<.0001
Functional class	Interstates									
Reference speed										
Agriculture										
College		1.717	0.503	0.001	1.345	0.458	0.003	1.648	0.456	<.0001
Government										
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial										
Light industrial		-2.698	0.640	<.0001	-2.318	0.491	<.0001	-1.625	0.594	0.006
Medical										
Multifamily residential										
Office		-5.381	1.495	<.0001				-3.298	1.308	0.012
Recreational										
Resource		20.237	5.986	0.001	13.925	6.124	0.023	18.498	4.542	<.0001
Retail		2.590	0.906	0.004	3.103	0.906	0.001			
Single family residential										
Transportation										
Unknown/Vacant										
Developed area										
Population					0.461	0.164	0.005			
# of household units					-1.101	0.378	0.004			
Population density										
Employment density		0.058	0.027	0.032	0.052	0.036	0.148			

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 61 Developed models for Buncombe County (0.50-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		1.298	0.560	0.021				0.263	0.463	0.570
Time of the day	Morning peak	0.041	0.013	0.001	0.041	0.013	0.001	0.031	0.010	0.002
Time of the day	Afternoon peak	0.030	0.015	0.039	0.031	0.014	0.032	0.024	0.013	0.060
Time of the day	Evening peak	0.094	0.019	<.0001	0.094	0.019	<.0001	0.071	0.013	<.0001
Day of the week	Weekday	0.060	0.014	<.0001	0.060	0.014	<.0001	0.046	0.009	<.0001
Ln(AADT)		0.084	0.039	0.031	0.130	0.016	<.0001	0.024	0.029	0.404
Number of through lanes	4									
Number of through lanes	6									
Number of through lanes	8									
Number of through lanes	10									
Speed limit		-0.021	0.004	<.0001	-0.006	0.004	0.165	-0.008	0.003	0.012
Functional class	Interstates									
Reference speed										
Agriculture					-0.321	0.166	0.053			
College		1.473	0.370	<.0001	0.868	0.440	0.049	1.037	0.262	<.0001
Government		0.184	0.075	0.013	0.201	0.047	<.0001	0.300	0.062	<.0001
Heavy commercial										
Heavy industrial		-1.204	0.279	<.0001	-1.199	0.300	<.0001	-0.940	0.229	<.0001
Institutional										
Light commercial								0.246	0.112	0.028
Light industrial								-1.144	0.373	0.002
Medical		8.895	1.432	<.0001				6.903	1.096	<.0001
Multifamily residential										
Office										
Recreational										
Resource		19.046	4.491	<.0001	16.544	4.121	<.0001	12.332	2.356	<.0001
Retail		2.558	0.508	<.0001	3.560	0.736	<.0001	2.597	0.468	<.0001
Single family residential										
Transportation										
Unknown/Vacant										
Developed area					-0.003	0.002	0.048	-0.002	0.001	0.034
Population					0.271	0.086	0.002			
# of household units		-0.067	0.017	<.0001	-0.670	0.198	0.001	-0.042	0.011	<.0001
Population density					0.071	0.013	<.0001	0.073	0.011	<.0001
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 62 Developed models for Buncombe County (1-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		1.009	0.812	0.214				-0.864	0.500	0.084
Time of the day	Morning peak	0.041	0.013	0.001	0.040	0.012	0.001	0.031	0.010	0.002
Time of the day	Afternoon peak	0.030	0.015	0.039	0.030	0.014	0.036	0.024	0.013	0.065
Time of the day	Evening peak	0.094	0.019	<.0001	0.094	0.019	<.0001	0.071	0.013	<.0001
Day of the week	Weekday	0.060	0.014	<.0001	0.060	0.014	<.0001	0.046	0.010	<.0001
Ln(AADT)		0.115	0.063	0.068	0.137	0.015	<.0001	0.121	0.039	0.002
Number of through lanes	4									
Number of through lanes	6									
Number of through lanes	8									
Speed limit		-0.023	0.004	<.0001	-0.009	0.003	0.002	-0.008	0.003	0.001
Functional class	Interstates									
Reference speed										
Agriculture										
College					1.072	0.297	0.000	1.035	0.277	0.000
Government					0.173	0.062	0.005	0.203	0.050	<.0001
Heavy commercial										
Heavy industrial					-1.419	0.357	<.0001	-1.252	0.334	0.000
Institutional										
Light commercial								-0.745	0.348	0.032
Light industrial		-1.041	0.326	0.001	-0.708	0.354	0.045			
Medical		1.204	0.732	0.100	3.546	0.672	<.0001	3.537	0.623	<.0001
Multifamily residential										
Office					-3.343	1.122	0.003	-3.277	0.879	0.000
Recreational								8.108	1.531	<.0001
Resource		8.661	1.406	<.0001	5.518	2.356	0.019	2.097	0.281	<.0001
Retail					2.359	0.338	<.0001			
Single family residential		0.059	0.030	0.049	0.059	0.025	0.018	0.051	0.023	0.025
Transportation					19.091	7.750	0.014			
Unknown/Vacant										
Developed area										
Population		-0.031	0.039	0.423	-0.033	0.007	<.0001	-0.029	0.007	<.0001
# of household units		0.065	0.085	0.447						
Population density								0.018	0.008	0.029
Employment density								-0.005	0.002	0.043

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

The variables like the time of the day, day of the week and other network characteristics like AADT, speed limit and number of through lanes are statistically significant at a 90% confidence level in all the models (for both linear and gamma log link). The coefficients of time of the day, day of the week, speed limit, AADT and number of through lanes are consistent. The results indicate that the ATTPM of truck for weekday is marginally higher than on a weekend (when all other variables are held constant). Similarly, the truck ATTPM values are slightly higher for the evening peak, followed by the morning peak and the afternoon peak (when all other variables are held constant). The results also indicate that an increase in AADT results in an increase in the truck ATTPM (when all other variables are held constant). The speed limit of the link has a decreasing influence on the truck ATTPM. An increase in the speed limit results in a decrease in the truck ATTPM. The model results for both linear and gamma log link indicate a mix of positive and negative values (depending on the model developed). While positive intercepts were observed in the case of linear models, negative intercepts were observed in the case of gamma log link models for 0.25- and 1-mile buffer width datasets.

The models developed using variables from 0.25-mile buffer width dataset indicate that college, retail, light industrial, and office land uses, population, number of household units, and employment density have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with light industrial and office land uses have a decreasing influence on the truck ATTPM whereas college and retail land uses have an increasing influence on the truck ATTPM. The model results also indicate that the number of household units have a decreasing influence on the truck ATTPM whereas population and employment density have an increasing influence on the truck ATTPM.

The models developed using variables from 0.50-mile buffer width dataset indicate that medical, resource, retail, light commercial, agriculture, heavy industrial, and light industrial land uses, population, population density, percent of the developed area, and number of household units have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with medical, resource, retail, and light commercial land uses have an increasing influence on the truck ATTPM. Contrarily, the areas with heavy industrial, light industrial, and agriculture land uses have a decreasing influence on the truck ATTPM. The population density and population have an increasing influence on the truck ATTPM while the number of household units and percent of the developed area have a decreasing influence on the truck ATTPM.

The model results from 1-mile buffer width dataset indicate college, government, medical, resource, single family residential, light industrial, office, and light commercial land uses, number of household units, population density, population, and employment density have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with college, government, medical, resource, and single family residential land uses have an increasing influence on the truck ATTPM, while the areas with light industrial, office and light commercial land uses have a decreasing influence on the truck ATTPM. The number of household units and population density have an increasing influence on the truck ATTPM, while population and employment density have a decreasing influence on the truck ATTPM.

9.4 Model Results for Wake County

The results from the models developed for dataset comprising of links in Wake County with variables from 0.25, 0.50 and 1-mile buffer widths separately are presented in this section. Tables 63-65 show the results for models developed using variables from 0.25, 0.50 and 1-mile buffer width datasets. Appendix C (Tables C23-C25) summarizes the variables which are significant in the models with all the variables and based on the backward elimination (linear and gamma log link models).

Table 63 Model Results for Wake County (0.25-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-0.639	0.545	0.241				-1.323	0.444	0.003
Time of the day	Morning peak	0.149	0.022	<.0001	0.148	0.022	<.0001	0.132	0.019	<.0001
Time of the day	Afternoon peak	-0.002	0.002	0.518	-0.002	0.002	0.360	-0.002	0.003	0.440
Time of the day	Evening peak	0.200	0.034	<.0001	0.200	0.034	<.0001	0.173	0.027	<.0001
Day of the week	Weekday	0.172	0.019	<.0001	0.171	0.019	<.0001	0.150	0.015	<.0001
Ln(AADT)		0.130	0.029	<.0001	0.098	0.010	<.0001	0.109	0.024	<.0001
Number of through lanes	4									
Number of through lanes	6									
Number of through lanes	8									
Speed limit		0.000	0.004	0.982	-0.004	0.002	0.016	-0.001	0.003	0.797
Functional class	Interstates									
Reference speed										
Agriculture		-0.156	0.089	0.079				-0.142	0.077	0.066
College		-1.184	0.593	0.046	-1.110	0.582	0.056	-1.000	0.477	0.036
Government										
Heavy commercial										
Heavy industrial										
Institutional										
Light commercial										
Light industrial										
Medical										
Multifamily residential										
Office										
Recreational										
Resource		-0.488	0.159	0.002	-0.454	0.148	0.002	-0.425	0.131	0.001
Retail		1.595	0.455	0.001	1.554	0.457	0.001	1.294	0.340	<.0001
Single family residential										
Transportation										
Unknown/Vacant										
Developed area										
Population										
# of household units										
Population density										
Employment density										

Note:
The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 64 Model Results for Wake County (0.50-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-0.107	0.513	0.836				-0.889	0.419	0.034
Time of the day	Morning peak	0.149	0.022	<.0001	0.149	0.022	<.0001	0.131	0.019	<.0001
Time of the day	Afternoon peak	-0.002	0.002	0.518	-0.002	0.002	0.509	-0.002	0.002	0.375
Time of the day	Evening peak	0.200	0.034	<.0001	0.200	0.034	<.0001	0.171	0.026	<.0001
Day of the week	Weekday	0.172	0.019	<.0001	0.172	0.019	<.0001	0.148	0.015	<.0001
Ln(AADT)		0.112	0.031	<.0001	0.106	0.012	<.0001	0.096	0.026	<.0001
Number of through lanes	4									
Number of through lanes	6									
Number of through lanes	8									
Speed limit		-0.004	0.003	0.206	-0.005	0.002	0.009	-0.005	0.003	0.087
Functional class	Interstates									
Reference speed										
Agriculture										
College										
Government										
Heavy commercial		1.074	0.356	0.003	1.080	0.363	0.003	0.889	0.282	0.002
Heavy industrial		-0.077	0.035	0.030	-0.073	0.032	0.024	-0.068	0.030	0.022
Institutional		0.669	0.376	0.076	0.661	0.366	0.071	0.530	0.293	0.071
Light commercial		-0.758	0.359	0.035	-0.779	0.374	0.037	-0.628	0.296	0.034
Light industrial										
Medical										
Multifamily residential										
Office										
Recreational										
Resource										
Retail										
Single family residential		-0.077	0.043	0.070	-0.076	0.039	0.053	-0.064	0.033	0.056
Transportation										
Unknown/Vacant		-0.124	0.041	0.003	-0.127	0.044	0.004	-0.105	0.035	0.003
Developed area										
Population		-0.218	0.077	0.005	-0.218	0.078	0.005	-0.177	0.061	0.004
# of household units		0.741	0.229	0.001	0.743	0.234	0.002	0.608	0.176	0.001
Population density		-0.051	0.017	0.003	-0.051	0.017	0.004	-0.043	0.014	0.002
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table 65 Model Results for Wake County (1-mile buffer width dataset)

Variable		Linear model (with intercept)			Linear model (without intercept)			Gamma log link		
		Coefficient	Standard error	P-value	Coefficient	Standard error	P-value	Coefficient	Standard error	P-value
Intercept		-0.139	0.454	0.760				-0.914	0.372	0.014
Time of the day	Morning peak	0.149	0.022	<.0001	0.149	0.022	<.0001	0.131	0.019	<.0001
Time of the day	Afternoon peak	-0.002	0.002	0.518	-0.002	0.002	0.491	-0.002	0.003	0.412
Time of the day	Evening peak	0.200	0.034	<.0001	0.200	0.034	<.0001	0.172	0.026	<.0001
Day of the week	Weekday	0.172	0.019	<.0001	0.172	0.019	<.0001	0.149	0.015	<.0001
Ln(AADT)		0.101	0.027	<0.001	0.093	0.012	<.0001	0.087	0.022	<.0001
Number of through lanes	4									
Number of through lanes	6									
Number of through lanes	8									
Speed limit		-0.003	0.003	0.428	-0.003	0.002	0.079	-0.003	0.003	0.215
Functional class	Interstates									
Reference speed										
Agriculture										
College										
Government										
Heavy commercial		0.493	0.217	0.023	0.493	0.218	0.023	0.406	0.172	0.019
Heavy industrial										
Institutional										
Light commercial		-0.739	0.334	0.027	-0.751	0.350	0.032	-0.599	0.259	0.021
Light industrial										
Medical		-0.333	0.140	0.017	-0.328	0.135	0.015	-0.282	0.120	0.019
Multifamily residential										
Office										
Recreational										
Resource										
Retail										
Single family residential										
Transportation		-0.284	0.092	0.002	-0.283	0.092	0.002	-0.243	0.076	0.001
Unknown/Vacant										
Developed area										
Population		-0.113	0.037	0.002	-0.114	0.038	0.002	-0.092	0.027	0.001
# of household units		0.302	0.098	0.002	0.305	0.100	0.002	0.246	0.072	0.001
Population density										
Employment density										

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

The variables like the time of the day, day of the week and other network characteristics like AADT, speed limit and number of through lanes are statistically significant at a 90% confidence level in all the models (for both linear and gamma log link). The coefficients of time of the day, day of the week, speed limit, AADT and number of through lanes are consistent. The results indicate that the ATTPM of truck for weekday is higher than on a weekend (when all other variables are held constant). Similarly, the truck ATTPM values are higher for the evening peak, followed by the morning peak and the afternoon peak (when all other variables are held constant). The results also indicate that an increase in AADT results in an increase in the truck ATTPM (when all other variables are held constant). The speed limit of the link has a decreasing influence on the truck ATTPM i.e., an increase in the speed limit results in a decrease in the truck ATTPM. Both, linear and gamma log link models have negative intercepts. In the case of linear models, negative intercepts indicates that the truck ATTPM is negative (when all the variables are zero), which is not feasible/practical in the real-world scenario. In the case of gamma log link, a negative intercept of -0.914 indicates a truck ATTPM of $e^{-0.914}$ i.e., 0.40 minute per mile.

The models developed using variables from 0.25-mile buffer width dataset indicate that resource, agriculture, college and retail land uses have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with agriculture, college, and resource land uses have a decreasing influence on the truck ATTPM whereas retail land use has an increasing influence on the truck ATTPM.

The models developed using variables from 0.50-mile buffer width dataset indicate that heavy commercial, institutional, heavy industrial, light commercial, and single family residential land uses, population, population density, and number of household units have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with heavy commercial and institutional land uses have an increasing influence on the truck ATTPM. Contrarily, the areas with heavy industrial, light commercial, and single family residential land uses have a decreasing influence on the truck ATTPM. The population density and population have a decreasing influence on truck ATTPM while the number of household units have an increasing influence on the truck ATTPM.

The model results from 1-mile buffer width dataset indicate heavy commercial, light commercial, medical, and transportation land uses, number of household units, and population have a significant (at a 90% confidence level) influence on the truck ATTPM. The areas with heavy commercial land use have an increasing influence on the truck ATTPM, while the areas with light commercial, medical, and transportation land uses have a decreasing influence on the truck ATTPM. The number of household units have an increasing influence on the truck ATTPM while population has a decreasing influence on the truck ATTPM.

9.5 Goodness of Fit and Validation Results

The QIC and QICC values for models developed by segregating the data based on county resulted in an improvement compared to the models using all the data (Chapter 7). Table 66 summarizes the goodness of fit statistics from the county-level models for varying buffer widths.

Table 66 Goodness of fit statistics for county-level models

			Linear model (with intercept)		Linear model (without intercept)		Gamma log linear	
			All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Mecklenburg	0.25-mile	QIC	1665.98	1656.15	1667.29	1655.07	36205.67	35560.28
		QICC	1682.00	1661.00	1681.00	1660.00	36221.31	35567.90
	0.50-mile	QIC	1668.23	1657.57	1670.19	1655.72	36769.57	35815.37
		QICC	1682.00	1660.00	1681.00	1664.00	36782.43	35821.53
	1-mile	QIC	1672.35	1659.90	1672.16	1657.38	36324.84	35438.90
		QICC	1682.00	1661.00	1681.00	1661.00	36331.54	35442.26
Buncombe	0.25-mile	QIC	510.13	510.61	521.09	513.32	83513.48	60420.21
		QICC	512.00	493.00	511.00	493.00	83508.25	60406.26
	0.50-mile	QIC	504.91	500.02	513.10	501.60	86041.18	85581.82
		QICC	513.00	494.00	512.00	496.00	86043.74	85575.46
	1-mile	QIC	508.45	513.92	511.78	507.28	83276.70	79766.94
		QICC	513.00	493.00	512.00	497.00	83273.40	79750.03
Wake	0.25-mile	QIC	884.97	883.69	884.81	883.98	27710.22	27036.91
		QICC	912.00	891.00	911.00	889.00	27737.67	27044.47
	0.50-mile	QIC	885.04	886.31	885.13	886.52	29378.55	28308.02
		QICC	912.00	896.00	911.00	895.00	29406.10	28317.62
	1-mile	QIC	885.18	887.05	885.24	887.22	29725.36	28681.71
		QICC	912.00	893.00	911.00	892.00	29752.66	28687.88

The linear models performed better in a majority of cases. The QIC and QICC values of linear models in Mecklenburg County are the highest of the three, followed by Wake County and Buncombe County. However, the gamma log link models for Buncombe County resulted in an increase in QIC and QICC values compared to all other models.

Using backward elimination for linear and gamma log link models resulted in a significant improvement in terms of both the magnitude of the QIC and QICC and also their difference. As the buffer width increased, the QIC and QICC values increased marginally. This implies that 0.25-mile dataset models performed better. However, models for Buncombe County are an exception as the value of QIC and QICC increased significantly for 0.50-mile dataset model than 0.25-mile and 1-mile buffer width dataset models.

Table 67 summarizes validation results of the county-level models for varying buffer widths.

The model validation results indicate similar trends in all the models for Mecklenburg and Wake County irrespective of the buffer width. However, in the case of Buncombe County, the results from 0.50-mile buffer width dataset show a significant increase in MPE compared to 0.25-mile buffer width dataset model. Similarly, the MPE values are higher for 1-mile buffer width dataset model than for the 0.25-mile buffer width dataset model.

Based on the model validation results, it can be observed that 0.25-mile would be appropriate to capture the truck travel characteristics, mainly due to their model accuracy and goodness of fit.

The results for both linear and gamma log link models showed better accuracy for 0.25-mile buffer width dataset-based model. However, the negative coefficients in the linear model for Wake County suggest implementation of either no-intercept linear models or gamma log link models for travel time estimation.

The MPE, MAPE, and RMSE values of 0.25-mile buffer width dataset-based models suggest that gamma log link performs better in terms of model accuracy than the linear model without intercept.

Table 67 Model validation results for county-level models

			Linear model		Gamma log link
			With intercept	Without intercept	
Mecklenburg	0.25-mile	MPE (%)	-4.35	4.00	-4.12
		MAPE (%)	13.94	12.58	10.72
		RMSE (minutes/mile)	0.65	0.70	0.65
	0.50-mile	MPE (%)	-4.26	-3.65	-4.48
		MAPE (%)	14.03	13.56	10.00
		RMSE (minutes/mile)	0.65	0.65	0.64
	1-mile	MPE (%)	-4.37	-3.54	-4.28
		MAPE (%)	14.30	13.76	10.80
		RMSE (minutes/mile)	0.65	0.65	0.64
Buncombe	0.25-mile	MPE (%)	0.26	0.33	2.50
		MAPE (%)	5.95	6.76	4.31
		RMSE (minutes/mile)	0.18	0.16	0.16
	0.50-mile	MPE (%)	-12.81	-3.63	-16.70
		MAPE (%)	6.90	5.72	7.92
		RMSE (minutes/mile)	0.31	0.17	0.37
	1-mile	MPE (%)	15.51	-8.77	-5.86
		MAPE (%)	12.52	6.97	5.66
		RMSE (minutes/mile)	0.24	0.22	0.19
Wake	0.25-mile	MPE (%)	-4.40	-3.92	-3.98
		MAPE (%)	9.45	9.60	8.24
		RMSE (minutes/mile)	0.27	0.27	0.26
	0.50-mile	MPE (%)	-2.74	-6.51	-2.69
		MAPE (%)	9.37	9.05	8.48
		RMSE (minutes/mile)	0.27	0.29	0.27
	1-mile	MPE (%)	3.07	-1.81	-2.24
		MAPE (%)	8.03	8.07	7.67
		RMSE (minutes/mile)	0.28	0.27	0.26

9.6 Discussion on Travel Time Estimation Models by County

The goodness of fit statistics and model validation results suggest the application of 0.25-mile buffer to capture potential off-network characteristics, and use them for truck ATTPM estimation.

The model results from county-level models indicate potential variation in the characteristics of county and influence of each land use. For example, in the case of Buncombe County, the number of household units was found to have a decreasing influence on the truck ATTPM, whereas the same variable – number of household units has an increasing influence on the truck ATTPM in both Wake and Mecklenburg Counties.

CHAPTER 10: CONCLUSIONS

Freight trucks are susceptible to traffic congestion and delays which can increase the transportation costs up to 250%. In the coming years, these delay and congestion patterns are expected to worsen due to the anticipated growth in the freight industry and truck traffic. Hence, a comprehensive traffic operational analysis of the existing network is needed to better understand the ramifications and improve truck travel performance. Also, a clear understanding of the variables which measure truck travel performance and the factors influencing (and to what extent) is needed to recommend potential improvements to the system. Link-level truck travel times were, therefore, considered for the analysis to understand the performance and the potential influence of on-/off-network characteristics.

On-network characteristics that were considered in this research include speed limit, AADT, number of through lanes, reference speed (85^{th} percentile – free flow speed), and data density. Surrounding land use and demographic characteristics were classified as the off-network characteristics.

The on-network characteristics were captured from the link-level information. Buffer analysis was conducted to capture off-network characteristics within 0.25, 0.50 and 1-mile buffer widths. Pearson correlation analysis was performed to study the correlation between various on-network and off-network characteristics with truck travel time performance measures. The results from this investigation are summarized next.

- From the Pearson correlation analysis, ATT, PTI, BTI and TTI were identified as suitable truck travel performance indicators.
- An increase in the value of the selected truck travel time measures (ATT, PTI, BTI and TTI) leads to a deterioration in the operational performance, whereas, a

decrease in the value of travel time measures reflects an improvement.

- Speed limit is inversely related to the travel time, in general. The results exhibited a negative correlation of the speed limit and reference speed with the truck travel time performance measures. Trucks were observed to perform better on roads with higher speed limits (and reference speeds) than on the roads with lower speed limits. These findings compliment the results based on the functional class and number of through lanes. Roads with of 4 or 6 through lanes and principal arterial roads are susceptible to lower operational performance of the freight trucks than the interstate roads and roads with 8 or more through lanes.
- The AADT was positively correlated with majority of the performance measures, indicating an increase in traffic volume results in a deterioration in truck performance.
- Out of all the data density variables, an increase in samples in density condition A is associated with better truck travel time performance measures.
- An increase in the light commercial, light industrial land uses, and percent of developed area results in a deterioration in the truck travel time performance plausibly due to the freight activity and shipments triggered in these areas.
- The residential land uses, the population and the number of household units are positively correlated with the ATT. Contrarily, a negative correlation with PTI, BTI and TTI was observed. The results imply that a deterioration in ATT is expected in areas with high population, and residential land uses. However, the measures reflecting the consistency and reliability (PTI, BTI and TTI) are better in such areas possibly due to no or low freight activity in areas with residential and living

characteristics.

- Overall, the results show that links in urban areas and roads with high traffic volumes or number of through lanes (<=6 lanes) are susceptible to higher truck travel times or lower operational performance.

The identified truck travel time performance measures were used to visualize through geospatial maps and identify truck-chokepoints. The truck travel time estimation models using GEE (linear and gamma log link models) were developed to understand the relationship between ATTPM and the on-network and off-network characteristics. The influence of off-network characteristics was captured using spatial proximity (buffer widths) and spatial weights. The modeling was performed using 75% of the data and the remaining 25% of the data was used for validation. The results from the truck travel time estimation models are summarized next.

- All the model results indicated the significant influence of temporal and on-network characteristics like the time of the day, day of the week, AADT, number of through lanes, and speed limit on the ATTPM. Truck travel times are expected to be higher during evening and morning peak hours, weekdays, and on roads with high AADT values.
- An increase in areas of agriculture, transportation, retail, single family residential, multifamily residential, and resource land uses result in a decrease in truck ATTPM. Contrarily, an increase in areas of light commercial, light industrial, office, and government land uses result in an increase in truck ATTPM, possibly due to the freight activity near these developments.
- Modeling the truck travel time data based on buffer width yielded better results than

spatial weights. Therefore, the buffer-width based datasets were used for developing models by the speed limit and county.

- The results from the speed limit and county-based classification suggest that light industrial, heavy commercial, and office land uses, and employment density have an increasing influence on truck ATTPM. These results align with the previous model and correlation results where the freight trucking activity is expected to play a key role on the roads surrounding these land uses.
- Contrarily, resource, agriculture, and college land uses have a decreasing influence on the ATTPM, which are also areas with no to low freight activity. The model results also indicate that population has a decreasing influence on the ATTPM whereas the number of household units has an increasing influence on the truck travel times, which align with the previously mentioned correlation results.
- Overall, the results from speed limit and county-level modeling indicate that a 0.25-mile buffer width is ideal to capture truck travel parameters. In some of the travel time estimation models, a negative intercept was observed for linear models which may not be applicable to estimate the truck travel times. Contrarily, gamma log link model performed consistently and is recommended for estimating the truck travel times.

The results from the correlation analysis and truck travel time estimation models imply that land uses like commercial, industrial, office, and government in the near vicinity of a link contribute to a deterioration in truck travel time performance, eventually, resulting as a chokepoint. Specifically, truck travel times in the evening or morning peak hours can have delays in shipments, truck loading or scheduling. Countermeasures like offering off-peak hour delivery incentives, providing truck exclusive lanes or signal priority can be implemented to avoid excessive truck demand and better manage traffic conditions (Hartshorn and Lamm, 2012).

10.1 Scope of Future Research

This research is aimed at understanding the travel time performance measures of freight trucks and their association with the surrounding network characteristics using statistical approaches. The links considered in this research accounted for variations in the study area, and travel patterns to understand the effect of trucks. Data filtering step, followed by a detailed cleaning of data resulted in some of the datasets having lower samples (for example, Buncombe County). Considering data for additional links when available or considering links in additional study areas for modeling and truck travel time estimation could improve model predictability. This merits investigation in the future.

The freight trucks are described as larger and heavier vehicles in this research. With increasing demand for freight transportation, unconventional approaches may be used for delivery of goods and services. An analysis by the type of trucks and other vehicles used for transportation of goods as well as an investigation of the effect of policies and technologies for better traffic demand management merit future research.

Statistical modeling approach was used to identify the best possible model to estimate the truck travel times and understand the potential influence of the on-network and off-network characteristics. Plausible spatial models should be explored to estimate the truck travel times and comparing with outputs from the statistical models. Using the spatial models, the local variations may be better accounted for than in the case of statistical models. Additionally, other supervised machine learning approaches could be used to train the models, test, and estimate the truck ATTPM.

The truck ATTPM was used as the dependent variable for modeling with on-network and off-network characteristics as the independent variables. Models could be developed to estimate PT (or 95th percentile travel time) by accounting for recurring and non-recurring congestion affects in the future. The models to estimate truck ATTPM and PT in conjunction with truck free-flow travel times could be used to quantify other truck reliability indices and performance measures. The accuracy of these models to estimate for a particular link, corridor, or network could also be explored in the future.

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APPENDIX A: TRUCK TRAVEL TIME PERFORMANCE AND THEIR ASSOCIATION WITH ON-NETWORK AND OFF-NETWORK CHARACTERISTICS

This appendix summarizes 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 significant at a 95% confidence level are presented (color-coded based on the following categories).

- High positive correlation coefficient: > 0.5
- Moderate positive correlation coefficient: 0.3 to 0.5
- Low positive correlation coefficient: 0 to 0.3
- Low negative correlation coefficient: -0.3 to 0
- Moderate negative correlation coefficient: -0.5 to -0.3
- High negative 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 datasets (weekday and weekend). Tables A3 and A4 summarize Pearson correlation coefficient results of the afternoon peak datasets (weekday and weekend). Tables A5 and A6 summarize the Pearson correlation coefficient results of the evening peak datasets (weekday and weekend). Tables A7 and A8 summarize the Pearson correlation coefficient results of the night-time datasets (weekday and weekend).

Tables A9 summarizes the Pearson correlation coefficient results for the selected truck travel time performance measures with on-network characteristics. Tables A10-A12 summarize the Pearson correlation coefficient results for the selected truck travel time performance measures with land use characteristics (for 0.25-mile, 0.50-mile and 1-mile buffers). Table A13 summarizes the Pearson correlation coefficient results for the selected truck travel time performance measures with demographic characteristics.

Table A1 Pearson correlation coefficients between truck travel time performance measures (morning peak, weekday)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.68																			
ATT	0.87	0.84																		
Var	0.43	0.75	0.70																	
Std	0.56	0.94	0.84	0.83																
TT5	0.99	0.68	0.88	0.44	0.57															
TT10	0.99	0.70	0.90	0.46	0.59	1.00														
TT15	0.98	0.72	0.92	0.49	0.62	0.99	1.00													
TT25	0.96	0.73	0.95	0.53	0.66	0.97	0.98	0.99												
TT50	0.90	0.76	0.98	0.59	0.73	0.91	0.93	0.96	0.98											
TT75	0.81	0.82	0.99	0.73	0.85	0.82	0.84	0.87	0.90	0.96										
TT85	0.75	0.83	0.97	0.76	0.89	0.76	0.79	0.82	0.85	0.92	0.99									
TT90	0.72	0.84	0.96	0.79	0.91	0.73	0.76	0.79	0.82	0.89	0.98	1.00								
TT95	0.69	0.87	0.94	0.80	0.95	0.70	0.72	0.76	0.79	0.86	0.96	0.98	0.99							
PT	0.69	0.87	0.94	0.80	0.95	0.70	0.72	0.76	0.79	0.86	0.96	0.98	0.99	1.00						
BT	0.48	0.81	0.81	0.82	0.95	0.49	0.51	0.55	0.59	0.68	0.84	0.90	0.93	0.96	0.96					
BTI		0.37	0.27	0.21	0.50				0.09	0.17	0.30	0.37	0.41	0.47	0.47	0.59				
PTI		0.36	0.35	0.25	0.51			0.11	0.16	0.27	0.40	0.46	0.47	0.51	0.51	0.60	0.84			
TTI		0.31	0.35	0.22	0.45			0.13	0.19	0.31	0.40	0.44	0.44	0.46	0.46	0.50	0.63	0.94		
λ^{Skew}		0.29	0.16	0.18	0.37						0.16	0.25	0.29	0.33	0.33	0.44	0.67	0.41	0.20	
λ^{Var}		0.37	0.32	0.26	0.53				0.12	0.20	0.37	0.45	0.49	0.52	0.52	0.63	0.89	0.86	0.68	0.70

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A2 Pearson correlation coefficients between truck travel time performance measures (morning peak, weekend)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.55																			
ATT	0.99	0.59																		
Var	0.16	0.66	0.21																	
Std	0.37	0.87	0.42	0.90																
TT5	0.99	0.57	1.00	0.16	0.38															
TT10	0.99	0.57	1.00	0.16	0.38	1.00														
TT15	0.99	0.57	1.00	0.17	0.38	1.00	1.00													
TT25	0.99	0.57	1.00	0.17	0.38	1.00	1.00	1.00												
TT50	0.99	0.57	1.00	0.17	0.38	1.00	1.00	1.00	1.00											
TT75	0.99	0.57	1.00	0.17	0.39	1.00	1.00	1.00	1.00	1.00										
TT85	0.99	0.57	1.00	0.18	0.39	1.00	1.00	1.00	1.00	1.00	1.00									
TT90	0.99	0.58	1.00	0.18	0.40	1.00	1.00	1.00	1.00	1.00	1.00	1.00								
TT95	0.99	0.59	1.00	0.22	0.44	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00							
PT	0.99	0.59	1.00	0.22	0.44	0.99	0.99	0.99	0.99	0.99	1.00	1.00	1.00	1.00						
BT	0.74	0.44	0.76	0.29	0.46	0.74	0.74	0.74	0.74	0.75	0.76	0.77	0.78	0.81	0.81					
BTI	-0.16	-0.11	-0.15			-0.17	-0.17	-0.17	-0.17	-0.16	-0.15	-0.14	-0.12	-0.09	-0.09	0.35				
PTI	-0.15		-0.13	0.23	0.22	-0.16	-0.16	-0.16	-0.15	-0.15	-0.14	-0.12	-0.11			0.36	0.95			
TTI	-0.12	0.17	-0.09	0.45	0.46	-0.13	-0.13	-0.13	-0.13	-0.12	-0.11	-0.10	-0.09			0.30	0.67	0.87		
λ^{Skew}	-0.10		-0.09			-0.10	-0.10	-0.10	-0.10	-0.11	-0.09					0.24	0.57	0.49	0.30	
λ^{Var}	-0.17		-0.15			-0.17	-0.17	-0.17	-0.17	-0.16	-0.15	-0.13	-0.12	-0.10	-0.10	0.28	0.92	0.89	0.68	0.57

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A3 Pearson correlation coefficients between truck travel time performance measures (afternoon, weekday)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.57																			
ATT	0.99	0.64																		
Var	0.38	0.86	0.47																	
Std	0.51	0.96	0.58	0.88																
TT5	0.99	0.60	1.00	0.42	0.54															
TT10	0.99	0.60	1.00	0.43	0.54	1.00														
TT15	0.99	0.60	1.00	0.43	0.54	1.00	1.00													
TT25	0.99	0.60	1.00	0.43	0.54	1.00	1.00	1.00												
TT50	0.99	0.61	1.00	0.43	0.54	1.00	1.00	1.00	1.00											
TT75	0.99	0.61	1.00	0.44	0.56	1.00	1.00	1.00	1.00	1.00										
TT85	0.99	0.62	1.00	0.45	0.57	0.99	1.00	1.00	1.00	1.00	1.00									
TT90	0.98	0.63	1.00	0.47	0.59	0.99	0.99	0.99	0.99	0.99	1.00	1.00								
TT95	0.96	0.65	0.98	0.50	0.63	0.97	0.97	0.97	0.97	0.97	0.98	0.99	0.99							
PT	0.96	0.65	0.98	0.50	0.63	0.97	0.97	0.97	0.97	0.97	0.98	0.99	0.99	1.00						
BT	0.48	0.47	0.54	0.42	0.57	0.49	0.50	0.50	0.50	0.50	0.53	0.56	0.60	0.69	0.69					
BTI		0.11		0.11	0.23									0.13	0.13	0.64				
PTI	-0.09	0.13		0.13	0.25	-0.09	-0.09									0.55	0.96			
TTI	-0.14	0.20	-0.09	0.17	0.31	-0.14	-0.13	-0.13	-0.13	-0.12	-0.10					0.38	0.78	0.91		
λ^{Skew}		0.15	0.09	0.11	0.25							0.13	0.16	0.21	0.21	0.58	0.63	0.55	0.41	
λ^{Var}	-0.11			0.09	0.19	-0.10	-0.10	-0.10	-0.10							0.49	0.87	0.92	0.86	0.67

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A4 Pearson correlation coefficients between truck travel time performance measures (afternoon, weekend)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.63																			
ATT	0.98	0.71																		
Var	0.40	0.75	0.49																	
Std	0.54	0.94	0.65	0.85																
TT5	0.99	0.63	0.99	0.39	0.54															
TT10	0.99	0.63	0.99	0.39	0.54	1.00														
TT15	0.99	0.63	0.99	0.39	0.54	1.00	1.00													
TT25	0.99	0.63	0.99	0.39	0.54	1.00	1.00	1.00												
TT50	0.99	0.64	0.99	0.40	0.55	1.00	1.00	1.00	1.00											
TT75	0.98	0.67	1.00	0.45	0.61	0.99	0.99	0.99	0.99	0.99										
TT85	0.96	0.72	0.99	0.53	0.67	0.96	0.96	0.96	0.96	0.97	0.99									
TT90	0.93	0.74	0.97	0.58	0.72	0.93	0.93	0.93	0.93	0.94	0.97	0.99								
TT95	0.85	0.78	0.92	0.70	0.81	0.86	0.86	0.86	0.86	0.87	0.91	0.94	0.97							
PT	0.85	0.78	0.92	0.70	0.81	0.86	0.86	0.86	0.86	0.87	0.91	0.94	0.97	1.00						
BT	0.42	0.66	0.55	0.80	0.82	0.43	0.43	0.43	0.43	0.44	0.52	0.61	0.70	0.83	0.83					
BTI		0.34	0.17	0.41	0.52						0.15	0.23	0.32	0.46	0.46	0.74				
PTI		0.36	0.16	0.41	0.54						0.16	0.25	0.34	0.45	0.45	0.73	0.96			
TTI		0.37	0.11	0.36	0.53						0.11	0.19	0.26	0.34	0.34	0.57	0.81	0.92		
λ^{Skew}	0.11	0.39	0.21	0.39	0.51	0.11	0.11	0.11	0.11	0.11	0.20	0.29	0.36	0.44	0.44	0.65	0.80	0.80	0.68	
λ^{Var}		0.32	0.15	0.37	0.48						0.16	0.25	0.34	0.41	0.41	0.67	0.84	0.94	0.88	0.84

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A5 Pearson correlation coefficients between truck travel time performance measures (evening peak, weekday)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.67																			
ATT	0.78	0.82																		
Var	0.54	0.81	0.74																	
Std	0.57	0.93	0.87	0.89																
TT5	0.97	0.72	0.87	0.58	0.63															
TT10	0.93	0.73	0.91	0.59	0.66	0.99														
TT15	0.91	0.73	0.92	0.59	0.68	0.98	1.00													
TT25	0.87	0.74	0.95	0.61	0.71	0.95	0.98	0.99												
TT50	0.79	0.77	0.99	0.67	0.79	0.89	0.93	0.95	0.97											
TT75	0.69	0.77	0.98	0.72	0.86	0.79	0.84	0.86	0.90	0.97										
TT85	0.65	0.77	0.97	0.73	0.88	0.75	0.80	0.82	0.86	0.94	0.99									
TT90	0.63	0.77	0.96	0.75	0.89	0.73	0.78	0.80	0.84	0.92	0.98	0.99								
TT95	0.62	0.81	0.95	0.80	0.93	0.70	0.75	0.77	0.80	0.89	0.96	0.98	0.99							
PT	0.62	0.81	0.95	0.80	0.93	0.70	0.75	0.77	0.80	0.89	0.96	0.98	0.99	1.00						
BT	0.43	0.73	0.82	0.78	0.90	0.50	0.54	0.57	0.61	0.74	0.85	0.90	0.92	0.96	0.96					
BTI		0.28	0.22	0.23	0.43					0.13	0.26	0.32	0.36	0.43	0.43	0.57				
PTI		0.30	0.41	0.28	0.50		0.11	0.15	0.22	0.36	0.48	0.54	0.55	0.55	0.55	0.63	0.76			
TTI		0.30	0.46	0.26	0.48		0.18	0.23	0.31	0.44	0.54	0.57	0.57	0.55	0.55	0.58	0.55	0.95		
λ^{Skew}		0.11			0.15			-0.09	-0.10	-0.10				0.12	0.12	0.23	0.68	0.25		
λ^{Var}		0.28	0.28	0.25	0.46					0.19	0.34	0.41	0.45	0.47	0.47	0.60	0.91	0.83	0.66	0.55

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A6 Pearson correlation coefficients between truck travel time performance measures (evening peak, weekend)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.60																			
ATT	0.99	0.64																		
Var	0.36	0.81	0.40																	
Std	0.51	0.95	0.56	0.88																
TT5	0.99	0.61	1.00	0.36	0.52															
TT10	0.99	0.61	1.00	0.36	0.52	1.00														
TT15	0.99	0.60	1.00	0.36	0.52	1.00	1.00													
TT25	0.99	0.61	1.00	0.37	0.52	1.00	1.00	1.00												
TT50	0.99	0.61	1.00	0.37	0.52	1.00	1.00	1.00	1.00											
TT75	0.99	0.61	1.00	0.37	0.53	1.00	1.00	1.00	1.00	1.00										
TT85	0.99	0.62	1.00	0.38	0.54	1.00	1.00	1.00	1.00	1.00	1.00									
TT90	0.99	0.62	1.00	0.38	0.55	0.99	1.00	1.00	1.00	1.00	1.00	1.00								
TT95	0.96	0.65	0.98	0.40	0.60	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.99							
PT	0.96	0.65	0.98	0.40	0.60	0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.99	1.00						
BT	0.52	0.46	0.57	0.26	0.52	0.53	0.53	0.53	0.53	0.54	0.55	0.57	0.59	0.72	0.72					
BTI	-0.10	0.09			0.21	-0.09	-0.09	-0.09	-0.09					0.11	0.11	0.64				
PTI	-0.11	0.11		0.09	0.26	-0.12	-0.11	-0.11	-0.11	-0.10	-0.09					0.55	0.95			
TTI	-0.13	0.16	-0.09	0.15	0.32	-0.14	-0.14	-0.14	-0.13	-0.13	-0.11	-0.09				0.33	0.69	0.87		
λ^{Skew}		0.13			0.20											0.46	0.73	0.69	0.52	
λ^{Var}	-0.16		-0.12		0.16	-0.16	-0.16	-0.16	-0.16	-0.15	-0.13	-0.11				0.37	0.80	0.89	0.84	0.69

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale	(blue)	(grey)	(orange)	(light pink)	(yellow)	(green)
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A7 Pearson correlation coefficients between truck travel time performance measures (night-time hour, weekday)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.60																			
ATT	0.98	0.68																		
Var	0.41	0.82	0.52																	
Std	0.48	0.93	0.60	0.92																
TT5	0.99	0.61	0.99	0.42	0.49															
TT10	0.99	0.61	0.99	0.42	0.49	1.00														
TT15	0.99	0.61	0.99	0.42	0.49	1.00	1.00													
TT25	0.99	0.61	0.99	0.41	0.49	1.00	1.00	1.00												
TT50	0.99	0.61	0.99	0.42	0.49	1.00	1.00	1.00	1.00											
TT75	0.99	0.62	0.99	0.43	0.51	1.00	1.00	1.00	1.00	1.00										
TT85	0.98	0.65	0.99	0.48	0.56	0.98	0.98	0.98	0.99	0.99	0.99									
TT90	0.93	0.68	0.97	0.56	0.64	0.94	0.94	0.94	0.94	0.94	0.95	0.98								
TT95	0.80	0.77	0.88	0.75	0.82	0.81	0.81	0.81	0.81	0.82	0.82	0.87	0.92							
PT	0.80	0.77	0.88	0.75	0.82	0.81	0.81	0.81	0.81	0.82	0.82	0.87	0.92	1.00						
BT	0.27	0.60	0.41	0.77	0.80	0.29	0.29	0.29	0.29	0.29	0.31	0.40	0.53	0.79	0.79					
BTI		0.35		0.45	0.56								0.19	0.46	0.46	0.80				
PTI		0.35		0.45	0.57								0.22	0.46	0.46	0.80	0.98			
TTI		0.38		0.45	0.58								0.17	0.39	0.39	0.69	0.87	0.92		
λ^{Skew}		0.27		0.40	0.45							0.13	0.30	0.41	0.41	0.69	0.72	0.79	0.71	
λ^{Var}		0.24		0.38	0.43							0.11	0.27	0.39	0.39	0.68	0.72	0.82	0.81	0.95

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A8 Pearson correlation coefficients between truck travel time performance measures (night-time hour, weekend)

	Min	Max	ATT	Var	Std	TT5	TT10	TT15	TT25	TT50	TT75	TT85	TT90	TT95	PT	BT	BTI	PTI	TTI	λ^{Skew}
Max	0.50																			
ATT	0.99	0.57																		
Var	0.21	0.79	0.28																	
Std	0.35	0.93	0.43	0.91																
TT5	0.99	0.51	1.00	0.21	0.36															
TT10	0.99	0.51	1.00	0.21	0.36	1.00														
TT15	0.99	0.51	1.00	0.21	0.36	1.00	1.00													
TT25	0.99	0.51	1.00	0.21	0.36	1.00	1.00	1.00												
TT50	0.99	0.51	1.00	0.21	0.36	1.00	1.00	1.00	1.00											
TT75	0.99	0.52	1.00	0.22	0.37	1.00	1.00	1.00	1.00	1.00										
TT85	0.99	0.53	1.00	0.23	0.38	1.00	1.00	1.00	1.00	1.00	1.00									
TT90	0.98	0.55	0.99	0.27	0.42	0.99	0.99	0.99	0.99	0.99	0.99	0.99								
TT95	0.87	0.64	0.91	0.53	0.63	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.92							
PT	0.87	0.64	0.91	0.53	0.63	0.88	0.88	0.88	0.88	0.88	0.88	0.89	0.92	1.00						
BT	0.22	0.46	0.30	0.71	0.67	0.23	0.23	0.23	0.23	0.23	0.24	0.27	0.33	0.67	0.67					
BTI	-0.09	0.28		0.54	0.52									0.36	0.36	0.87				
PTI	-0.09	0.30		0.58	0.55	-0.09	-0.09	-0.09						0.37	0.37	0.87	0.99			
TTI	-0.15	0.33		0.50	0.55	-0.15	-0.15	-0.15	-0.15	-0.14	-0.13	-0.10		0.22	0.22	0.64	0.78	0.84		
λ^{Skew}		0.19		0.29	0.35									0.23	0.23	0.55	0.58	0.57	0.54	
λ^{Var}	-0.12	0.14		0.26	0.32	-0.12	-0.12	-0.12	-0.12	-0.11	-0.09			0.18	0.18	0.52	0.60	0.63	0.76	0.86

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A9 Pearson correlation coefficients between truck travel time performance measures and on-network characteristics

			Number of through lanes				Functional class		Area type		AADT	Speed limit	Reference speed	Data density		
			4	6	8	10	Interstates	Principal arterials (Freeways and other expressways)	Rural	Urban				A	B	C
Weekday	Morning peak	ATT			-0.11									-0.10	0.09	
		PTI		0.11					-0.14	0.14	0.10	-0.24	-0.11			
		BTI							-0.10	0.10	0.12	-0.22	-0.10			
		TTI		0.15					-0.14	0.14	0.12	-0.23	-0.13			
	Afternoon peak	ATT	0.11		-0.13						-0.14	0.17				
		PTI	0.13		-0.15		-0.11	0.11				-0.47	-0.23			
		BTI	0.14		-0.18							-0.40	-0.21			
		TTI	0.10		-0.11	-0.10	-0.12	0.12				-0.58	-0.33	0.09	-0.11	
	Evening peak	ATT	0.09		-0.14									-0.18	0.18	0.13
		PTI		0.16			0.15	-0.15	-0.17	0.17	0.24	-0.30	-0.21			
		BTI					0.13	-0.13	-0.11	0.11	0.25	-0.38	-0.31			
		TTI		0.16	-0.09		0.15	-0.15	-0.18	0.18	0.25	-0.23	-0.14			
	Night-time	ATT	0.10		-0.11						-0.12	0.16		-0.11	0.11	
		PTI							-0.09	0.09	0.18	-0.26	-0.22	-0.14	0.14	0.11
		BTI							-0.10	0.10	0.19	-0.24	-0.22	-0.18	0.18	0.14
		TTI									0.14	-0.40	-0.30	-0.10	0.10	0.11
Weekend	Morning peak	ATT	0.11		-0.13						-0.15	0.19		-0.16	0.16	0.10
		PTI	0.11				-0.23	0.23			-0.15	-0.37	-0.12	0.16	-0.16	
		BTI	0.10				-0.21	0.21			-0.11	-0.41	-0.16	0.13	-0.13	
		TTI	0.11		-0.14	-0.09	-0.20	0.20			-0.19	-0.27		0.20	-0.20	
	Afternoon peak	ATT	0.12		-0.13				0.11	-0.11	-0.15	0.16		-0.21	0.21	
		PTI	0.17		-0.13				0.22	-0.22		-0.31	-0.26	-0.23	0.23	
		BTI	0.18		-0.12				0.20	-0.20		-0.32	-0.27	-0.26	0.26	
		TTI	0.18		-0.16				0.23	-0.23	-0.10	-0.40	-0.33	-0.15	0.15	
	Evening peak	ATT	0.11		-0.12						-0.14	0.17		-0.17	0.17	0.11
		PTI										-0.43	-0.20			0.12
		BTI									0.10	-0.37	-0.20	-0.13	0.12	0.16
		TTI					-0.09	0.09				-0.49	-0.26			
	Night-time	ATT	0.10		-0.11						-0.13	0.17				
		PTI									0.14	-0.26	-0.15			
		BTI									0.15	-0.25	-0.16	-0.11	0.11	
		TTI									0.09	-0.41	-0.22			

Note 1: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.
Note 2:

Agri = Agriculture land use	SFam = Single family residential land use
Clg = College land use	MFam = Multifamily residential land use
Gov = Government land use	Ofc = Office land use
LCom = Light commercial land use	Rec = Recreational land use
HCom = Heavy commercial land use	Resc = Resource land use
LInd = Light industrial land use	Retl = Retail land use
HInd = Heavy industrial land use	Transp = Transportation land use
Inst = Institutional land use	Vac/ukn = Vacant or unknown land use
Med = Medical land use	DevArea = Percent of developed area

Table A10 Pearson correlation coefficients between truck travel time performance measures and land use characteristics (0.25-mile buffer)

			Agri	Clg	Gov	LCom	HCom	LInd	HInd	Inst	Med	SFam	MFam	Ofc	Rec	Resc	Retl	Transp	Vac/ukn	DevArea
Weekday	Morning peak	ATT	0.31	0.13	0.13	0.41		0.18	0.12	0.33	0.20	0.51	0.40	0.24	0.11			0.09	0.21	
		PTI	-0.12			0.13								0.20						
		BTI	-0.12			0.18								0.16						
		TTI	-0.11											0.22					-0.10	
	Afternoon peak	ATT	0.50	0.16	0.18	0.36		0.20	0.19	0.36	0.22	0.62	0.49	0.16	0.19	0.10	0.11		0.33	
		PTI	-0.09			0.14						-0.10		0.12		-0.09			-0.12	
		BTI				0.18					0.10	-0.09		0.17		-0.09			-0.11	0.09
		TTI	-0.11			0.11						-0.13				-0.11			-0.15	
	Evening peak	ATT	0.29	0.09	0.11	0.42		0.21	0.12	0.28	0.20	0.38	0.38	0.30	0.15				0.16	0.13
		PTI	-0.13			0.14						-0.20		0.23		-0.12			-0.17	0.14
		BTI	-0.15			0.16						-0.20		0.11		-0.16			-0.17	0.13
		TTI	-0.12			0.13						-0.18		0.28		-0.11			-0.15	0.15
	Night-time	ATT	0.49	0.17	0.18	0.36		0.23	0.18	0.35	0.24	0.61	0.49	0.15	0.20	0.09	0.10		0.31	
		PTI						0.13							0.13				-0.16	0.22
		BTI	-0.09			0.11		0.14							0.13	-0.09			-0.17	0.23
		TTI	-0.11			0.10		0.11	-0.10							-0.11			-0.19	0.21
Weekend	Morning peak	ATT	0.51	0.16	0.19	0.32		0.20	0.20	0.38	0.22	0.63	0.48	0.14	0.20	0.11	0.11		0.35	
		PTI											-0.10	-0.10						
		BTI										-0.11	-0.09	-0.09						
		TTI				-0.11		-0.11					-0.10	-0.10						
	Afternoon peak	ATT	0.52	0.15	0.20	0.35		0.18	0.19	0.36	0.26	0.59	0.53	0.14	0.18	0.09	0.12		0.33	
		PTI			0.09	0.19					0.13		0.09				0.10			
		BTI			0.12	0.22					0.16		0.12				0.09			
		TTI				0.16		-0.11			0.10						0.10			
	Evening peak	ATT	0.51	0.16	0.18	0.34		0.20	0.19	0.37	0.23	0.61	0.50	0.15	0.19	0.10	0.11		0.34	
		PTI										-0.11				-0.09			-0.11	
		BTI										-0.11				-0.10			-0.11	
		TTI					-0.09					-0.11							-0.11	
	Night-time	ATT	0.51	0.16	0.18	0.33		0.22	0.20	0.37	0.22	0.61	0.49	0.15	0.19	0.10	0.11		0.33	
		PTI						0.12				-0.09							-0.11	0.17
		BTI						0.12				-0.09							-0.11	0.17
		TTI										-0.13							-0.15	0.13

Note 1: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Note 2:

Agri = Agriculture land use
Clg = College land use
Gov = Government land use
LCom = Light commercial land use
HCom = Heavy commercial land use
LInd = Light industrial land use
HInd = Heavy industrial land use
Inst = Institutional land use
Med = Medical land use
SFam = Single family residential land use
MFam = Multifamily residential land use
Ofc = Office land use
Rec = Recreational land use
Resc = Resource land use
Retl = Retail land use
Transp = Transportation land use
Vac/ukn = Vacant or unknown land use
DevArea = Percent of developed area

Color scale						
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A11 Pearson correlation coefficients between truck travel time performance measures and land use characteristics (0.50-mile buffer)

			Agri	Clg	Gov	LCom	HCom	LInd	HInd	Inst	Med	SFam	MFam	Ofc	Rec	Resc	Retl	Transp	Vac/ukn	DevArea
Weekday	Morning peak	ATT	0.30	0.09	0.11	0.35		0.15	0.09	0.33	0.21	0.48	0.39	0.21	0.10		0.12		0.14	
		PTI	-0.13			0.10								0.22					-0.09	
		BTI	-0.13			0.14								0.15			0.15	0.11		
		TTI	-0.12											0.26					-0.11	
	Afternoon peak	ATT	0.49	0.11	0.16	0.31		0.15	0.14	0.36	0.21	0.59	0.46	0.11	0.17	0.12	0.14		0.25	
		PTI	-0.11			0.11						-0.10				-0.10			-0.14	
		BTI	-0.10			0.13					0.11	-0.09		0.13		-0.10			-0.12	
		TTI	-0.13			0.11	-0.10					-0.14				-0.13			-0.16	
	Evening peak	ATT	0.27	0.12		0.38		0.18	0.10	0.31	0.18	0.34	0.38	0.28	0.12		0.09		0.10	
		PTI	-0.16			0.16		0.10				-0.24		0.29		-0.13			-0.18	0.12
		BTI	-0.18			0.20		0.12				-0.23		0.15		-0.16			-0.17	0.12
		TTI	-0.14			0.13						-0.20		0.33		-0.11			-0.16	0.11
	Night-time	ATT	0.48	0.11	0.16	0.32		0.18	0.13	0.35	0.23	0.58	0.47	0.10	0.18	0.11	0.14		0.23	
		PTI	-0.10			0.11		0.16									-0.10		-0.17	0.19
		BTI	-0.11			0.12		0.18									-0.10		-0.17	0.20
		TTI	-0.13			0.13		0.15	-0.10							-0.11			-0.21	0.19
Weekend	Morning peak	ATT	0.51	0.10	0.16	0.28		0.15	0.15	0.37	0.21	0.60	0.45	0.09	0.18	0.13	0.15		0.26	
		PTI				-0.09	-0.09				-0.09		-0.10							
		BTI									-0.10	-0.11	-0.09							
		TTI				-0.10	-0.10	-0.10					-0.11							
	Afternoon peak	ATT	0.51	0.09	0.19	0.32		0.13	0.14	0.36	0.23	0.57	0.51	0.09	0.17	0.11	0.16		0.24	
		PTI			0.19	0.19					0.10		0.14							
		BTI			0.22	0.21					0.15		0.16			-0.09			-0.09	
		TTI			0.14	0.17		-0.10					0.12			-0.09			-0.09	
	Evening peak	ATT	0.51	0.11	0.16	0.30		0.15	0.14	0.37	0.22	0.59	0.48	0.10	0.18	0.12	0.15		0.25	
		PTI					-0.10					-0.13				-0.10			-0.12	
		BTI		0.09								-0.13				-0.10			-0.11	
		TTI					-0.11					-0.13				-0.09			-0.12	
	Night-time	ATT	0.50	0.10	0.16	0.29		0.17	0.14	0.36	0.20	0.58	0.46	0.10	0.18	0.12	0.14		0.25	
		PTI						0.17				-0.10							-0.12	0.15
		BTI						0.17				-0.10							-0.12	0.15
		TTI	-0.11					0.14			-0.10	-0.15							-0.15	0.12

Note 1: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Note 2:

Agri = Agriculture land use
Clg = College land use
Gov = Government land use
LCom = Light commercial land use
HCom = Heavy commercial land use
LInd = Light industrial land use
HInd = Heavy industrial land use
Inst = Institutional land use
Med = Medical land use
SFam = Single family residential land use
MFam = Multifamily residential land use
Ofc = Office land use
Rec = Recreational land use
Resc = Resource land use
Retl = Retail land use
Transp = Transportation land use
Vac/ukn = Vacant or unknown land use
DevArea = Percent of developed area

Color scale						
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A12 Pearson correlation coefficients between truck travel time performance measures and land use characteristics (1-mile buffer)

			Agri	Clg	Gov	LCom	HCom	LInd	HInd	Inst	Med	SFam	MFam	Ofc	Rec	Resc	Retl	Transp	Vac/ukn	DevArea
Weekday	Morning peak	ATT	0.24	0.10		0.24		0.10		0.33	0.13	0.44	0.36	0.15	0.14		0.13		0.10	
		PTI	-0.18							0.12				0.20		-0.09				
		BTI	-0.18			0.10				0.12	0.12			0.15			0.16			
		TTI	-0.17					0.10		0.11				0.23		-0.10			-0.11	0.10
	Afternoon peak	ATT	0.43	0.11	0.13	0.21	0.09			0.31	0.11	0.55	0.43		0.21	0.11	0.13		0.18	
		PTI	-0.13	0.09		0.13				0.12		-0.11				-0.11			-0.14	
		BTI	-0.12			0.14				0.11		-0.09		0.10		-0.10			-0.12	
		TTI	-0.16			0.17				0.15		-0.16				-0.13	-0.09		-0.16	
	Evening peak	ATT	0.20	0.14		0.28	0.10	0.12		0.29		0.33	0.38	0.22	0.13					
		PTI	-0.21			0.20		0.13		0.10		-0.24		0.31		-0.13	-0.09		-0.19	0.12
		BTI	-0.23		0.09	0.26		0.14		0.15		-0.26		0.23		-0.14			-0.19	0.12
		TTI	-0.19			0.15		0.11				-0.19		0.32		-0.11	-0.10		-0.18	0.13
	Night-time	ATT	0.42	0.12	0.14	0.22	0.10	0.10		0.30	0.11	0.54	0.44		0.21	0.11	0.12		0.16	
		PTI	-0.12			0.15		0.18									-0.12		-0.18	0.17
		BTI	-0.13	0.10		0.16		0.19								-0.09	-0.13		-0.18	0.17
		TTI	-0.16	0.09		0.19	-0.09	0.19	-0.09	0.09	-0.09	-0.11				-0.12	-0.13		-0.23	0.18
Weekend	Morning peak	ATT	0.44	0.10	0.14	0.18	0.09			0.30	0.11	0.56	0.42		0.22	0.13	0.15		0.20	
		PTI					-0.14				-0.10	-0.09	-0.11							
		BTI	-0.09				-0.14				-0.09	-0.12	-0.10							
		TTI					-0.12			0.11	-0.11		-0.11							
	Afternoon peak	ATT	0.45	0.09	0.17	0.21				0.30	0.12	0.53	0.48		0.22	0.11	0.14		0.18	
		PTI			0.27	0.14				0.14			0.15							
		BTI			0.29	0.15				0.15			0.18			-0.09			-0.09	
		TTI			0.23	0.16	-0.09			0.14			0.14			-0.09				
	Evening peak	ATT	0.44	0.11	0.14	0.19				0.31	0.11	0.55	0.45		0.22	0.12	0.14		0.19	
		PTI		0.09		0.09	-0.12					-0.15							-0.11	
		BTI					-0.11					-0.15							-0.10	
		TTI	-0.11			0.12	-0.11		-0.09	0.11	-0.09	-0.16				-0.10			-0.12	
	Night-time	ATT	0.44	0.11	0.15	0.19		0.09		0.30	0.10	0.55	0.43		0.22	0.12	0.13		0.18	
		PTI	-0.09		0.16			0.16				-0.10							-0.12	0.14
		BTI	-0.09		0.16			0.16				-0.10							-0.12	0.14
		TTI	-0.13		0.15		-0.11	0.17			-0.11	-0.17							-0.15	0.12

Note 1: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Note 2:

Agri = Agriculture land use
Clg = College land use
Gov = Government land use
LCom = Light commercial land use
HCom = Heavy commercial land use
LInd = Light industrial land use
HInd = Heavy industrial land use
Inst = Institutional land use
Med = Medical land use
SFam = Single family residential land use
MFam = Multifamily residential land use
Ofc = Office land use
Rec = Recreational land use
Resc = Resource land use
Retl = Retail land use
Transp = Transportation land use
Vac/ukn = Vacant or unknown land use
DevArea = Percent of developed area

Color scale						
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

Table A13 Pearson correlation coefficients between truck travel time performance measures and demographic characteristics

Variables →			Population			# of household units			Population density			Employment density		
Buffer width →			0.25	0.50	1	0.25	0.50	1	0.25	0.50	1	0.25	0.50	1
Weekday	Morning peak	ATT	0.49	0.46	0.43	0.49	0.46	0.43			-0.19			-0.12
		PTI	-0.11	-0.10		-0.10	-0.09		0.09	0.13		0.18		
		BTI								0.12		0.18		
		TTI	-0.13	-0.11	-0.10	-0.12	-0.11	-0.09		0.13		0.19	0.09	
	Afternoon peak	ATT	0.65	0.61	0.55	0.65	0.60	0.55	-0.15	-0.17	-0.27	-0.12	-0.14	-0.14
		PTI	-0.12	-0.10		-0.11			0.20	0.28	0.12	0.22	0.21	
		BTI	-0.10			-0.09			0.13	0.21	0.12	0.21	0.17	
		TTI	-0.17	-0.15	-0.15	-0.16	-0.14	-0.13	0.32	0.39	0.15	0.29	0.32	
	Evening peak	ATT	0.47	0.45	0.44	0.47	0.45	0.44			-0.15			
		PTI	-0.13	-0.11	-0.09	-0.11	-0.09		0.28	0.32	0.12	0.47	0.44	
		BTI	-0.16	-0.15	-0.15	-0.13	-0.12	-0.12	0.35	0.38		0.43	0.49	
		TTI	-0.11			-0.10			0.18	0.21	0.13	0.41	0.32	0.12
	Night-time	ATT	0.65	0.60	0.55	0.64	0.60	0.55	-0.16	-0.17	-0.26	-0.13	-0.15	-0.14
		PTI	-0.12	-0.11	-0.10	-0.12	-0.11	-0.09		0.11	0.12			0.12
		BTI	-0.12	-0.11	-0.09	-0.12	-0.11	-0.09			0.11			0.11
		TTI	-0.14	-0.14	-0.12	-0.13	-0.12	-0.10	0.15	0.21	0.14	0.13	0.13	0.13
Weekend	Morning peak	ATT	0.66	0.62	0.55	0.66	0.61	0.55	-0.16	-0.19	-0.28	-0.14	-0.16	-0.15
		PTI	-0.15	-0.15	-0.17	-0.14	-0.14	-0.15	0.16	0.19	0.14		0.14	
		BTI	-0.17	-0.17	-0.18	-0.16	-0.16	-0.16	0.15	0.19	0.13		0.13	
		TTI	-0.11	-0.11	-0.13	-0.09	-0.10	-0.11	0.17	0.18	0.13		0.17	
	Afternoon peak	ATT	0.66	0.61	0.55	0.66	0.61	0.56	-0.16	-0.18	-0.27	-0.14	-0.15	-0.14
		PTI												
		BTI												
		TTI							0.13	0.16	0.10	0.11	0.14	
	Evening peak	ATT	0.66	0.61	0.55	0.66	0.61	0.55	-0.15	-0.17	-0.27	-0.13	-0.15	-0.14
		PTI	-0.14	-0.14	-0.15	-0.12	-0.12	-0.13	0.25	0.30	0.15	0.17	0.23	0.10
		BTI	-0.13	-0.13	-0.15	-0.11	-0.12	-0.13	0.19	0.22	0.16	0.14	0.16	0.11
		TTI	-0.15	-0.14	-0.16	-0.13	-0.12	-0.13	0.35	0.40	0.15	0.24	0.35	0.09
	Night-time	ATT	0.65	0.60	0.54	0.65	0.60	0.54	-0.17	-0.19	-0.28	-0.14	-0.16	-0.14
		PTI	-0.18	-0.17	-0.16	-0.17	-0.17	-0.15			0.09	0.15		0.11
		BTI	-0.18	-0.17	-0.16	-0.17	-0.17	-0.15				0.14		0.10
		TTI	-0.22	-0.23	-0.22	-0.21	-0.21	-0.21	0.10	0.13	0.13	0.17	0.16	0.10

Note: Cells with blank values indicate that the correlation coefficient is not significant at a 95% confidence level.

Color scale						
	< -0.5	-0.8	-0.3	0 - 0.3	0.3-0.5	> 0.5

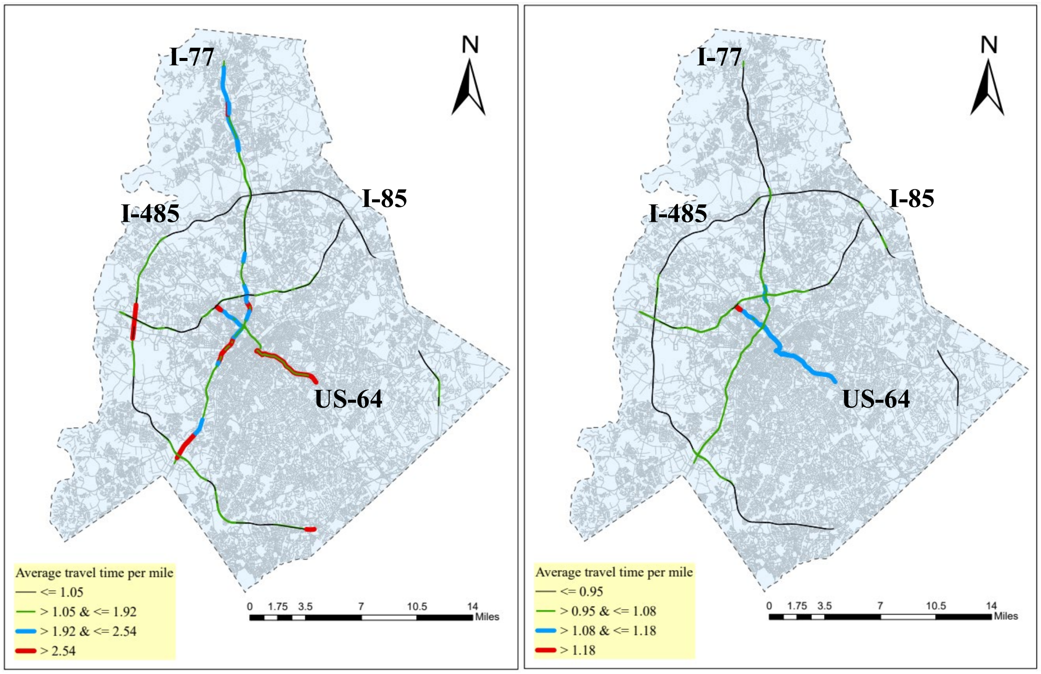
APPENDIX B: GEOPATIAL MAPS DEPICTING TRUCK TRAVEL TIME PERFORMANCE MEASURES

This appendix presents the geospatial maps for the three counties: Mecklenburg County, Buncombe County and Wake County.

Figures B1-B8 show the geospatial maps for Mecklenburg County. Figures B1 (a-b) and B2 (a-b) show the geospatial maps generated using ATTPM for morning and afternoon peak hours (weekday and weekend). Figures B3 (a-b) and B4 (a-b) show the geospatial maps generated using PTI for morning and afternoon peak hours (weekday and weekend). Figures B5 (a-b) and B6 (a-b) show the geospatial maps generated using BTI for morning and afternoon peak hours (weekday and weekend). Figures B7 (a-b) and B8 (a-b) show the geospatial maps generated using TTI for morning and afternoon peak hours (weekday and weekend).

Figures B9-B24 show the geospatial maps for Buncombe County. Figures B9 (a-b) and B10 (a-b) show the geospatial maps generated using ATTPM for morning and afternoon peak hours (weekday and weekend). Figures B11 (a-b) and B12 (a-b) show the geospatial maps generated using ATTPM for evening peak and night-time hours (weekday and weekend). Figures B13 (a-b) and B14 (a-b) show the geospatial maps generated using PTI for morning and afternoon peak hours (weekday and weekend). Figures B15 (a-b) and B16 (a-b) show the geospatial maps generated using PTI for evening peak and night-time hours (weekday and weekend). Figures B17 (a-b) and B18 (a-b) show the geospatial maps generated using BTI for morning and afternoon peak hours (weekday and weekend). Figures B19 (a-b) and B20 (a-b) show the geospatial maps generated using BTI for evening peak and night-time hours (weekday and weekend). Figures B21 (a-b) and B22 (a-b) show the geospatial maps generated using BTI for morning and afternoon peak hours (weekday and weekend). Figures B23 (a-b) and B24 (a-b) show the geospatial maps generated using BTI for evening peak and night-time hours (weekday and weekend).

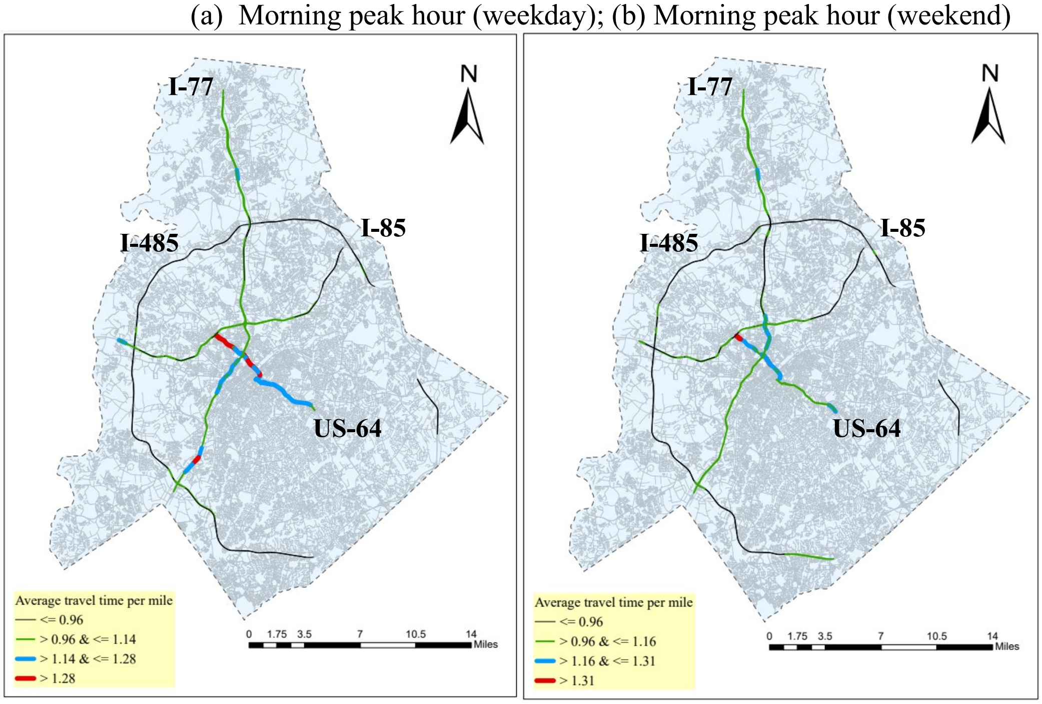
Figures B25-B40 show the geospatial maps for Wake County. Figures B25 (a-b) and B26 (a-b) show the geospatial maps generated using ATTPM for morning and afternoon peak hours (weekday and weekend). Figures B27 (a-b) and B28 (a-b) show the geospatial maps generated using ATTPM for evening peak and night-time hours (weekday and weekend). Figures B29 (a-b) and B30 (a-b) show the geospatial maps generated using PTI for morning and afternoon peak hours (weekday and weekend). Figures B31 (a-b) and B32 (a-b) show the geospatial maps generated using PTI for evening peak and night-time hours (weekday and weekend). Figures B33 (a-b) and B34 (a-b) show the geospatial maps generated using BTI for morning and afternoon peak hours (weekday and weekend). Figures B35 (a-b) and B36 (a-b) show the geospatial maps generated using BTI for evening peak and night-time hours (weekday and weekend). Figures B37 (a-b) and B38 (a-b) show the geospatial maps generated using BTI for morning and afternoon peak hours (weekday and weekend). Figures B39 (a-b) and B40 (a-b) show the geospatial maps generated using BTI for evening peak and night-time hours (weekday and weekend).



(a) (b)

Figure B1 Maps depicting ATTPM during the morning peak hour for links in Mecklenburg County

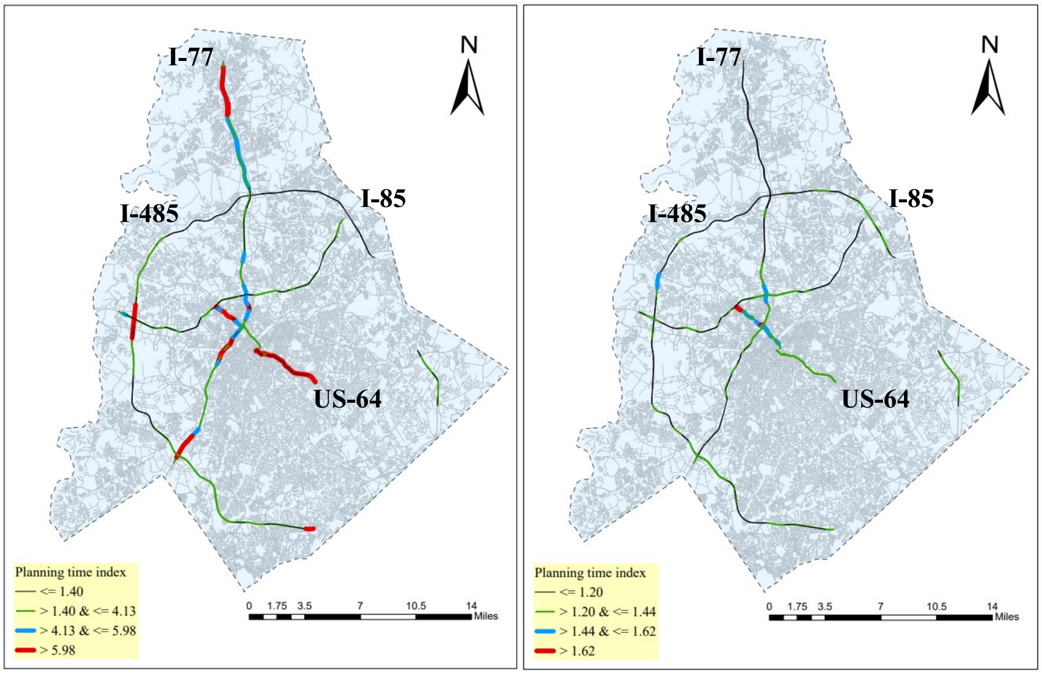
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



(a) (b)

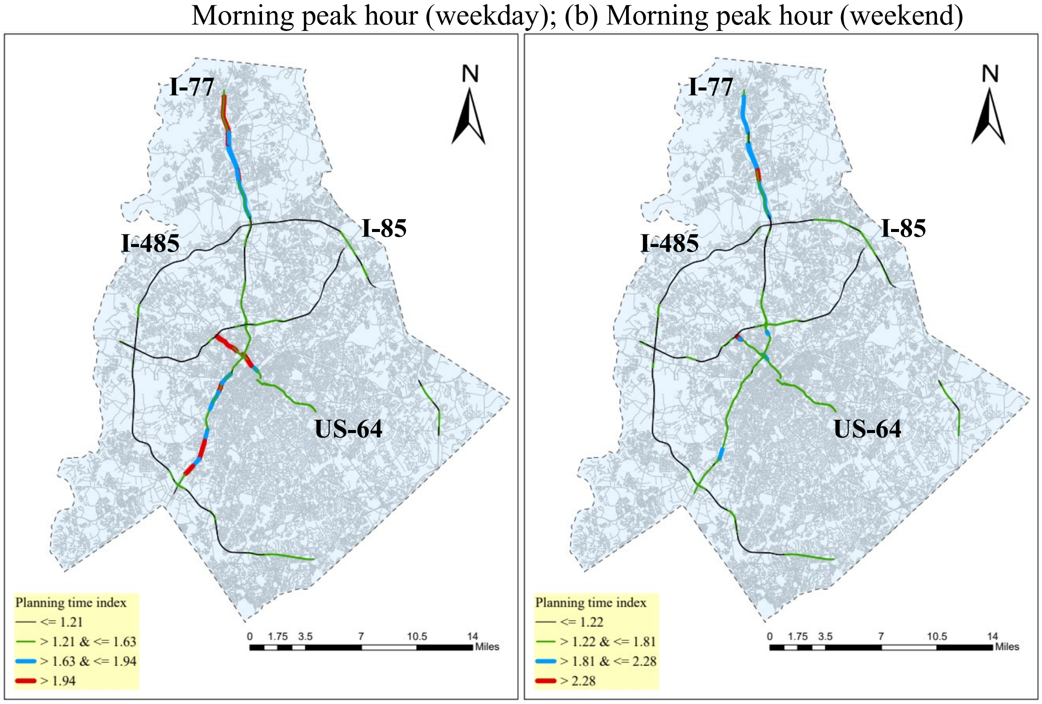
Figure B2 Maps depicting ATTPM during the afternoon peak hour for links in Mecklenburg County

Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



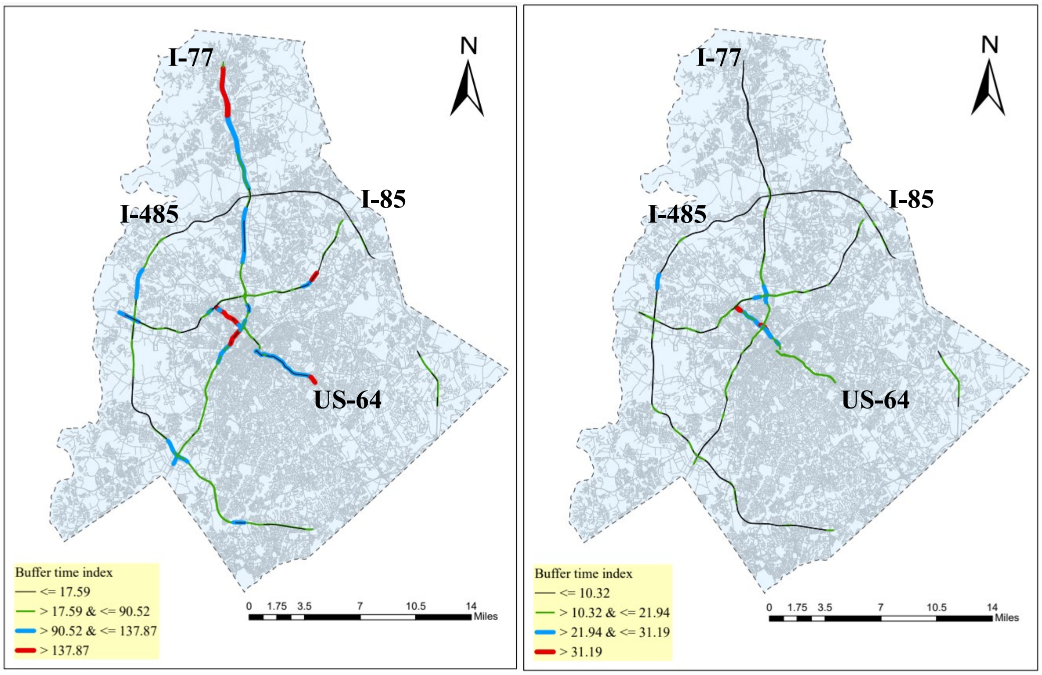
(a) (b)

Figure B3 Maps depicting PTI during the morning peak hour for links in Mecklenburg County Morning peak hour (weekday); (b) Morning peak hour (weekend)



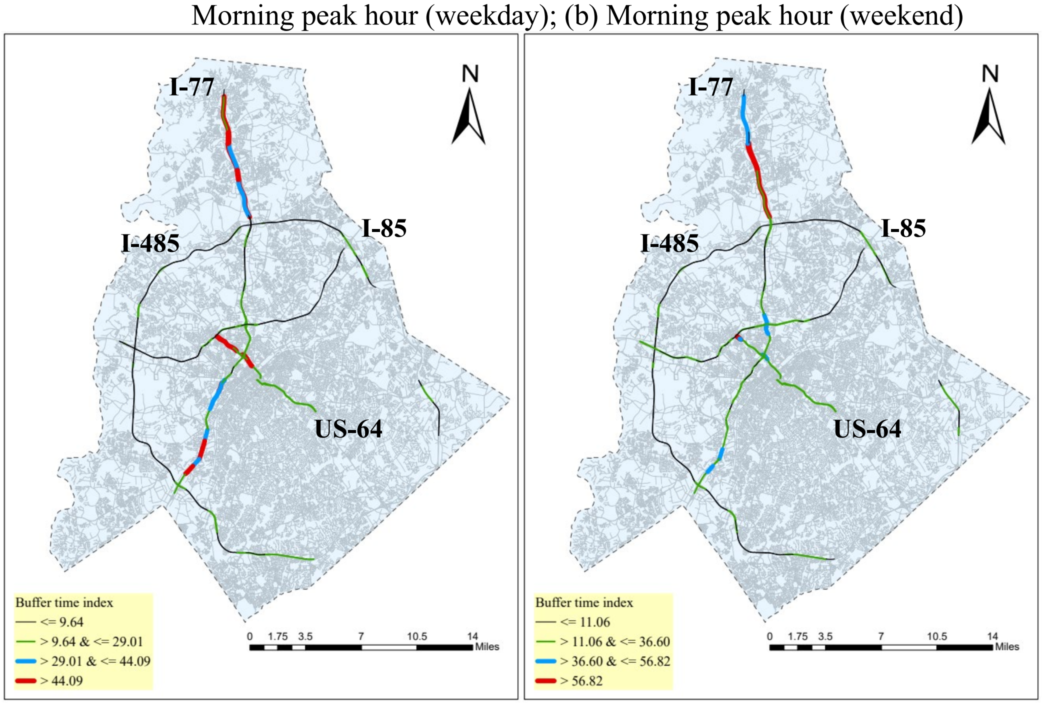
(a) (b)

Figure B4 Maps depicting PTI during the afternoon peak hour for links in Mecklenburg County Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



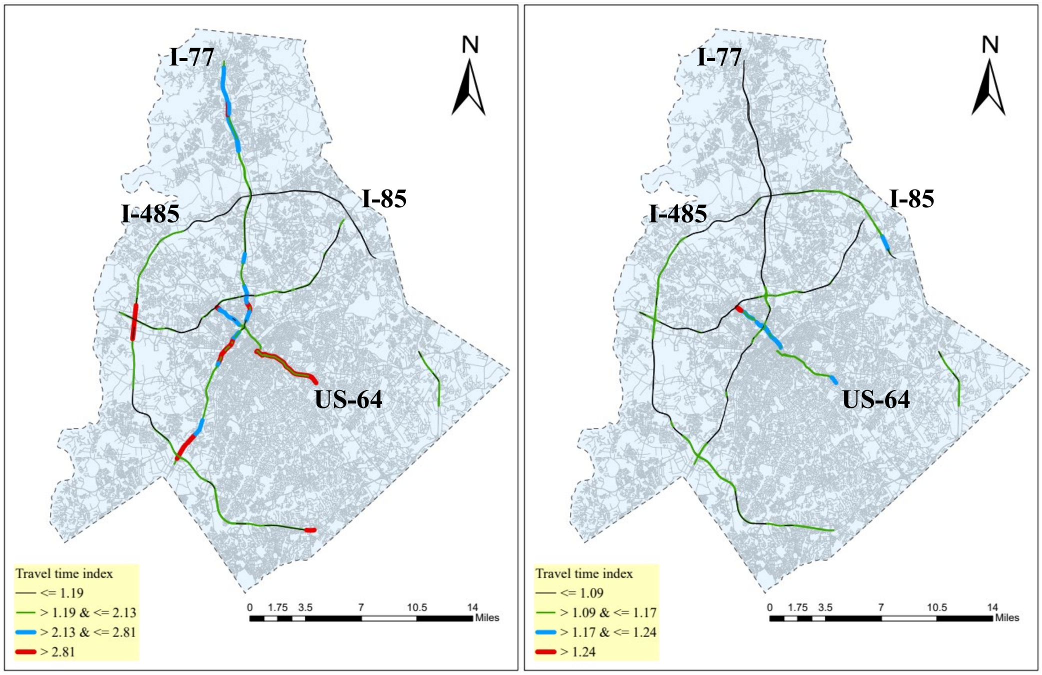
(a) (b)

Figure B5 Maps depicting BTI during the morning peak hour for links in Mecklenburg County Morning peak hour (weekday); (b) Morning peak hour (weekend)



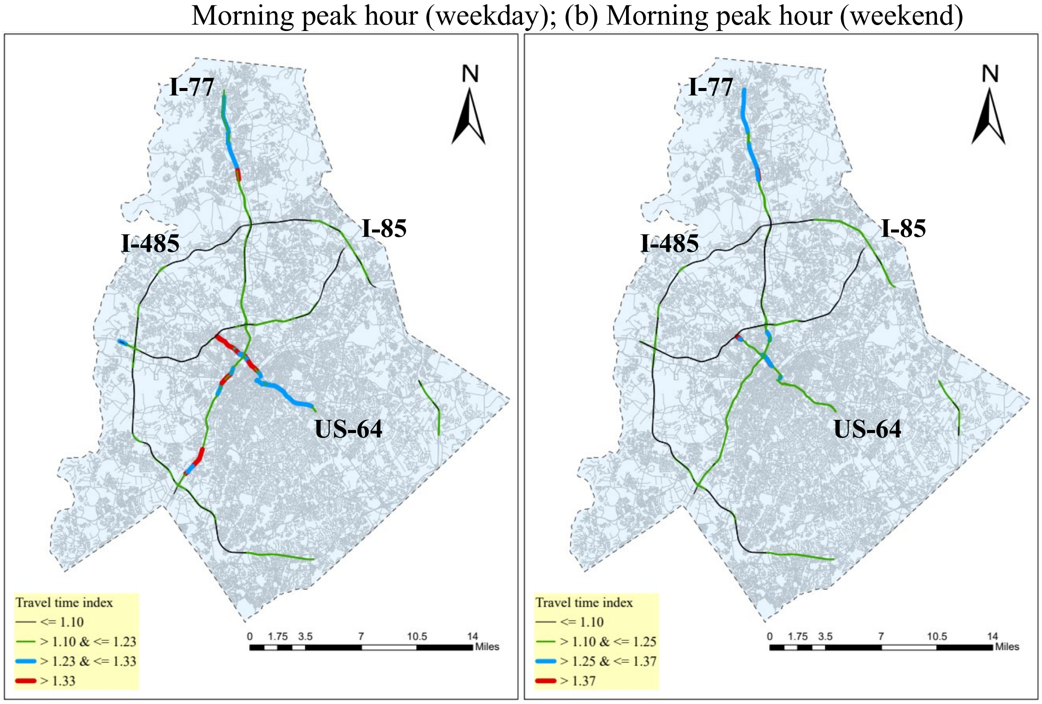
(a) (b)

Figure B6 Maps depicting PTI during the afternoon peak hour for links in Mecklenburg County Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



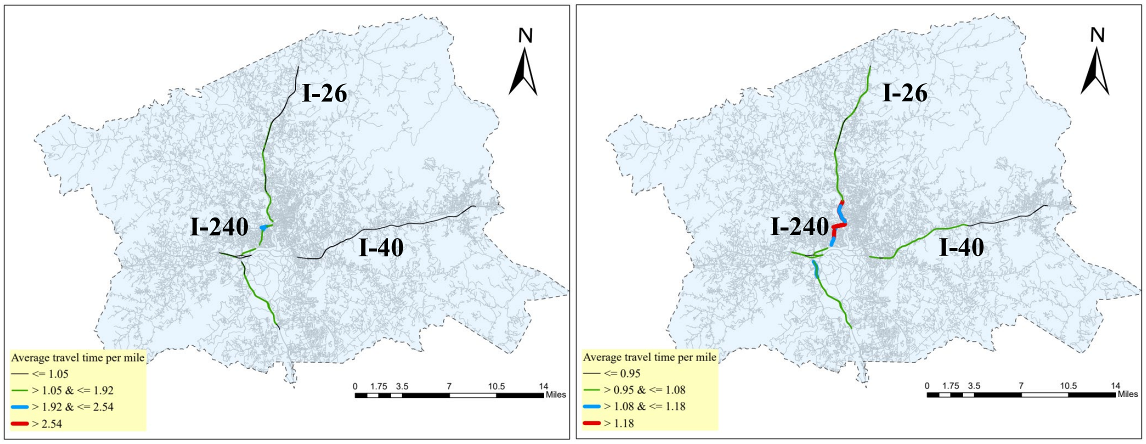
(a) (b)

Figure B7 Maps depicting TTI during the morning peak hour for links in Mecklenburg County Morning peak hour (weekday); (b) Morning peak hour (weekend)



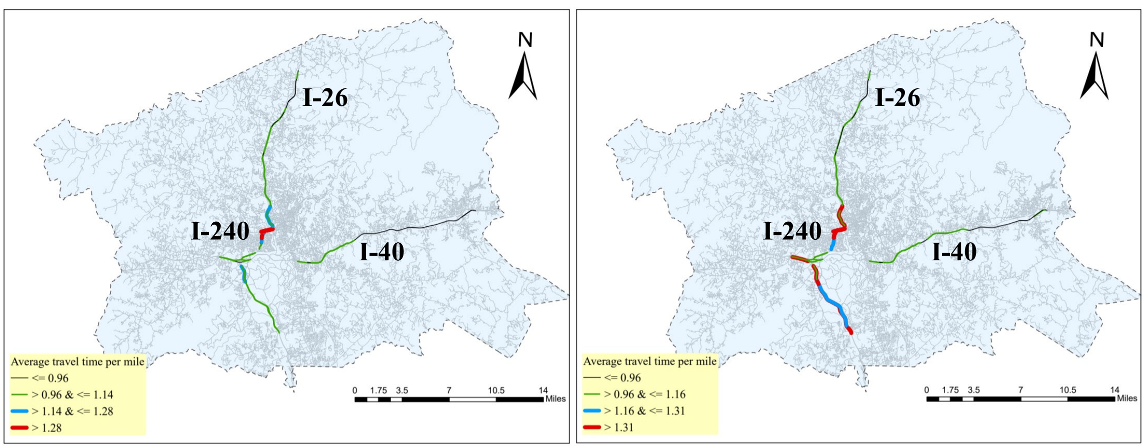
(a) (b)

Figure B8 Maps depicting PTI during the afternoon peak hour for links in Mecklenburg County Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



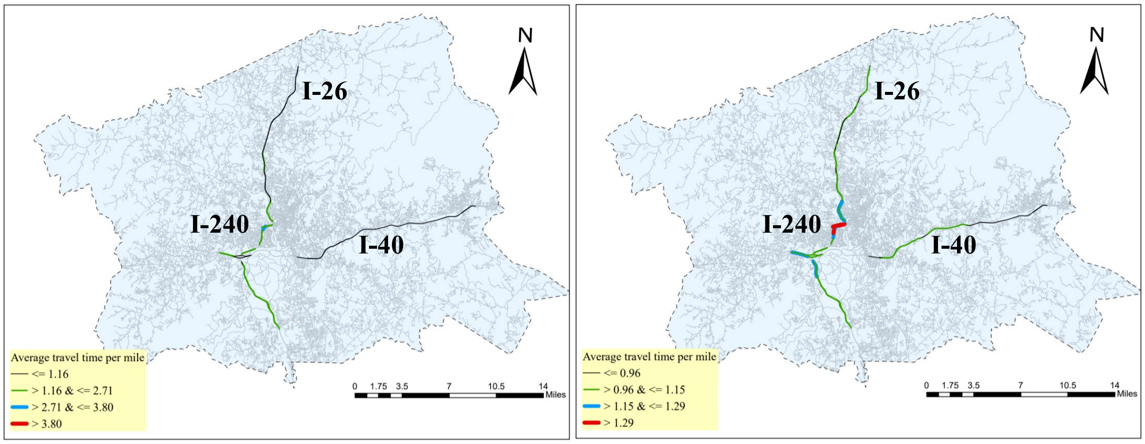
(a) (b)

Figure B9 Maps depicting ATTPM during the morning peak hour for links in Buncombe County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



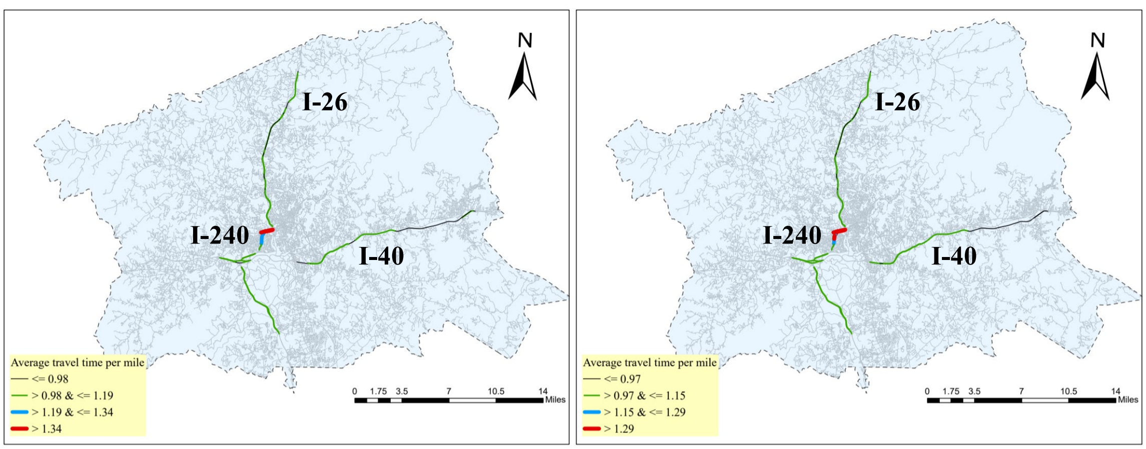
(a) (b)

Figure B10 Maps depicting ATTPM during the afternoon peak hour for links in Buncombe County
Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



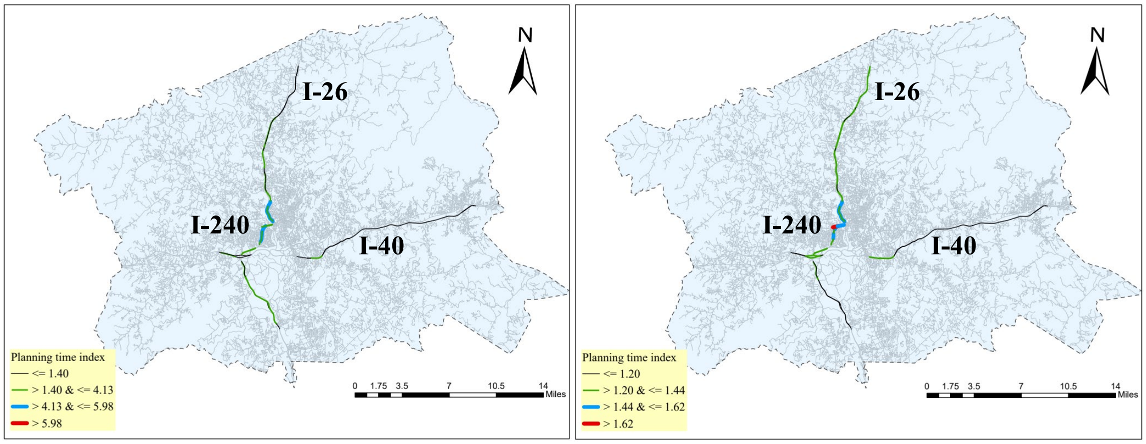
(a) (b)

Figure B11 Maps depicting ATTPM during the evening peak hour for links in Buncombe County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



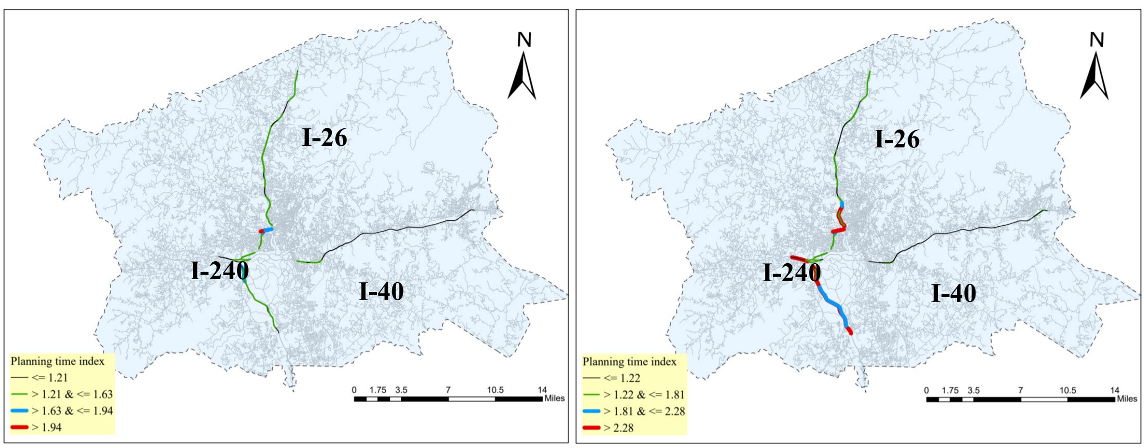
(a) (b)

Figure B12 Maps depicting ATTPM during the night-time hour for links in Buncombe County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)



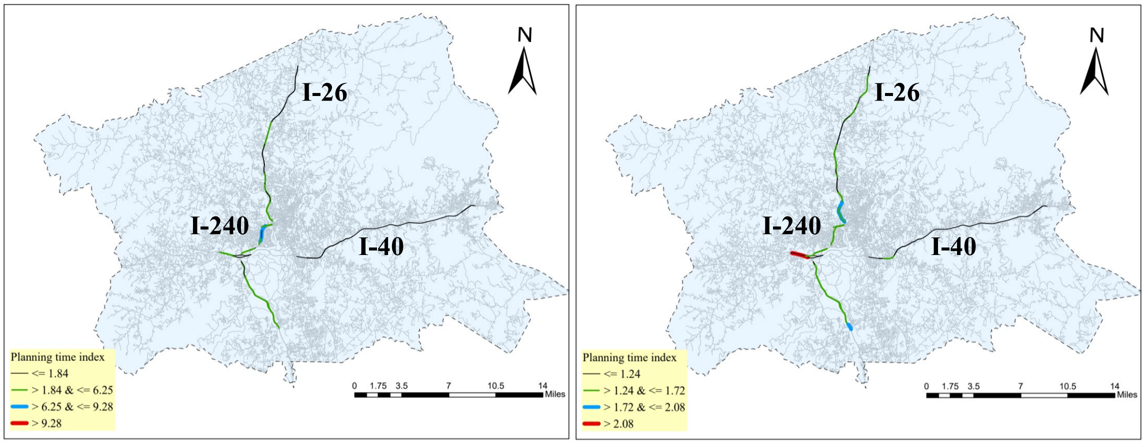
(a) (b)

Figure B13 Maps depicting PTI during the morning peak hour for links in Buncombe County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



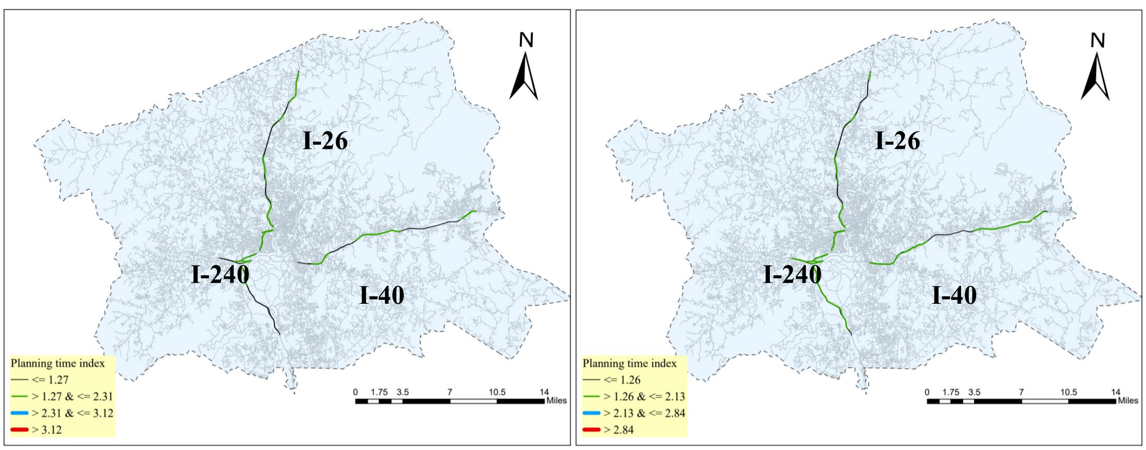
(a) (b)

Figure B14 Maps depicting PTI during the afternoon peak hour for links in Buncombe County
(a) Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



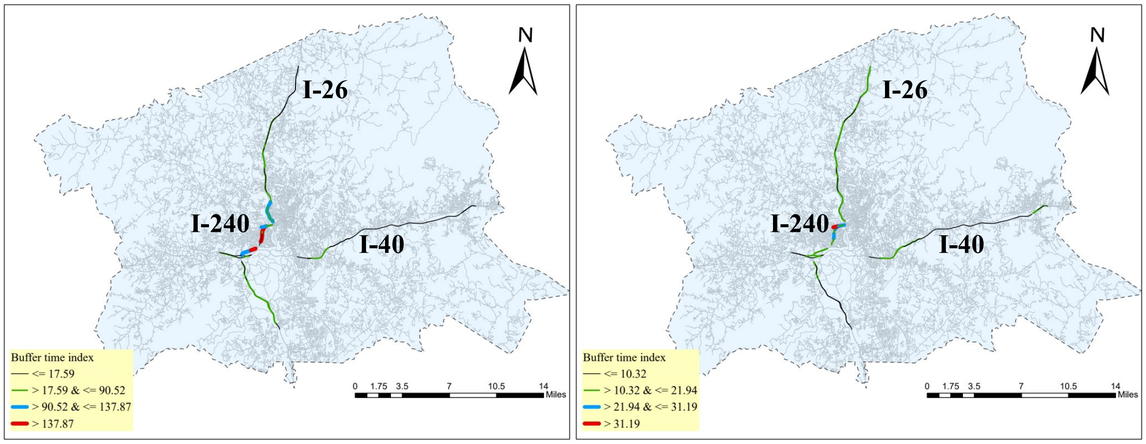
(a) (b)

Figure B15 Maps depicting PTI during the evening peak hour for links in Buncombe County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



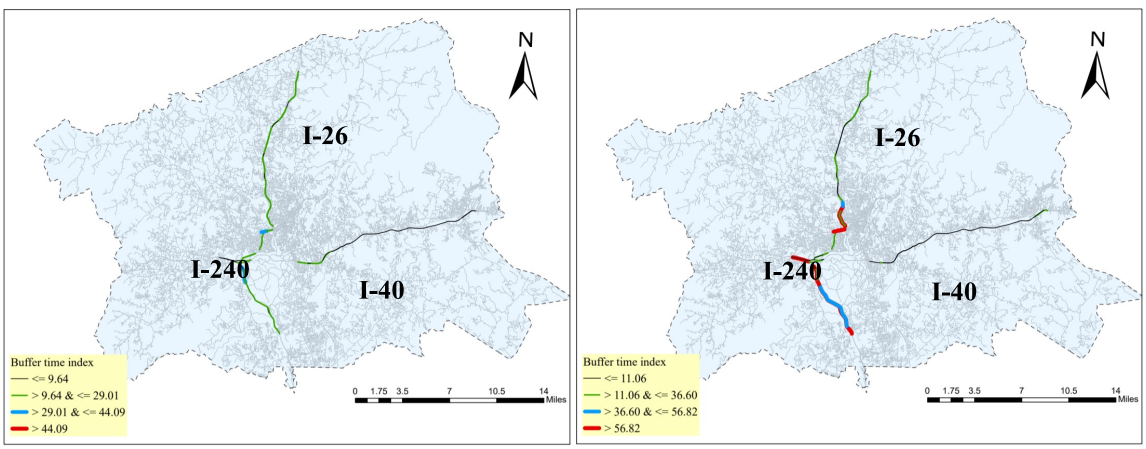
(a) (b)

Figure B16 Maps depicting PTI during the night-time hour for links in Buncombe County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)



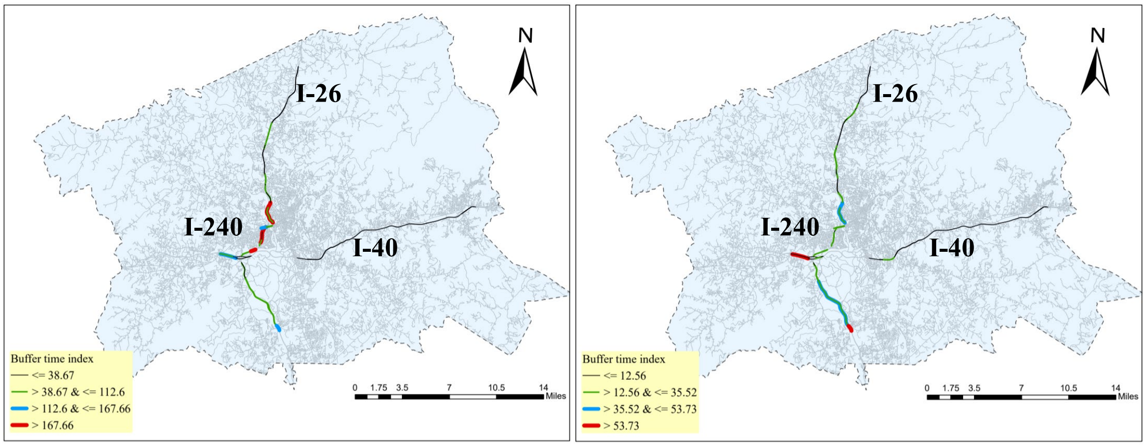
(a) (b)

Figure B17 Maps depicting BTI during the morning peak hour for links in Buncombe County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



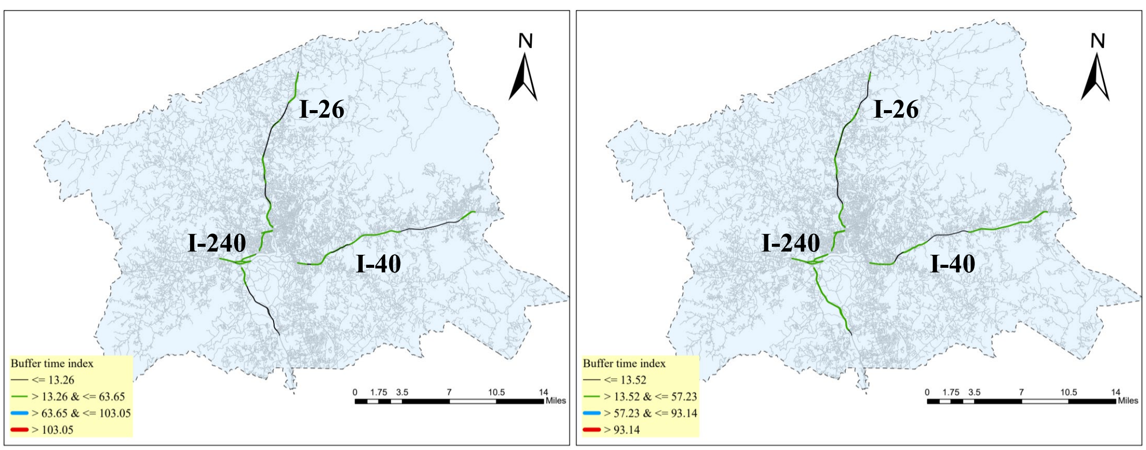
(a) (b)

Figure B18 Maps depicting BTI during the afternoon peak hour for links in Buncombe County
(a) Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



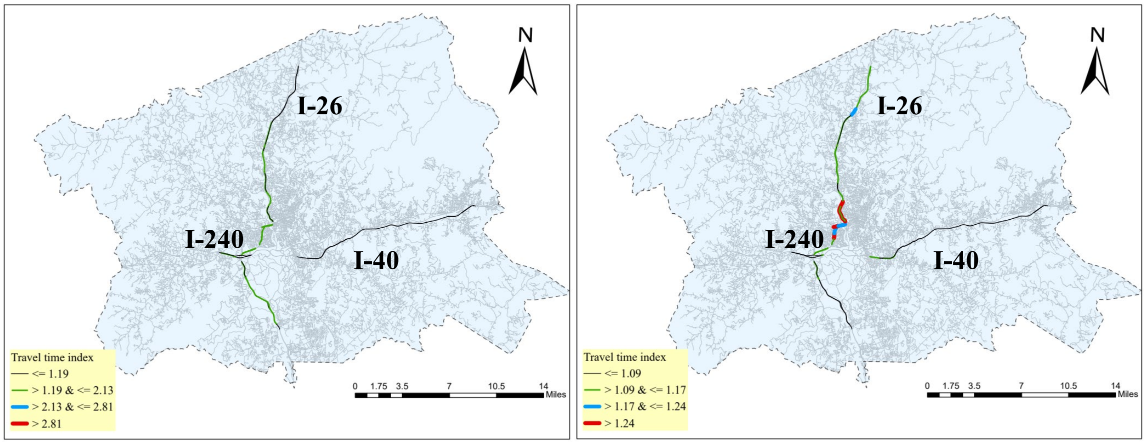
(a) (b)

Figure B19 Maps depicting BTI during the evening peak hour for links in Buncombe County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



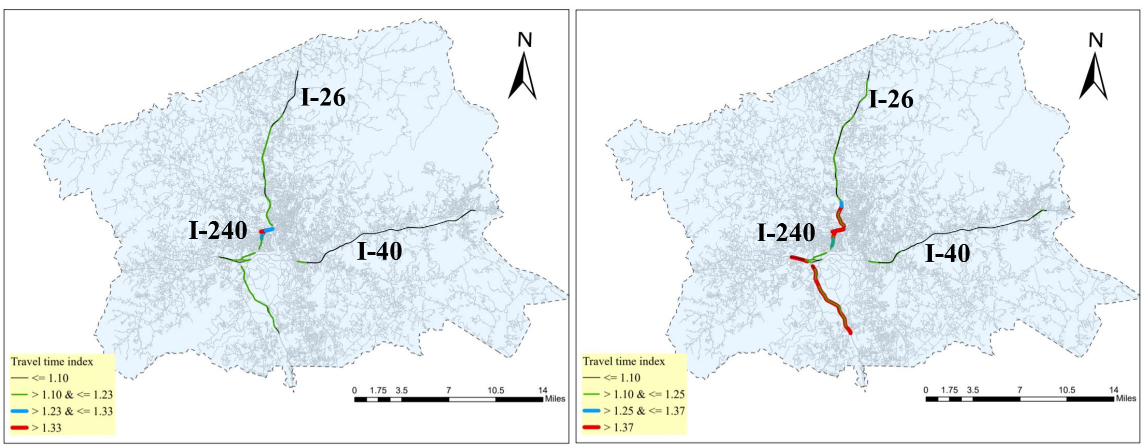
(a) (b)

Figure B20 Maps depicting BTI during the night-time hour for links in Buncombe County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)



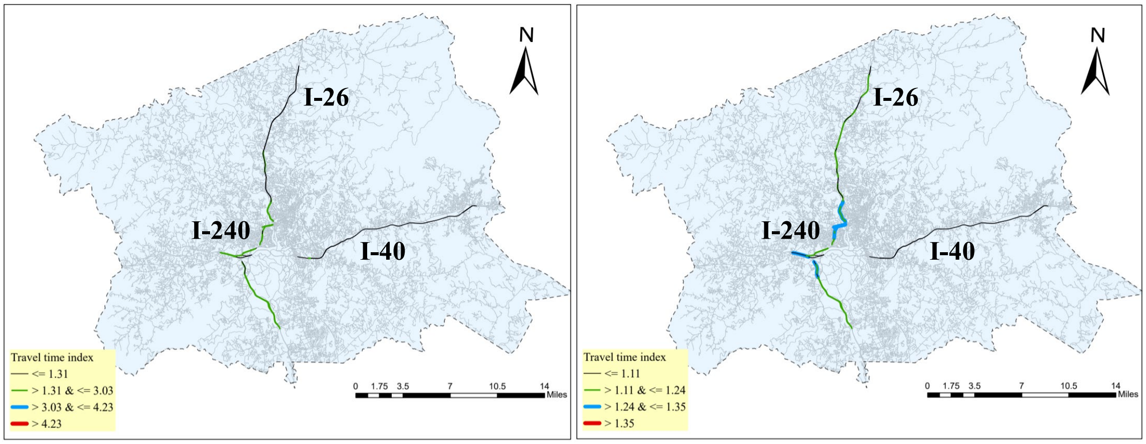
(a) (b)

Figure B21 Maps depicting TTI during the morning peak hour for links in Buncombe County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



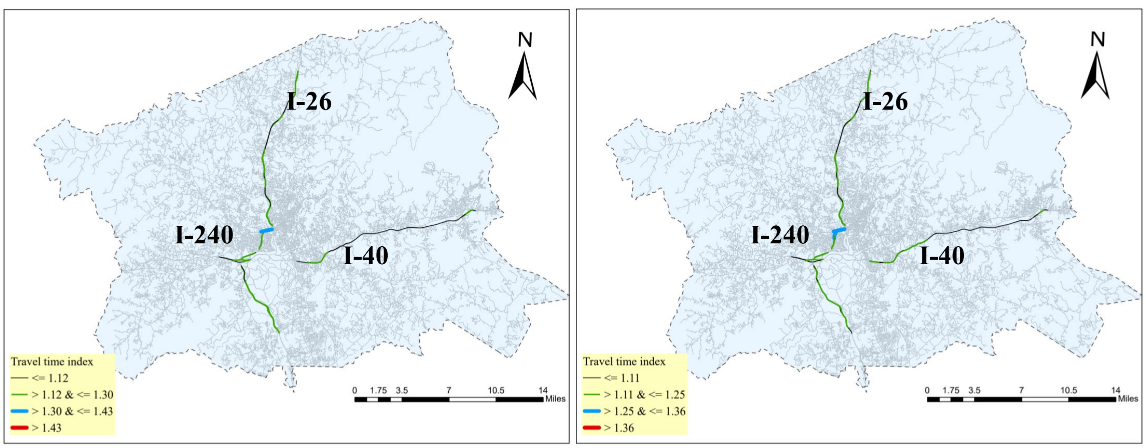
(a) (b)

Figure B22 Maps depicting TTI during the afternoon peak hour for links in Buncombe County
(a) Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



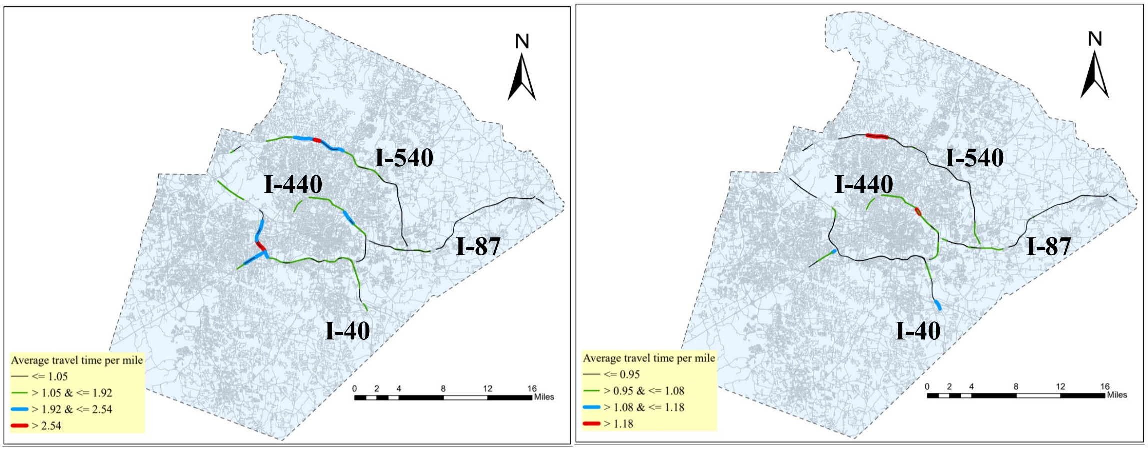
(a) (b)

Figure B23 Maps depicting TTI during the evening peak hour for links in Buncombe County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



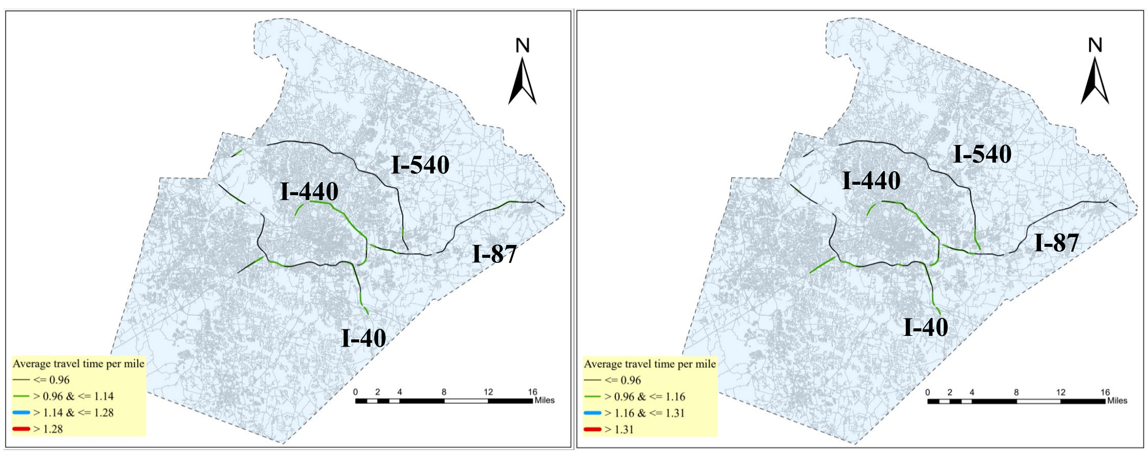
(a) (b)

Figure B24 Maps depicting TTI during the night-time hour for links in Buncombe County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)



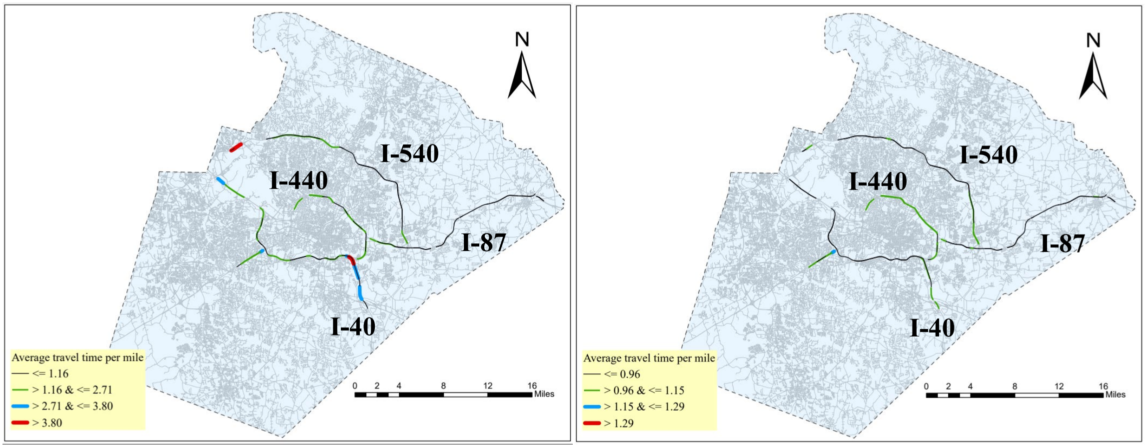
(a) (b)

Figure B25 Maps depicting ATTPM during the morning peak hour for links in Wake County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



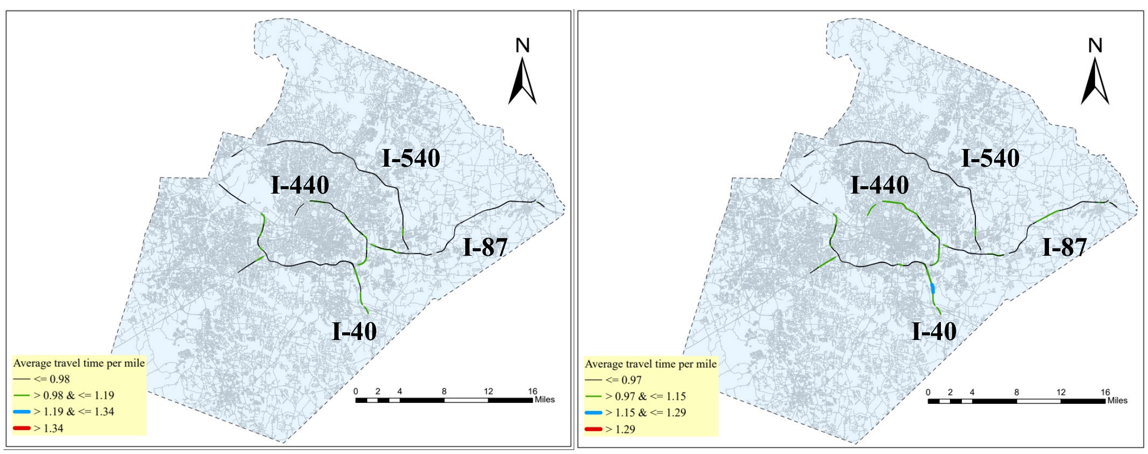
(a) (b)

Figure B26 Maps depicting ATTPM during the afternoon peak hour for links in Wake County
(a) Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



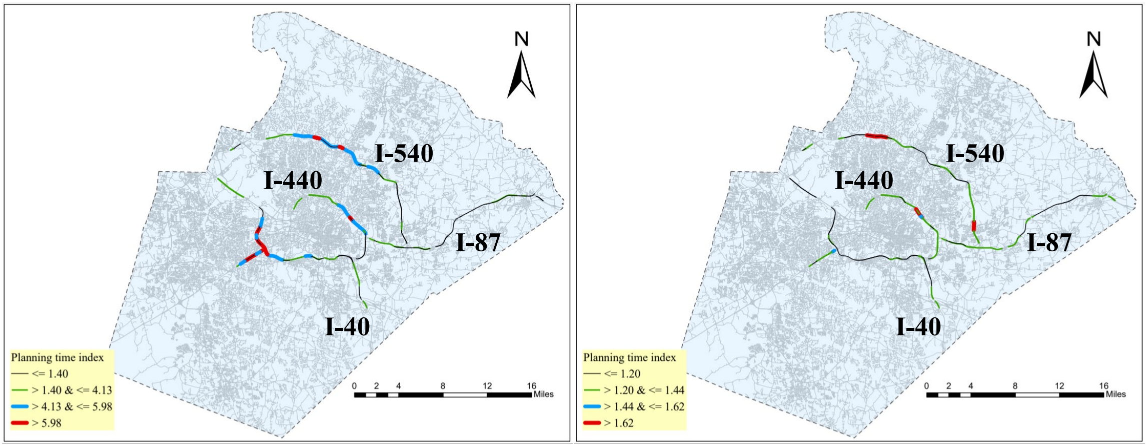
(a) (b)

Figure B27 Maps depicting ATTPM during the evening peak hour for links in Wake County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



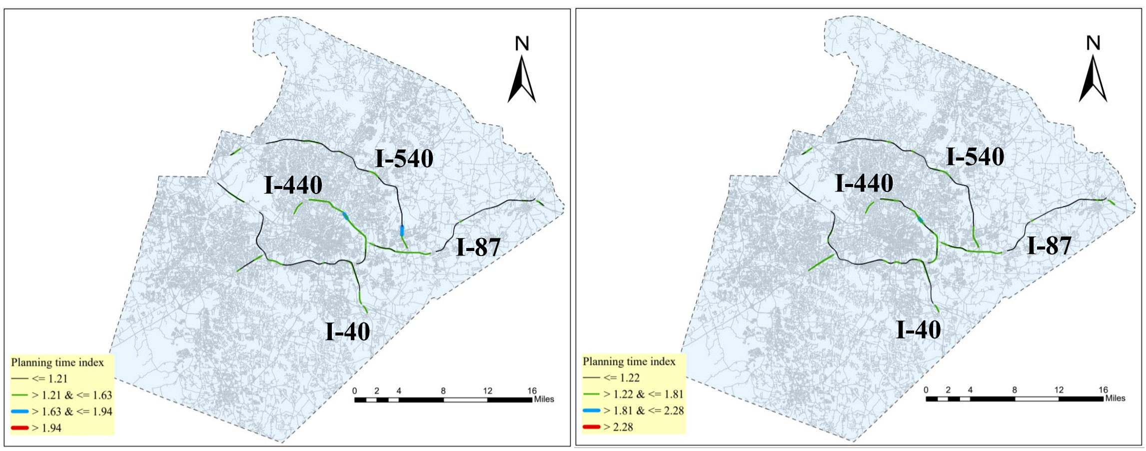
(a) (b)

Figure B28 Maps depicting ATTPM during the night-time hour for links in Wake County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)



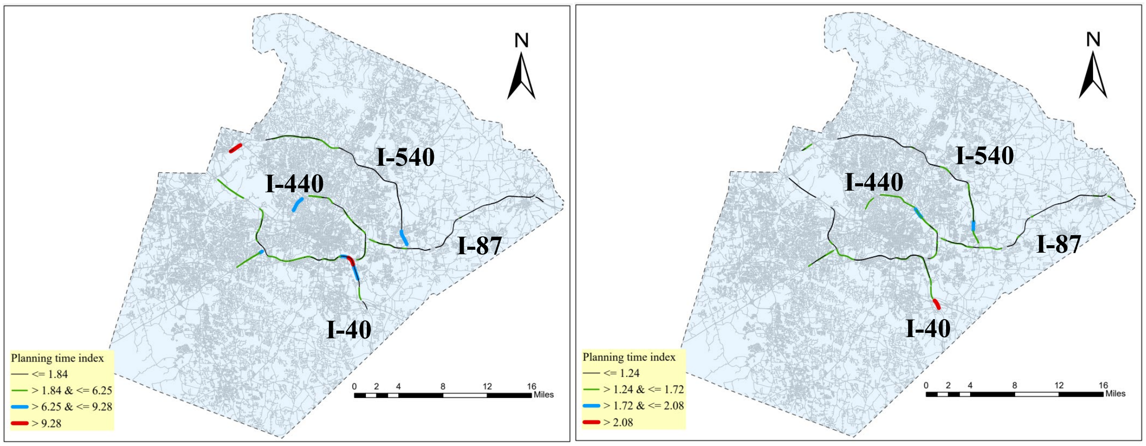
(a) (b)

Figure B29 Maps depicting PTI during the morning peak hour for links in Wake County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



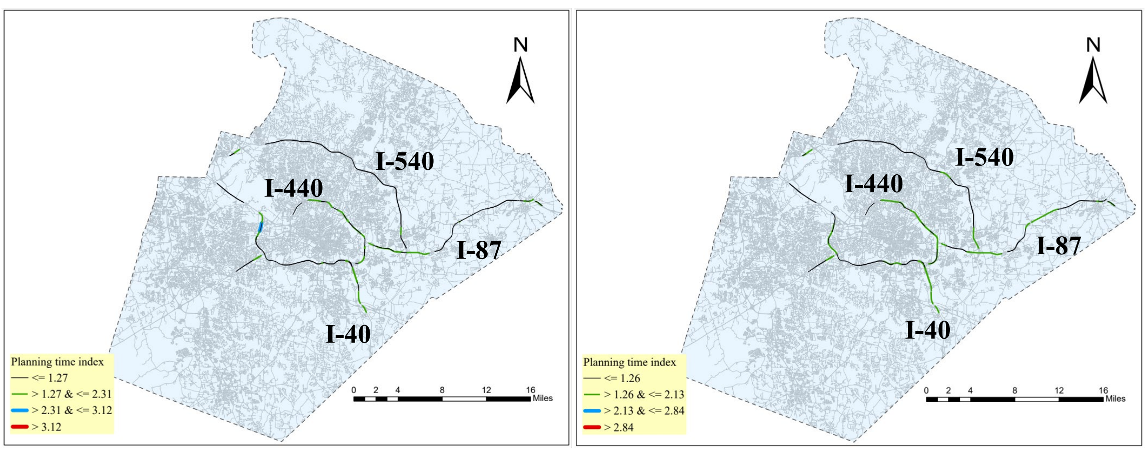
(a) (b)

Figure B30 Maps depicting PTI during the afternoon peak hour for links in Wake County
(a) Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



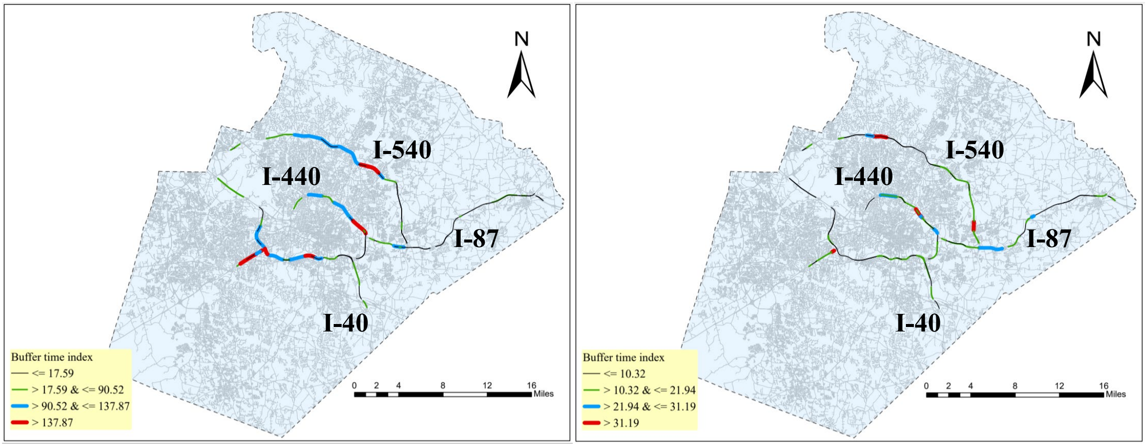
(a) (b)

Figure B31 Maps depicting PTI during the evening peak hour for links in Wake County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



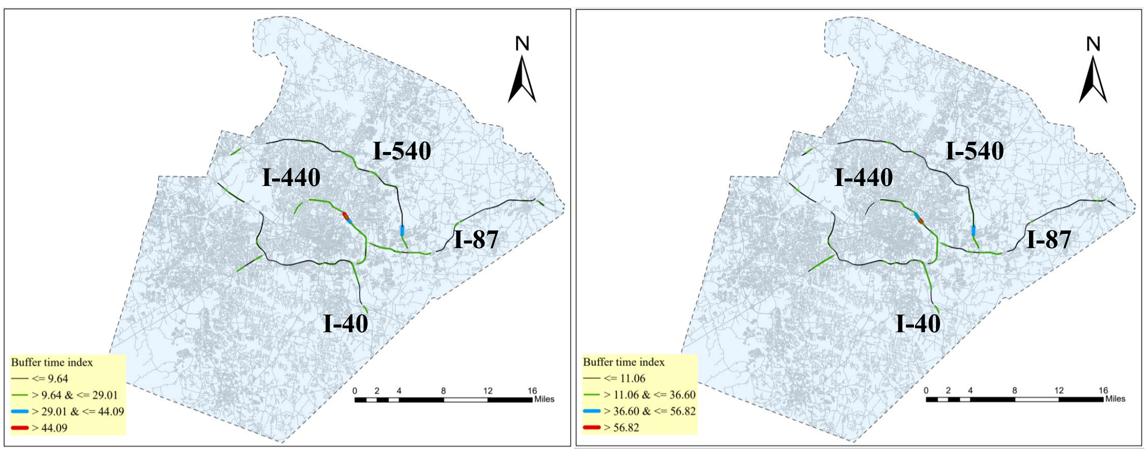
(a) (b)

Figure B32 Maps depicting PTI during the night-time hour for links in Wake County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)



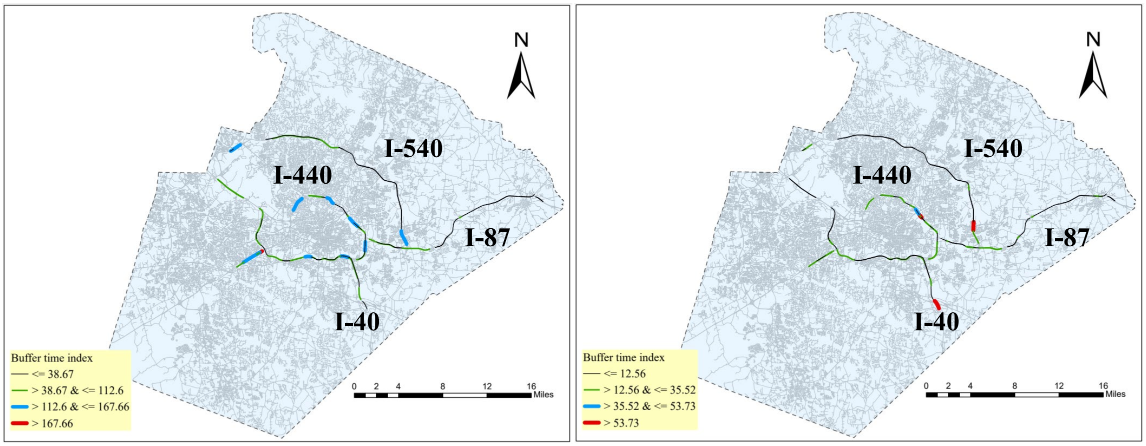
(a) (b)

Figure B33 Maps depicting BTI during the morning peak hour for links in Wake County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



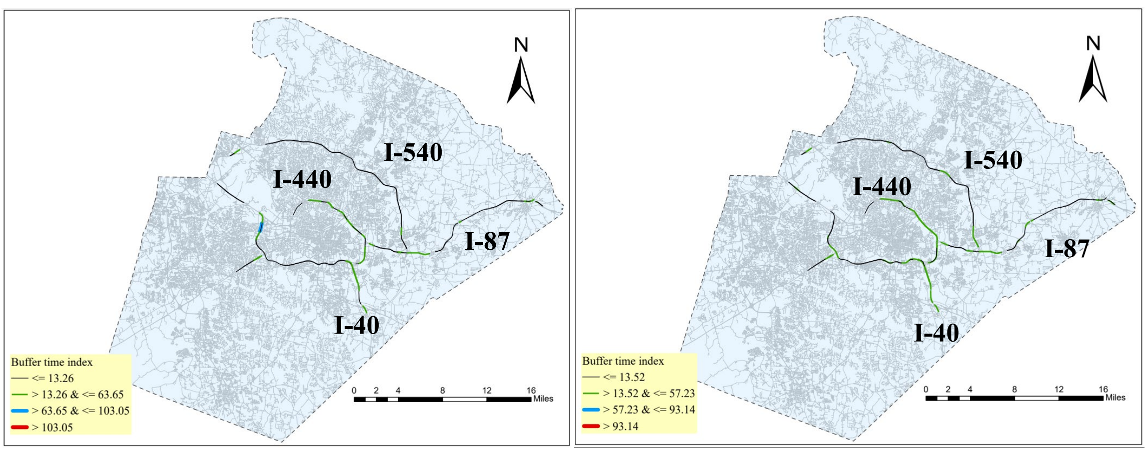
(a) (b)

Figure B34 Maps depicting BTI during the afternoon peak hour for links in Wake County
(a) Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



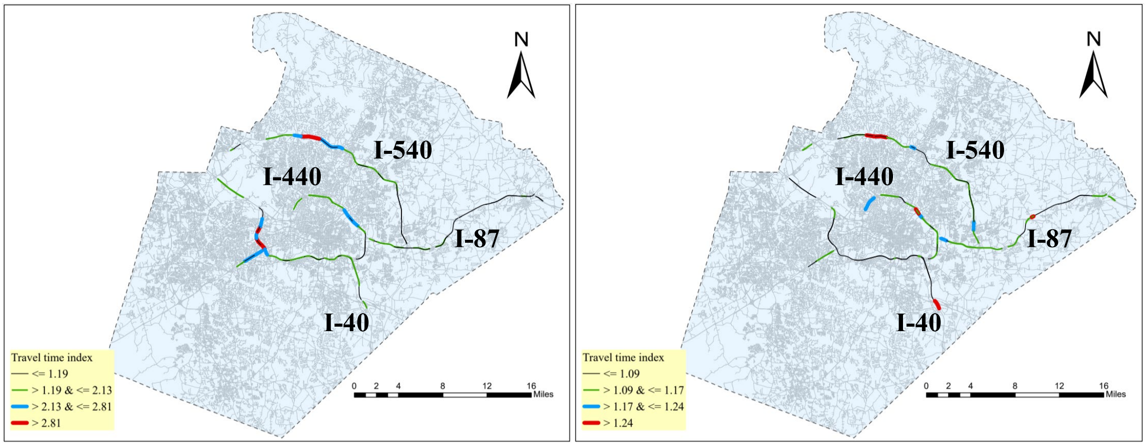
(a) (b)

Figure B35 Maps depicting BTI during the evening peak hour for links in Wake County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



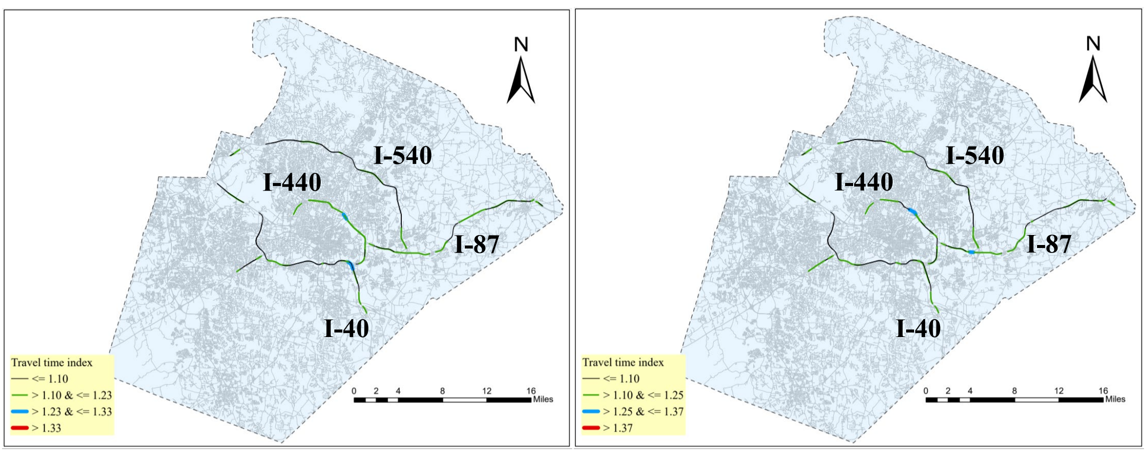
(a) (b)

Figure B 36 Maps depicting BTI during the night-time hour for links in Wake County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)



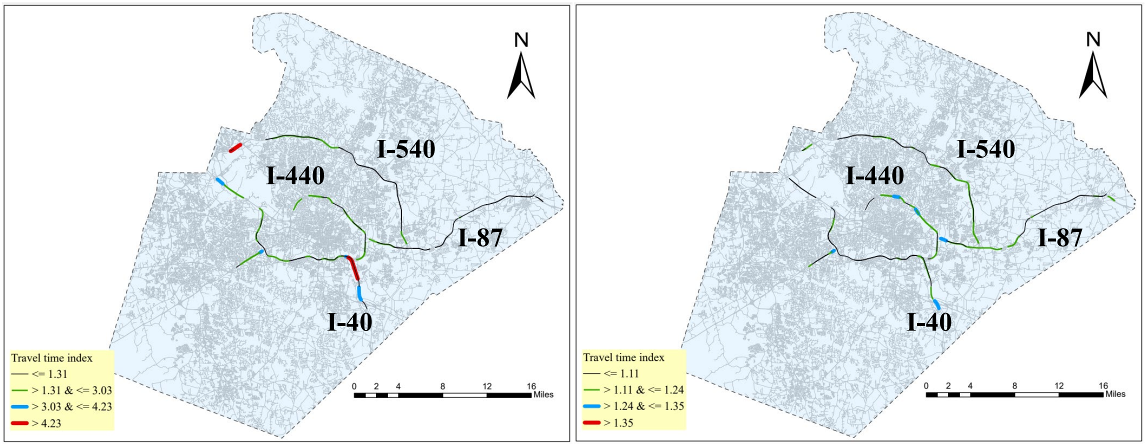
(a) (b)

Figure B37 Maps depicting TTI during the morning peak hour for links in Wake County
(a) Morning peak hour (weekday); (b) Morning peak hour (weekend)



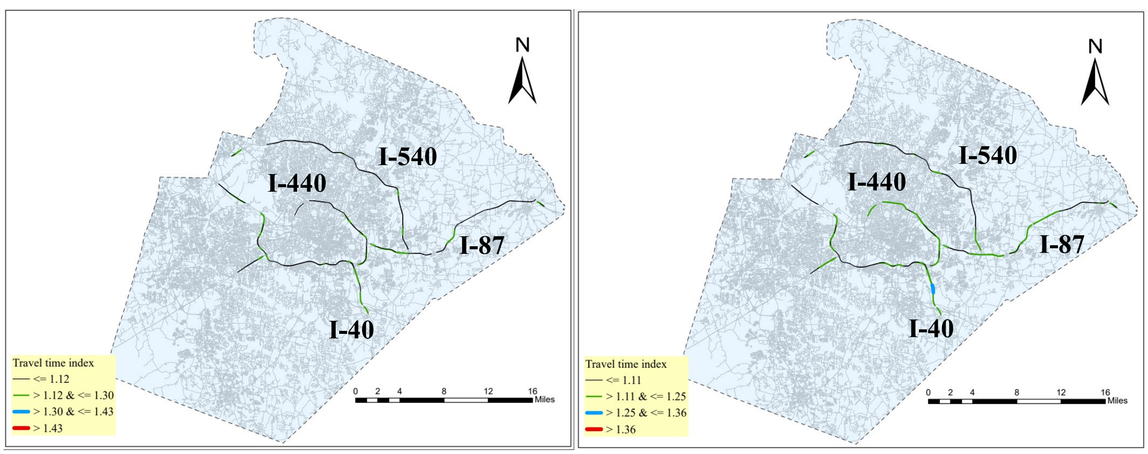
(a) (b)

Figure B38 Maps depicting BTI during the afternoon peak hour for links in Wake County
(a) Afternoon peak hour (weekday); (b) Afternoon peak hour (weekend)



(a) (b)

Figure B39 Maps depicting TTI during the evening peak hour for links in Wake County
(a) Evening peak hour (weekday); (b) Evening peak hour (weekend)



(a) (b)

Figure B40 Maps depicting TTI during the night-time hour for links in Wake County
(a) Night-time hour (weekday); (b) Night-time hour (weekend)

APPENDIX C: SIGNIFICANT VARIABLES IN TRUCK TRAVEL TIME ESTIMATION MODELS

This appendix summarizes significant variables in travel time estimation models developed in this research. The tables include summaries of linear models with/without intercept and gamma log link models developed using all the variables and through backward elimination.

Table C1 shows the variables significant in models developed using all the variables from multiple buffer widths. Tables C2-C4 show the variables significant in models developed using all the variables from specific buffer widths (say, 0.25 mile). Tables C5-C7 show the variables significant in models developed using all the variables by assigning spatial weights based on distance decay function.

Tables C8-C10 show the variables significant in models with speed limit <= 50 mph, Tables C11-C13 show the variables significant in models with speed limit >50 mph & <=60 mph, and Tables C14-C16 show the variables significant in models with speed limit >60 mph.

Tables C17-C19 show the variables significant in models for Mecklenburg County, Tables C20-C22 show the variables significant in models for Buncombe County, and Tables C23-C25 show the variables significant in models for Wake County.

Table C1 Significant variables in the models using data of all buffer widths

Parameter		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓	✓				
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture (0.25 mile)		✓	✓	✓	✓	✓	✓
College (0.25 mile)			✓		✓		✓
Government (0.25 mile)							
Heavy commercial (0.25 mile)							✓
Heavy industrial (0.25 mile)							
Institutional (0.25 mile)							
Light commercial (0.25 mile)			✓				
Light industrial (0.25 mile)							✓
Medical (0.25 mile)		✓	✓	✓		✓	✓
Multifamily residential (0.25 mile)							
Office (0.25 mile)		✓	✓	✓		✓	✓
Recreational (0.25 mile)							
Resource (0.25 mile)							
Retail (0.25 mile)			✓				✓
Single family residential (0.25 mile)							
Transportation (0.25 mile)							
Unknown/Vacant (0.25 mile)			✓				✓
Agriculture (0.50 mile)							
College (0.50 mile)							
Government (0.50 mile)			✓				✓
Heavy commercial (0.50 mile)			✓	✓			✓
Heavy industrial (0.50 mile)			✓				✓
Institutional (0.50 mile)							
Light commercial (0.50 mile)							
Light industrial (0.50 mile)			✓				✓
Medical (0.50 mile)				✓			
Multifamily residential (0.50 mile)							
Office (0.50 mile)		✓	✓	✓	✓	✓	✓
Recreational (0.50 mile)							
Resource (0.50 mile)							
Retail (0.50 mile)							
Single family residential (0.50 mile)							
Transportation (0.50 mile)			✓				✓
Unknown/Vacant (0.50 mile)					✓		

Parameter		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Agriculture (1 mile)		✓	✓		✓	✓	✓
College (1 mile)					✓		
Government (1 mile)							
Heavy commercial (1 mile)			✓				✓
Heavy industrial (1 mile)							
Institutional (1 mile)							
Light commercial (1 mile)			✓				✓
Light industrial (1 mile)							
Medical (1 mile)		✓	✓	✓	✓	✓	✓
Multifamily residential (1 mile)							
Office (1 mile)							
Recreational (1 mile)							
Resource (1 mile)							
Retail (1 mile)			✓				✓
Single family residential (1 mile)							
Transportation (1 mile)							
Unknown/Vacant (1 mile)		✓	✓	✓	✓	✓	✓
Developed area (0.25 mile)			✓		✓		✓
Developed area (0.50 mile)			✓				✓
Developed area (1 mile)					✓		
Population (0.25 mile)							
Population (0.50 mile)							
Population (1 mile)		✓	✓	✓	✓		
# of household units (0.25 mile)							
# of household units (0.50 mile)							
# of household units (1 mile)		✓	✓	✓	✓		
Population density (0.25 mile)							
Population density (0.50 mile)							
Population density (1 mile)							
Employment density (0.25 mile)			✓		✓		
Employment density (0.50 mile)		✓	✓		✓	✓	
Employment density (1 mile)							

Note 1: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.
Note 2: Variable with representing off-network characteristics (land use and demographic) showing "(0.25-mile)", "(0.50-mile)" and "(1 mile)" indicate their corresponding their buffer width information.

Table C2 Significant variables in the models using 0.25-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture							
College							
Government		✓	✓	✓	✓	✓	✓
Heavy commercial							
Heavy industrial		✓	✓	✓	✓	✓	✓
Institutional							
Light commercial							
Light industrial							
Medical							
Multifamily residential							
Office		✓	✓	✓	✓	✓	✓
Recreational							
Resource							
Retail						✓	
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area							
Population		✓	✓				
# of household units			✓				
Population density							
Employment density			✓				✓

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes and functional class) are, not included in the table.

Table C3 Significant variables in the models using 0.50-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓					
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture							
College							
Government		✓	✓	✓	✓	✓	✓
Heavy commercial				✓		✓	
Heavy industrial			✓	✓	✓		✓
Institutional							
Light commercial		✓				✓	
Light industrial		✓	✓		✓	✓	✓
Medical							
Multifamily residential				✓			
Office		✓	✓	✓	✓	✓	✓
Recreational							
Resource						✓	
Retail						✓	
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area		✓	✓		✓	✓	✓
Population			✓				
# of household units			✓				
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C4 Significant variables in the models using 1-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓	✓				
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture							
College					✓		
Government		✓	✓	✓		✓	✓
Heavy commercial							
Heavy industrial							
Institutional							
Light commercial							
Light industrial		✓	✓			✓	✓
Medical		✓	✓	✓	✓	✓	
Multifamily residential							
Office		✓	✓	✓	✓	✓	✓
Recreational							
Resource							
Retail							
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area		✓	✓		✓	✓	✓
Population		✓	✓	✓	✓	✓	✓
# of household units		✓	✓		✓	✓	✓
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C5 Significant variables in the models based on spatial weights (1/d function)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓	✓				
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture							
College							
Government		✓	✓	✓	✓	✓	✓
Heavy commercial							
Heavy industrial							
Institutional							
Light commercial							
Light industrial			✓		✓		✓
Medical							
Multifamily residential							
Office		✓	✓	✓	✓	✓	✓
Recreational							
Resource							
Retail							
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area			✓		✓		✓
Population		✓	✓	✓	✓	✓	✓
# of household units		✓	✓	✓	✓	✓	✓
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C6 Significant variables in the models based on spatial weights ($1/d^2$ function)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture					✓		
College							
Government		✓	✓	✓	✓	✓	✓
Heavy commercial							
Heavy industrial		✓	✓	✓	✓	✓	✓
Institutional							
Light commercial							
Light industrial							✓
Medical							
Multifamily residential					✓		
Office		✓	✓	✓	✓	✓	✓
Recreational							
Resource							
Retail						✓	
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area							✓
Population		✓		✓		✓	
# of household units		✓					
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C7 Significant variables in the models based on spatial weights ($1/d^3$ function)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓		✓	✓	✓	✓
Ln(AADT)		✓		✓	✓	✓	✓
Number of through lanes	4	✓		✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Number of through lanes	10		✓				
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture							
College							
Government		✓	✓	✓	✓	✓	✓
Heavy commercial				✓			
Heavy industrial		✓	✓	✓	✓	✓	
Institutional							
Light commercial							
Light industrial							
Medical							
Multifamily residential					✓		
Office		✓	✓	✓	✓	✓	✓
Recreational							
Resource							
Retail						✓	
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area							
Population		✓	✓				
# of household units		✓	✓				
Population density							
Employment density			✓				

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C8 Significant variables in the models with speed limit <= 50 mph and 0.25-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Time of the day	Night time						
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓		✓		✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Functional class	Interstates	✓		✓		✓	
Agriculture							
College		✓		✓		✓	
Government		✓		✓		✓	
Heavy commercial		✓		✓		✓	
Heavy industrial		✓		✓	✓	✓	✓
Institutional		✓	✓	✓	✓	✓	✓
Light commercial		✓	✓	✓		✓	
Light industrial							
Medical							
Multifamily residential		✓		✓		✓	
Office		✓	✓	✓	✓	✓	✓
Recreational							
Resource		✓		✓		✓	
Retail		✓	✓	✓		✓	
Single family residential		✓		✓		✓	
Transportation							
Unknown/Vacant				✓		✓	
Developed area		✓	✓	✓	✓	✓	✓
Population		✓		✓		✓	
# of household units							
Population density		✓		✓		✓	✓
Employment density		✓		✓		✓	

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C9 Significant variables in the models with speed limit <= 50 mph and 0.50-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓				✓	
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓		✓	✓	
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓		✓	✓	✓	
Functional class	Interstates						
Agriculture							
College		✓	✓	✓	✓	✓	✓
Government		✓	✓	✓	✓	✓	✓
Heavy commercial					✓		
Heavy industrial		✓		✓	✓	✓	
Institutional		✓		✓	✓	✓	
Light commercial		✓			✓	✓	
Light industrial		✓	✓			✓	✓
Medical							
Multifamily residential			✓	✓	✓		✓
Office				✓	✓		
Recreational		✓	✓	✓	✓	✓	✓
Resource							
Retail		✓		✓	✓	✓	
Single family residential		✓	✓	✓	✓	✓	✓
Transportation		✓	✓	✓	✓	✓	✓
Unknown/Vacant		✓		✓	✓	✓	
Developed area			✓	✓	✓		✓
Population		✓	✓	✓	✓	✓	✓
# of household units		✓	✓	✓	✓	✓	✓
Population density		✓	✓	✓	✓	✓	✓
Employment density		✓	✓	✓	✓	✓	✓

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C10 Significant variables in the models with speed limit <= 50 mph and 1-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓	✓			✓	✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Functional class	Interstates	✓		✓		✓	
Agriculture		✓	✓	✓	✓	✓	✓
College		✓	✓	✓	✓	✓	✓
Government		✓	✓	✓	✓	✓	✓
Heavy commercial		✓	✓	✓	✓	✓	✓
Heavy industrial		✓	✓	✓	✓	✓	✓
Institutional		✓	✓	✓	✓	✓	✓
Light commercial		✓	✓	✓	✓	✓	✓
Light industrial		✓	✓	✓	✓	✓	✓
Medical		✓	✓	✓	✓	✓	✓
Multifamily residential		✓	✓	✓	✓	✓	✓
Office		✓	✓	✓	✓	✓	✓
Recreational		✓	✓	✓	✓	✓	✓
Resource		✓	✓	✓	✓	✓	✓
Retail		✓	✓	✓	✓	✓	✓
Single family residential		✓	✓	✓	✓	✓	✓
Transportation		✓	✓	✓	✓	✓	✓
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area		✓	✓	✓	✓	✓	✓
Population		✓	✓	✓	✓	✓	✓
# of household units		✓	✓	✓	✓	✓	✓
Population density		✓	✓	✓	✓	✓	✓
Employment density			✓	✓	✓		✓

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C11 Significant variables in the models with speed limit > 50 mph and <=60 mph and 0.25-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)				✓	✓		
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8		✓		✓	✓	✓
Functional class	Interstates						
Agriculture			✓				
College							✓
Government							
Heavy commercial							
Heavy industrial							
Institutional		✓		✓	✓	✓	✓
Light commercial							
Light industrial		✓	✓		✓	✓	✓
Medical							
Multifamily residential					✓		✓
Office		✓		✓	✓	✓	
Recreational							
Resource							
Retail		✓		✓	✓	✓	✓
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area							
Population							
# of household units			✓		✓		✓
Population density		✓	✓		✓	✓	✓
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C12 Significant variables in the models with speed limit > 50 mph and <=60 mph and 0.50-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓	✓	✓		✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8		✓		✓		✓
Functional class	Interstates						
Agriculture							
College							
Government							
Heavy commercial							
Heavy industrial		✓	✓	✓	✓	✓	✓
Institutional		✓	✓	✓	✓	✓	✓
Light commercial							
Light industrial						✓	
Medical							
Multifamily residential							
Office		✓	✓	✓	✓	✓	✓
Recreational		✓		✓		✓	
Resource							
Retail							
Single family residential							
Transportation							
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area			✓		✓	✓	✓
Population							
# of household units			✓		✓		✓
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C13 Significant variables in the models with speed limit > 50 mph and <=60 mph and 1-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept						✓	
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓		✓	✓	✓	
Number of through lanes	4	✓	✓		✓	✓	✓
Number of through lanes	6	✓	✓			✓	✓
Number of through lanes	8		✓				✓
Functional class	Interstates						
Agriculture		✓		✓	✓	✓	
College							
Government							
Heavy commercial		✓		✓	✓	✓	
Heavy industrial			✓				✓
Institutional							✓
Light commercial							
Light industrial			✓				✓
Medical							
Multifamily residential			✓				✓
Office			✓		✓		✓
Recreational							
Resource			✓				✓
Retail		✓		✓	✓	✓	✓
Single family residential					✓		
Transportation							
Unknown/Vacant			✓		✓		✓
Developed area			✓				✓
Population			✓				✓
# of household units					✓		
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C14 Significant variables in the models with speed limit >60 mph and 0.25-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept						✓	✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓			✓	✓
Functional class	Interstates						
Agriculture			✓				✓
College				✓		✓	
Government							
Heavy commercial							
Heavy industrial							
Institutional		✓					
Light commercial							
Light industrial		✓					
Medical							
Multifamily residential							
Office		✓					
Recreational							
Resource				✓	✓	✓	
Retail		✓		✓		✓	
Single family residential						✓	
Transportation							
Unknown/Vacant		✓					
Developed area							
Population							
# of household units							
Population density		✓					
Employment density			✓	✓	✓	✓	✓

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C15 Significant variables in the models with speed limit >60 mph and 0.50-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept						✓	✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓		✓	✓	✓
Number of through lanes	8	✓	✓			✓	✓
Functional class	Interstates						
Agriculture							✓
College							
Government		✓		✓	✓	✓	
Heavy commercial							
Heavy industrial							
Institutional							
Light commercial							
Light industrial							
Medical							
Multifamily residential							
Office					✓		✓
Recreational							
Resource					✓		
Retail		✓		✓	✓	✓	✓
Single family residential		✓	✓	✓	✓	✓	✓
Transportation							
Unknown/Vacant							
Developed area							
Population					✓		✓
# of household units			✓				
Population density							
Employment density			✓	✓	✓		✓

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C16 Significant variables in the models with speed limit >60 mph and 1-mile buffer width data

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept			✓			✓	✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓	✓		✓	✓	✓
Number of through lanes	6	✓	✓			✓	✓
Number of through lanes	8		✓				✓
Functional class	Interstates						
Agriculture		✓	✓	✓	✓	✓	✓
College							
Government							
Heavy commercial		✓		✓	✓	✓	✓
Heavy industrial							
Institutional							
Light commercial							
Light industrial							
Medical							
Multifamily residential							
Office			✓		✓		
Recreational							
Resource							
Retail		✓		✓	✓	✓	✓
Single family residential			✓		✓		✓
Transportation							
Unknown/Vacant					✓		
Developed area							
Population							
# of household units			✓		✓		✓
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C17 Significant variables in the models for Mecklenburg County (0.25-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓				✓	
Time of the day	Morning peak	✓	✓	✓		✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓		✓	✓
Ln(AADT)			✓	✓			✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓		✓	✓
Functional class	Interstates	✓			✓	✓	
Reference speed							
Agriculture						✓	✓
College							
Government		✓		✓		✓	✓
Heavy commercial		✓				✓	
Heavy industrial		✓		✓		✓	
Institutional							
Light commercial							
Light industrial							
Medical		✓		✓		✓	
Multifamily residential							
Office							
Recreational							
Resource							
Retail							
Single family residential		✓	✓	✓		✓	✓
Transportation		✓	✓	✓	✓	✓	✓
Unknown/Vacant				✓	✓		
Developed area							
Population							
# of household units			✓				✓
Population density					✓		
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C18 Significant variables in the models for Mecklenburg County (0.50-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓				✓	
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓	✓	✓		✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates	✓				✓	
Reference speed							
Agriculture						✓	
College		✓				✓	
Government							
Heavy commercial		✓		✓	✓	✓	✓
Heavy industrial							
Institutional							
Light commercial							
Light industrial							
Medical					✓		
Multifamily residential			✓				
Office							
Recreational							
Resource		✓				✓	
Retail		✓		✓	✓		
Single family residential		✓	✓	✓	✓	✓	✓
Transportation							
Unknown/Vacant		✓		✓	✓		
Developed area							
Population							
# of household units					✓		✓
Population density							
Employment density		✓		✓	✓	✓	✓

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C19 Significant variables in the models for Mecklenburg County (1-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓	✓				
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)				✓	✓		✓
Number of through lanes	4	✓	✓	✓	✓	✓	✓
Number of through lanes	6	✓	✓	✓	✓	✓	✓
Number of through lanes	8	✓	✓	✓	✓	✓	✓
Speed limit		✓	✓	✓	✓	✓	✓
Functional class	Interstates						
Reference speed							
Agriculture			✓				
College							
Government							
Heavy commercial							
Heavy industrial							
Institutional							
Light commercial					✓		✓
Light industrial							
Medical							
Multifamily residential							
Office			✓				
Recreational							
Resource							
Retail							
Single family residential		✓	✓	✓	✓	✓	✓
Transportation							
Unknown/Vacant		✓		✓	✓		✓
Developed area							
Population							
# of household units					✓		✓
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C20 Significant variables in the models for Buncombe County (0.25-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓				✓	
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓	✓	✓		✓
Number of through lanes	4	✓				✓	
Number of through lanes	6			✓			
Number of through lanes	8						
Speed limit		✓	✓		✓	✓	✓
Functional class	Interstates	✓		✓			
Reference speed		✓		✓		✓	
Agriculture							
College			✓	✓	✓		✓
Government							
Heavy commercial							
Heavy industrial				✓			
Institutional							
Light commercial							
Light industrial		✓	✓	✓	✓	✓	✓
Medical						✓	
Multifamily residential							
Office			✓				✓
Recreational							
Resource		✓	✓	✓	✓	✓	✓
Retail			✓	✓	✓		
Single family residential							
Transportation							
Unknown/Vacant							
Developed area							
Population				✓	✓		
# of household units					✓		
Population density							
Employment density		✓	✓				

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C21 Significant variables in the models for Buncombe County (0.50-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓	✓			✓	
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓	✓	✓		
Number of through lanes	4						
Number of through lanes	6						
Number of through lanes	8						
Speed limit		✓	✓			✓	✓
Functional class	Interstates						
Reference speed		✓				✓	
Agriculture					✓		
College			✓	✓	✓	✓	✓
Government		✓	✓	✓	✓	✓	✓
Heavy commercial							
Heavy industrial		✓	✓	✓	✓	✓	✓
Institutional							
Light commercial							✓
Light industrial							✓
Medical		✓	✓	✓		✓	✓
Multifamily residential							
Office		✓				✓	
Recreational							
Resource		✓	✓	✓	✓	✓	✓
Retail		✓	✓	✓	✓	✓	✓
Single family residential							
Transportation							
Unknown/Vacant							
Developed area					✓		✓
Population		✓		✓	✓	✓	
# of household units		✓	✓	✓	✓	✓	✓
Population density		✓			✓	✓	✓
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C22 Significant variables in the models for Buncombe County (1-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept		✓				✓	✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak	✓	✓	✓	✓	✓	✓
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)			✓	✓	✓		✓
Number of through lanes	4	✓					
Number of through lanes	6			✓			
Number of through lanes	8						
Speed limit		✓	✓		✓	✓	✓
Functional class	Interstates						
Reference speed		✓				✓	
Agriculture							
College		✓			✓		✓
Government					✓		✓
Heavy commercial							
Heavy industrial					✓		✓
Institutional							
Light commercial							✓
Light industrial		✓	✓	✓	✓	✓	
Medical		✓			✓	✓	✓
Multifamily residential							
Office		✓		✓	✓	✓	✓
Recreational							✓
Resource		✓	✓	✓	✓	✓	✓
Retail		✓		✓	✓	✓	
Single family residential		✓	✓	✓	✓		✓
Transportation					✓		
Unknown/Vacant							
Developed area							
Population		✓			✓	✓	✓
# of household units							
Population density				✓			✓
Employment density				✓			✓

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C23 Significant variables in the models for Wake County (0.25-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak						
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4						
Number of through lanes	6						
Number of through lanes	8						
Speed limit					✓		
Functional class	Interstates						
Reference speed		✓		✓		✓	
Agriculture			✓				✓
College		✓	✓	✓	✓	✓	✓
Government							
Heavy commercial							
Heavy industrial		✓		✓		✓	
Institutional							
Light commercial		✓		✓		✓	
Light industrial							
Medical							
Multifamily residential		✓		✓		✓	
Office							
Recreational							
Resource		✓	✓	✓	✓	✓	✓
Retail		✓	✓	✓	✓	✓	✓
Single family residential							
Transportation							
Unknown/Vacant							
Developed area							
Population		✓		✓		✓	
# of household units		✓		✓		✓	
Population density						✓	
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C24 Significant variables in the models for Wake County (0.50-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak						
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4			✓		✓	
Number of through lanes	6	✓		✓		✓	
Number of through lanes	8						
Speed limit					✓		✓
Functional class	Interstates						
Reference speed		✓		✓		✓	
Agriculture							
College						✓	
Government							
Heavy commercial		✓	✓	✓	✓	✓	✓
Heavy industrial		✓	✓	✓	✓	✓	✓
Institutional		✓	✓	✓	✓	✓	✓
Light commercial			✓		✓		✓
Light industrial		✓				✓	
Medical							
Multifamily residential							
Office							
Recreational							
Resource							
Retail							
Single family residential		✓	✓	✓	✓	✓	✓
Transportation		✓		✓		✓	
Unknown/Vacant		✓	✓	✓	✓	✓	✓
Developed area							
Population		✓	✓	✓	✓	✓	✓
# of household units		✓	✓	✓	✓	✓	✓
Population density		✓	✓	✓	✓	✓	✓
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.

Table C25 Significant variables in the models for Wake County (1-mile buffer width data)

All variables		Linear (with intercept)		Linear (without intercept)		Gamma log link	
		All variables	Backward elimination	All variables	Backward elimination	All variables	Backward elimination
Intercept							✓
Time of the day	Morning peak	✓	✓	✓	✓	✓	✓
Time of the day	Afternoon peak						
Time of the day	Evening peak	✓	✓	✓	✓	✓	✓
Day of the week	Weekday	✓	✓	✓	✓	✓	✓
Ln(AADT)		✓	✓	✓	✓	✓	✓
Number of through lanes	4	✓		✓		✓	
Number of through lanes	6						
Number of through lanes	8						
Speed limit				✓	✓		
Functional class	Interstates					✓	
Reference speed		✓		✓		✓	
Agriculture							
College							
Government							
Heavy commercial		✓	✓	✓	✓	✓	✓
Heavy industrial				✓		✓	
Institutional							
Light commercial		✓	✓	✓	✓	✓	✓
Light industrial							
Medical		✓	✓	✓	✓	✓	✓
Multifamily residential							
Office							
Recreational							
Resource		✓		✓		✓	
Retail		✓		✓		✓	
Single family residential		✓		✓		✓	
Transportation		✓	✓	✓	✓	✓	✓
Unknown/Vacant							
Developed area							
Population		✓	✓	✓	✓	✓	✓
# of household units		✓	✓	✓	✓	✓	✓
Population density							
Employment density							

Note: The reference categories of the categorical variables (time of the day, day of the week, number of through lanes, and functional class) are not included in the table.