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Understanding the Effect of Pervasive Events on Vehicle Travel Time Patterns

Chirag Akbari, M.Tech. Ninad Gore, Ph.D. Srinivas S. Pulugurtha, Ph.D., P.E., F.ASCE

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16. Abstract

The COVID-19 pandemic has disrupted daily activities and travel patterns, affecting personal and commercial trips. This study investigates the effect of different stages of the pandemic on travel time patterns. Eighty-six geographically distributed links (sections of road) in Mecklenburg County and Buncombe County, North Carolina, were selected for analysis. The selected links accounted for the variation in road geometry, land use, and speed limit. Travel time data for three years (i.e., 2019, 2020, and 2021) were extracted from a private data source at 5-min intervals. Travel time reliability (TTR) and travel time variability (TTV) are estimated for different phases of the pandemic and compared to analyze the effect of COVID-19 on TTR and TTV. The seasonal arithmetic integrated moving average (SARIMA) model was developed to investigate the effect of COVID-19 on average daily travel time patterns. Unreliable and uncertain travel times were observed on lower speed limit links during the off-peak hours while reliable and certain travel times were observed during morning and evening peak hours of the COVID-19 pandemic. This highlights that the COVID-19 pandemic significantly affected the scheduling of trips. For higher speed limits, travel times were reliable and certain during off-peak and peak hours. Among the different phases of COVID-19, significant improvement in TTR and TTV was observed during Phase II, which could be attributed to stay-at-home directives. Trucks followed a similar pattern as passenger cars. Post-COVID-19, i.e., for 2021, travel times were reliable and certain for most links during the morning peak hours. The SARIMA model revealed a significant effect of COVID-19 on average daily travel time patterns. Stable travel time patterns were noted during Phase II of COVID-19. Moreover, a maximum reduction in travel time was observed during Phase II of the COVID-19 pandemic. The findings emphasize the influence of government norms and regulations on travel time patterns during pervasive events such as COVID-19.

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Executive Summary

The aim of this project is to investigate the effect of pervasive events, specifically the COVID-19 pandemic and its different phases, on travel time patterns. The travel time data for links or segments with varying area type, road functional class, road geometry, and speed limit in Mecklenburg County (urban) and Buncombe County (rural) were extracted for three years, i.e., 2019 (pre COVID-19), 2020 (during COVID-19) and 2021 (post COVID-19).

Travel time reliability (TTR) and travel time variability (TTV) analysis were conducted for the three phases of the pandemic, wherein the TTR and TTV indicators for the COVID-19 period were compared with pre COVID-19 and post COVID-19 conditions to investigate the effect of the COVID-19 pandemic on TTR and TTV. Further, a Seasonal Autoregressive Integrated Moving Average (SARIMA) model was developed to comprehend the effect of COVID-19 on travel time patterns.

The findings indicate that the off-peak hours are unreliable and uncertain for links with a lower speed limit. However, most links are observed to be reliable and certain regardless of the time of the day for links with a higher speed limit. This result was consistent for passenger cars and trucks. Moreover, a similar trend was observed for the rural and urban counties. Most of the trips amidst the pandemic were scheduled during off-peak hours. As a result, travel times were uncertain and unreliable for most links during the off-peak hours. Post pandemic trips were scheduled during off-peak and evening peak hours. Therefore, a larger percentage of links were reliable during the morning peak hours. This can be due to the after-effects of COVID-19, which caused public and private sectors to change work policies and timings.

The findings also indicate that during Phase I, passenger cars and trucks experienced a marginal change in TTR and TTV, which further improved in Phase II due to stricter government restrictions. However, as restrictions were relaxed in Phase III, the number of links showing improved reliability decreased. Trucks exhibited a similar pattern but had a slower tendency to return to normality after the pandemic.

The study demonstrated the effectiveness of SARIMA models in modeling average daily travel time for passenger cars and trucks, considering seasonal variations. The analysis of actual and forecasted travel times highlighted a significant impact of COVID-19 on average daily travel time patterns. Travel time patterns were stable (lesser variation in average daily travel times) for Phase II of the pandemic. An overall improvement in reliability and change in travel time patterns during the COVID-19 pandemic was influenced by governmental rules and regulations. Strict restrictions implemented during Phase II significantly altered travel time patterns, gradually returning to normal with relaxations in Phase III.

These findings emphasize the significance of governmental norms and regulations in shaping travel time patterns during pervasive events such as the COVID-19 pandemic. It is crucial to

consider the effect of the pandemic and the corresponding governmental interventions when assessing the effects on travel. By understanding these dynamics, policymakers can develop strategies to effectively manage travel disruptions and ensure reliable transportation systems during future pervasive events.

1. Introduction

The outbreak of the COVID-19 pandemic has had a profound impact on various aspects of society. In response to the pandemic caused by the deadly SARS-CoV-2 virus, many countries imposed restrictions such as stay-at-home orders, social distancing, and face-covering. These restrictions were put in place to curtail the spread of infection. However, these restrictions also have had a significant effect on travel patterns and travel behavior. The global pandemic and other such pervasive events disrupt day-to-day activities, affecting personal trips, such as home-to-work commutes, and commercial trips, such as shopping and freight transportation. These disruptions arise from concerns regarding safety, the risk of infection, and other associated factors. Consequently, the actual travel patterns during such events differ significantly from the normal travel patterns forecasted by the regional travel demand models.

According to recent economic studies, the COVID-19 pandemic has caused a significant reduction in travel and transportation activities. For instance, a report by the International Air Transport Association (IATA) estimated that global air passenger traffic declined by a staggering 65.9% in 2020 compared to the previous year (IATA, 2021). This decline in air travel led to substantial revenue losses for airlines and airports worldwide. Similarly, the road transportation sector also experienced a considerable downturn. A significant decrease in vehicle miles traveled (VMT) was also observed by Stavrinos et al. (2020). This reduction in VMT reflects a decline in personal and commercial travel, impacting various aspects of the economy, such as fuel consumption, toll revenues, and transportation-related businesses. Furthermore, the COVID-19 pandemic significantly affected freight transportation and supply chains. The World Trade Organization (WTO) reported a decline of 5.3% in global merchandise trade volume in 2020 (WTO, 2021). This reduction in trade has disrupted the flow of goods, impacting industries reliant on global supply chains and causing financial hardships for businesses worldwide.

While these economic facts and figures provide an overview of the widespread impact of the COVID-19 pandemic on travel and transportation, it is apparent that its effect on travel patterns would have essentially varied between different phases of the pandemic. For instance, restrictions were imposed during the pandemic's initial phases. However, in the latter phase, the restrictions were relaxed. Therefore, for a comprehensive understanding, it is essential to delve deeper into the specific travel time patterns during different stages of pervasive events such as the COVID-19 pandemic. This research aims to fill this gap by focusing on travel time patterns during different phases of the COVID-19 pandemic in Mecklenburg County (urban area) and Buncombe County (rural area) in North Carolina. By examining travel time patterns during each stage of the pandemic for different vehicle types, road functional classes, and area types, this study provides valuable insights into how different policies have impacted travel behavior. These findings will assist policymakers and transportation stakeholders in developing targeted strategies to mitigate economic disruptions, to enhance transportation resilience, and to foster economic recovery during similar pervasive events in the future.

1.1 Research Objectives

The objective of the proposed project is to research the effect of pervasive events, analyze the temporal variations in travel times by vehicle type, and understand the effect on travel time patterns during various stages of the COVID-19 pandemic.

1.2 Organization of the Report

The remainder of the report consists of four chapters. The second chapter discusses past research focusing on the impact of the COVID-19 pandemic on travel behavior and patterns; the research gaps are also identified and summarized in Chapter 2. The third chapter illustrates the methodology adopted for the study. The effect of different phases of COVID-19 is investigated at two levels, (a) the effect on travel time reliability (TTR) and travel time variability (TTV), and (b) the effect of travel time patterns. The fourth chapter details the results obtained from the analysis. Chapter 5 summarizes the results, provides conclusions and recommendations based on the research findings, and elaborates on the future scope of the study.

1.3 Contribution of the Study

This study will help planners understand the change in travel time patterns during and after the COVID-19 pandemic at various stages by vehicle type (passenger car or truck), area type, and different times of the day. Moreover, the analysis period selected at various stages of the study considers governmental norms and regulations, which significantly impact travel time patterns. This will help authorities during the decision-making process in the case of such pervasive events.

2. Literature Review

This chapter summarizes past studies on the impact of the COVID-19 pandemic. It is divided into five sections, wherein each section provides a summary of the impact of COVID-19 on different aspects, such as the economy, travel behavior, driving behavior, and travel time. Moreover, research gaps are articulated and presented at the end of the chapter.

2.1 Impact on the United States

The COVID-19 pandemic has significantly impacted transportation in the United States and worldwide. The pandemic has decreased travel demand, as people have worked from home, avoided public transportation, and stayed home more often. This has decreased traffic congestion, car ownership, and greenhouse gas emissions (Kim, 2023). However, it has also had a negative impact on businesses that rely on transportation.

Due to the COVID-19 pandemic, VMT decreased by as much as 22% (Hughes et al., 2021), CO2 emissions fell by 46 million metric tons (approximately 19%) (Cicala et al., 2021), the number of people telecommuting increased to a considerable extent (Javadinasr et al., 2022), and walking and biking activities went down by as much as 48% for densely populated cities and increased significantly in less densely populated cities (Zhang and Fricker, 2021). About 75% of the study's panelists reported taking less transit since the pandemic (Parker et al., 2021).

The COVID-19 pandemic has had a significant impact on travel patterns. With many people working from home and avoiding public transportation, traffic volumes have decreased significantly in many areas. However, this has also increased TTV, as drivers are more likely to encounter unexpected delays.

2.2 Economic Impact

The COVID-19 pandemic has had a significant impact on the global economy. During the pandemic, the International Monetary Fund (IMF) estimated that the global economy would contract by 3% in 2020, the worst contraction since the Great Depression (IMF, 2020). Moreover, the pandemic has led to job losses on a massive scale. Unemployment rose significantly (Maital et al., 2020); the unemployment rate in the United Kingdom reached a 40-year high in April 2020. The pandemic has also led to business closures. In the United States, the number of businesses closed in April 2020 was more than in April 2019 (Beckman et al., 2021).

The pandemic has led to a decrease in demand for goods and services. Retail sales fell by 16.4% in the United States in April 2020, the most significant decline on record (Kaye et al., 2021). The World Trade Organization (WTO) estimated that global trade would decline by 13% in 2020, the most significant decline since World War II. The pandemic has also had a negative impact on financial markets. The stock market experienced a sharp decline in March 2020, and the price of

oil fell to its lowest level in decades. The IMF estimates that the total cost of the pandemic to the global economy could reach $8 trillion (IMF, 2020).

The long-term economic impacts of COVID-19 are still uncertain. However, the pandemic could lead to increased inequality, a decline in economic growth, and a permanent shift in how we work and live.

2.3 Effect of COVID-19 on Travel Behavior

The COVID-19 pandemic has had a significant impact on travel behavior. A shift from public transportation to private vehicles and non-motorized modes was observed and has been attributed to several factors, including concerns about the risk of infection from crowded spaces, changes in work and school schedules, and government policies. Several studies have investigated the impact of COVID-19 on mode choice. Abdullah et al. (2020) reported a significant decrease in public transportation use and an increase in private vehicle use in the United States during the pandemic. In a panel survey, it was revealed that transit ridership was reduced by 75% (Parker et al., 2021). Similarly, a study by Zhang and Fricker (2021) found a decline in non-motorized transportation (walking and biking) in the United States during the pandemic. Kalambay and Pulugurtha (2022) found a negative correlation between daily trips and COVID-19 cases and patients. Chen et al. (2022) revealed the shared bicycle system to be a sustainable and resilient method of transportation when the urban transportation system experiences difficulties. Overall, there is a significant impact on mode choice, public transportation demand, bicycle riding, and non-motorized vehicle use. The shift from public transportation to private vehicles and non-motorized modes will likely have several implications for transportation planning and policy.

2.4 Effect of COVID-19 on Traffic Behavior

Before the COVID-19 pandemic, traffic behavior was relatively stable. Traffic volumes were high during peak commuting hours. Drivers were generally aggressive, with high rates of speeding and tailgating (Hamada et al., 2016; Ma et al., 2019; Katrakazas et al., 2021). The COVID-19 pandemic significantly impacted traffic behavior. Traffic volumes decreased dramatically as many people began working from home and avoiding public transportation. This led to reduced congestion and air pollution. However, there was also an increase in risky driving behaviors, such as speeding and distracted driving (Cunningham et al., 2011; Ma et al., 2019; Yuniar et al., 2020). Time series analysis has been used to study the changes in driver behavior during the pandemic. Katrakazas et al. (2021) used time series forecasting to identify the impact of the pandemic on driving behavior and found that traffic volumes decreased significantly during the pandemic while there was an increase in risky driving behavior, such as speeding and distracted driving (Tan et al., 2017).

In the past, researchers used the Autoregressive Integrated Moving Average (ARIMA) model to forecast short-term travel time due to incidents (Reza et al., 2015). Traffic behavior is still evolving

in the post COVID-19 era. Traffic volumes have increased somewhat, but they are still below pre pandemic levels. Drivers are still more cautious than before the pandemic, and there are lower rates of speeding and tailgating. However, it is still too early to judge the pandemic's long-term impact on traffic behavior (Ma et al., 2019; Pantangi et al., 2020; Xing et al., 2020).

2.5 Travel Time Reliability (TTR) and COVID-19

TTR is important for several reasons. TTR analysis is a tool that can be used to measure the TTV. This information can be used to improve transportation planning and decision-making. For example, transportation agencies can use TTR analysis to identify areas with unreliable transportation system performance and develop strategies to mitigate these delays. Recurrent factors such as traffic volumes, traffic compositions, traffic control and its characteristics, and non-recurrent factors such as inclement weather conditions, special events, pervasive events, and work zones are some of the factors that affect TTR (Kodupuganti & Pulugurtha, 2019; Kukkapalli & Pulugurtha, 2021; Pulugurtha & Koilada, 2021; Duvvuri & Pulugurtha, 2022; Mathew & Pulugurtha, 2022; Gore et al., 2023). TTR can be improved by traffic management, investing in transportation infrastructure, and educating drivers. Researchers also developed a methodology for predicting TTR on interstate highways in Virginia. Their methodology considers traffic volume, speed, and weather conditions (Babiceanu & Lahiri, 2022). Likewise, past research also includes monetizing the value of travel time and willingness to pay and TTR (Duddu et al., 2018; Pulugurtha et al., 2017, 2019, 2021).

Although the travel time and reliability patterns depend on various factors, it is crucial to study the effect of the COVID-19 pandemic at the micro and macro levels. With travel patterns constantly changing, it is essential to have accurate information about TTV, which can help transportation agencies ensure that people can go where they need to, even during a pandemic.

Travel times on arterial roadways in Nebraska decreased by an average of 14% during the COVID-19 pandemic. However, the standard deviation of travel times also increased by 43%, highlighting a wider range of possible travel times (Rilett et al., 2021). In some regions, a "double-humped" peak period was observed during the pandemic because people were traveling during off-peak hours to avoid crowds (Gao & Levinson, 2021; Tufuor and Rilett, 2022). In heterogeneous traffic conditions, such as those in India, TTR decreased when the restrictions were relaxed due to an increase in traffic volumes (Singh et al., 2023). It was found that the pandemic has led to a decrease in the willingness of people to pay for travel time savings and reliability. This is likely because people are now more likely to work from home, reducing their need to travel (Cherry et al., 2021).

2.6 Research Gaps

From the literature review, it can be inferred that the COVID-19 pandemic has significantly impacted the economy, travel behavior, TTR, and driving behavior. However, a few research gaps still need to be addressed:

- The effect of the COVID-19 pandemic on TTR and TTV has been studied by only a handful of studies. These studies concluded the effect of COVID-19 by analyzing a few links. However, the effect of COVID-19 would vary significantly by area type, speed limit, road functional class, and road geometry. Therefore, it is necessary to consider these factors for a holistic assessment of COVID-19's impact on TTR and TTV.

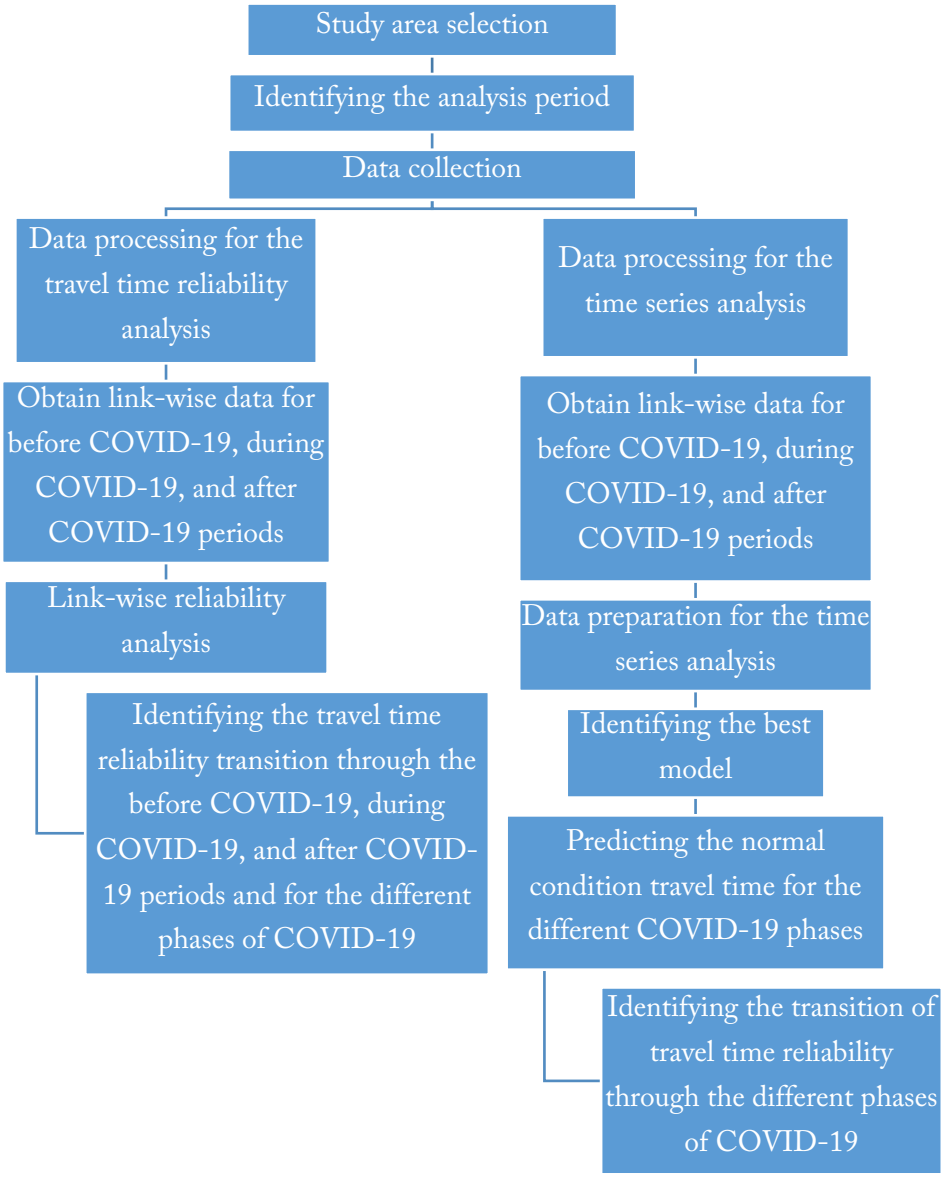
- Most studies studied the initial phase of the COVID-19 pandemic, i.e., March to May 2020. However, the effect of a pervasive event such as COVID-19 is not limited to a single time frame but a series of stages due to the mutations and variants (such as Delta, Omicron, etc.). For instance, mutated variants of COVID-19, namely, Delta and Omicron, were reported from April to September 2021, and many cities globally witnessed a spike in the number of reported cases. Different phases affect travel patterns based on the restrictions and measures imposed by state and federal health agencies. Therefore, the effect of COVID-19 would vary during different phases of the pandemic. To the best of the authors' knowledge, no studies have investigated the effect of different phases of COVID-19 on TTR and TTV.

Transportation system users' needs and perceptions of travel change throughout pervasive events. Over the past two years, numerous researchers have analyzed the effects of COVID-19 on travel and related metrics to understand the underlying patterns. While past research provides insights on the overall effect of COVID-19, they fall short of a deeper understanding of travel or travel time patterns during the various stages of such a pervasive event. This research aims to bridge these research gaps and focuses on travel time patterns during different phases of the COVID-19 pandemic by vehicle type (passenger car or truck, road functional class, and area type).

3. Methodology

This chapter presents the methodology adopted to investigate the effect of the COVID-19 pandemic and its various phases on TTR, TTV, and average daily travel time patterns. The research framework adopted for this study is illustrated in Figure 1.

Figure 1. Methodology

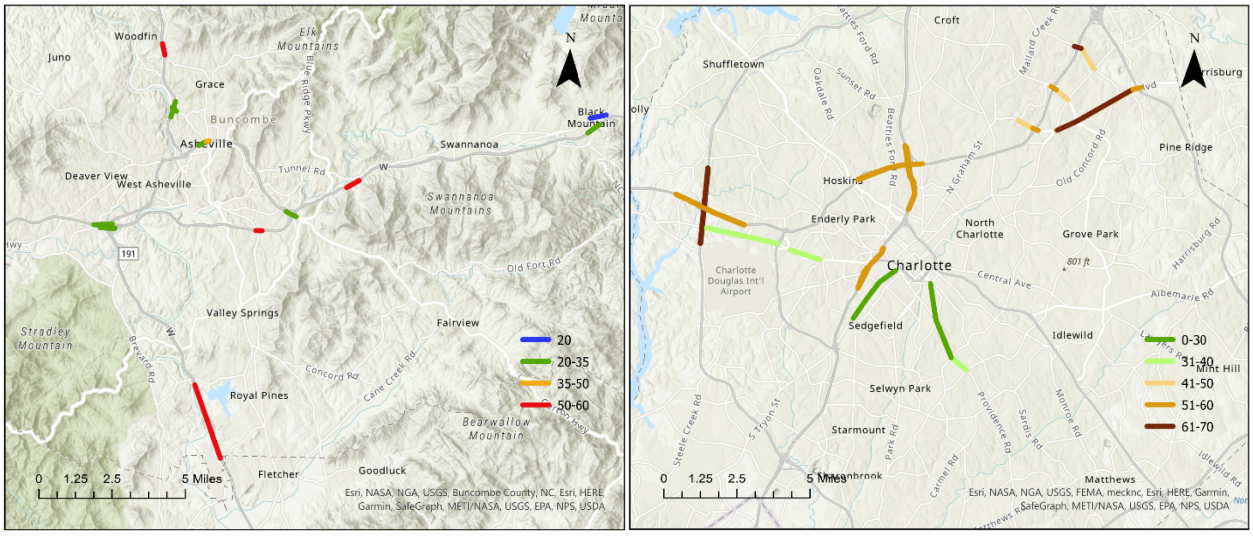


The methodology consists of five steps: study area selection and roadway links, identification of the COVID-19 analysis period, data collection and processing, performing TTR and TTV analysis for the selected links and time period, and comparing the results. In the end, a time-series analysis is performed to comprehend the impact of COVID-19 on daily average travel time patterns. Each step of the framework is explained next.

3.1 Study Area Selection

Selecting links with varying area types, roadway geometries, speed limits, and road functional classes is essential from a network perspective. This assists in understanding how the effect of COVID-19 varies with the aforementioned factors. To accomplish this goal, road links from Mecklenburg County, primarily an urban area, and Buncombe County, primarily a rural area, both located in North Carolina, were selected based on the speed limit, functional class, road geometry, and area type. Figure 2 shows the selected links from each county, which are color-coded according to the speed limit.

Figure 2. Selected Road Links



Buncombe County Mecklenburg County

Table 1 summarizes the number of links selected from each county by the speed limit. A detailed list of the selected links with their characteristics is provided in the Appendix. In total, 16 links from Buncombe County and 70 links from Mecklenburg County were selected, encompassing a variety of road types, including interstates, US routes, NC routes (state routes), and local routes. The travel time dynamics across different transportation networks are captured by including various road types. Furthermore, links from various locations within each county, i.e., from the center and outskirts, were strategically selected to account for the variation in land-use patterns.

Table 1. Number of Links by Speed Limit and Each County

Speed Limit	Total # of Links	
	Mecklenburg	Buncombe
20	7	1
25	6	-
30	4	-
35	6	8
50	-	1
55	19	-
60	20	6
70	8	-
Total	**70**	**16**
Total Links	**86**	

3.2 Identifying the Analysis Period

Under the directives issued by the federal and state health agencies, local agencies implemented various measures and interventions to control the spread of COVID-19. These measures included declaring a state-wide emergency, implementing stay-at-home orders, closing non-essential businesses, and issuing travel restrictions. These administrative actions reflected the virus's variants and its transmission dynamics. Table 2 shows the list of important orders North Carolina's state government released during the COVID-19 pandemic.

Table 2. Important Dates

Date	Order ID	Action
10-Mar-20	Executive Order 116	Declares a state of emergency to coordinate response and protective actions to prevent the spread of COVID-19.
14-Mar-20	Executive Order 117	Closes K-12 public schools state-wide.
17-Mar-20	Executive Order 118	Closes restaurants and bars for dine-in service; makes unemployment benefits more widely available.
21-Mar-20	Executive Order 119	Waives restrictions on childcare and elder care and provides the North Carolina Division of Motor Vehicles with flexibility.
23-Mar-20	Executive Order 120	Closes K–12 public schools state-wide through May 15, bans mass gatherings of more than 50 people, and closes some businesses.
27-Mar-20	Executive Order 121	Issues a state-wide stay-at-home order beginning Monday, March 30, 2020, at 5 p.m. until April 29, 2020, and directs people to stay at home except to visit essential businesses, exercise outdoors, or help a family member. Specifically, the order bans gatherings of more than 10 people and directs everyone to physically stay at least 6 feet apart from others.
9-Apr-20	Executive Order 131	Issues stronger social distancing requirements for retail stores still operating, makes earlier COVID-19 guidelines mandatory for nursing facilities, and issues changes to speed up certain benefit payments to those who are out of work.
17-Apr-20	Executive Order 133	Extends certain provisions in previous executive orders that are related to transportation.
23-Apr-20	Executive Order 135	Extends North Carolina's stay-at-home (Executive Order 121) until May 8, as well as other orders regarding the closures of restaurants for dine-in service, bars, and other close-contact businesses.
5-May-20	Executive Order 138	Effective 5 p.m. May 8, 2020, eases some restrictions on travel, business operations, and mass gatherings.
20-May-20	Executive Order 141	Lifts the state-wide stay-at-home order and moves the state to a Safer At Home recommendation.
24-Jun-20	Executive Order 147	Extends Executive Order 141's safer-at-home restrictions and requires people, with some exceptions, to wear face coverings in public when social distancing is not possible.
16-Jul-20	Executive Order 151	Extends Executive Order 141's safer-at-home Phase II measures until at least Aug. 7, 2020.
5-Aug-20	Executive Order 155	Extends Executive Order 141's safer-at-home Phase II measures until at least Sep. 11, 2020.

Table 2 shows that local agencies issued directives almost weekly, making it challenging to analyze the effect of COVID-19 on TTR and TTV based on these directives. Several researchers have considered the phases of COVID-19 for their respective studies. This seems to be a more prudent and rational approach, as examining TTR and TTV across these phases allows for a holistic

assessment of the effectiveness of various administrative measures. Moreover, it also helps evaluate the impact of lockdowns, easing restrictions, and reopening efforts on travel behavior and traffic flow. By comparing the travel time patterns across the phases, researchers, planners, and policymakers can identify the effectiveness of different strategies and policies in managing travel demand and congestion during the pandemic. Phase I of COVID-19 was taken from March 11, 2020 to March 29, 2020; Phase II was considered to be from March 30, 2020 to May 21, 2020, and Phase III was from May 22, 2020 to July 7, 2020 (Nyante et al., 2021).

Phase I represents the early stage of the pandemic, where the outbreak was becoming more widespread, and various precautionary measures and restrictions were being implemented globally. During this period, many countries, including the United States, experienced a rapid increase in COVID-19 cases, leading to a declaration of a state of emergency and the implementation of initial control measures. These measures included social distancing guidelines, closures of non-essential businesses, restrictions on gatherings, and travel advisories. Hence, this phase enables us to examine the baseline travel time patterns before substantial changes occurred due to the pandemic. In the same way, during Phase II, state-wide stay-at-home orders were issued, which directed people to stay at home except to visit essential businesses, exercise outdoors, or help a family member. This was supposed to have a huge impact on TTR and TTV as there was a significant reduction in traffic volume on the roads. In Phase III, restrictions were gradually lifted, and reopening efforts such as reopening businesses, relaxation of stay-at-home orders, and the resumption of certain activities in many regions, including North Carolina, were undertaken. Therefore, this phase enables an understanding of how relaxation efforts impacted TTR and TTV.

3.3 Data Collection and Data Processing

The travel time for the selected links of Buncombe County and Mecklenburg County before COVID-19 (2019), during COVID-19 (2020), and after COVID-19 (2021) were extracted from the Regional Integrated Transportation Information Systems (RITIS) database. The intention to extract travel time for 2021 was primarily due to the spike in reported cases due to mutated variants of COVID-19. Travel time data for cars and trucks were extracted separately. Each link is identified with a unique nine-digit Traffic Message Channel (TMC) code. This dataset contains date and time stamps, average speed, car/truck travel time, a reference speed, and data density recorded at 5-minute intervals. The reference speed is an indicator of the free-flow speed of the corresponding link. The data density is the number of reporting vehicles in the corresponding time interval (an indicator of traffic volume/condition). As mentioned earlier, the study investigates the effect of COVID-19 on TTR, TTV, and average daily travel time patterns. Therefore, the travel time data were processed separately for TTR and TTV analysis, and average daily travel time pattern analysis.

3.3.1 Data Processing for the Travel Time Reliability (TTR) Analysis

As mentioned previously, 16 links from Buncombe County and 70 links from Mecklenburg County were selected for the analysis. The travel time data extracted for the selected links were processed using a structured query to compute TTR and TTV measures for each link by the time of the day. Morning and evening peak hours and off-peak hours were determined based on the traffic trends of the study area.

3.3.2 Data Processing for the Time Series Analysis

The Seasonal Autoregressive Integrated Moving Average (SARIMA) model was selected for the time series analysis. The SARIMA model requires a dataset with no missing values. Hence, travel time data for every five-minute interval were converted to daily average travel time as some values were missing in the five-minute interval data. The same process was followed for all three years—2019, 2020, and 2021—considered for the analysis. The methodology for TTR and time series analysis is explained next.

3.4 Link-wise Travel Time Reliability (TTR) and Travel Time Variability (TTV) Analysis

TTR and TTV measures were computed for each link separately by the time of the day. For this analysis, 6:00 AM to 9:00 AM was selected as the morning peak hours, 4:00 to 7:00 PM was selected as the evening peak hours, and 11:00 AM to 2:00 PM was selected as the off-peak hours. To ensure a fair comparison and account for the seasonal effect on travel time, the same day and month of the years 2019, 2020, and 2021 were selected to comprehend the effect of COVID-19 on TTR and TTV.

Different measures are computed to analyze TTR and TTV. The literature shows that different indicators present different results, and one measure cannot explain the whole story regarding the roadway's performance. In this study, the Travel Time Index (TTI), Planning Time Index (PTI), and Buffer Time (BT) were used to analyze TTR. TTV, also termed Travel Time Uncertainty (TTU), was used to analyze the variabilities in travel times. The description and mathematical formulation of the indicators are explained next.

TTI is the ratio of average travel time (ATT) and average free-flow travel time (FFTT). TTI represents the extra time the motorists travel than the FFTT to reach their destination on time. A value of TTI close to one indicates that the link for that period is reliable. Mathematically, it can be represented as

$$TTI_{ts} = \frac{ATT_{ts}}{FFTT_{ts}} \quad \forall\, t = 1, T; s = 1, S \qquad (1)$$

where TTI_{ts}, ATT_{ts}, and $FFTT_{ts}$ represent the TTI, ATT, and FFTT, respectively, for segment s for period t. t is the time period. Here, t takes the value of 1 for the evening peak hours, 2 for the morning peak hours, and 3 for the off-peak hours. T is the total number of periods. s is the segment, and S represents the total number of segments analyzed.

PTI is the ratio of the 95th percentile travel time and the FFTT. PTI compares the "near worst" or "worst" travel time to the FFTT. A higher PTI value indicates higher congestion and poor reliability (Gore et al. 2021). Mathematically, it can be represented as

$$PTI_{ts} = \frac{T95_{ts}}{FFTT_{ts}} \quad \forall\, t = 1, T; s = 1, S \qquad (2)$$

where PTI_{ts} and $T95_{ts}$ represent the PTI and 95th percentile travel time, respectively, for the period t and link s.

The Buffer Time Index (BTI) is the ratio of BT and ATT. BT is further defined as the difference between the 95th percentile travel time and ATT (Equation 3). BT indicates the extra time the motorists consider planning to reach their destination on time, and BTI indicates the percentage of extra time the motorists consider planning to reach their destination on time. Mathematically, it can be represented as

$$BTI_{ts} = \frac{T95_{ts} - ATT_{ts}}{ATT_{ts}} \quad \forall\, t = 1, T; s = 1, S \qquad (3)$$

where BTI_{ts} represents the BTI for the period t and link s.

TTV is a percentile-based indicator of TTV. It is well-known that travel times are either left- or right-skewed, and therefore, standard deviations or other moment-based indicators would be sensitive to outliers. On the other hand, percentile-based indicators such as TTV are insensitive to outliers. Therefore, the same is used in the present study. TTV explains the degree of travel time variation for a trip on the same route over a specific period of time. It is defined as the difference between the 90th and the 10th percentile travel time. TTV was normalized over length to compare it with other links. Mathematically, TTV can be represented as

$$TTV_{ts} = \frac{T90_{ts} - T10_{ts}}{l_s} \quad \forall\, t = 1, T; s = 1, S \qquad (4)$$

where TTV_{ts}, $T90_{ts}$, and $T10_{ts}$ represent the TTV, 90th percentile travel time, and 10th percentile travel time, respectively, for the period t and link s. l_s is the length of the link or segment s.

It is essential to mention that the aforementioned measures are computed for each link of Buncombe and Mecklenburg County separately by the time of the day, vehicle type, and different phases of the COVID-19 pandemic. To comprehend the effect of COVID-19, TTR and TTV measures for each link, vehicle type, and phase of COVID-19 are compared for different time periods (2019, 2020, and 2021), and percentage changes in the values are computed by the time

of day, vehicle type, and phase of COVID-19. A comparison between 2020 and 2019 highlights the effect of the first wave of COVID-19 on TTR and TTV. Similarly, a comparison between 2021 and 2019 highlights the effect of the second wave of COVID-19 (Delta and Omicron) on TTR. On the other hand, the comparison between 2020 and 2021 highlights the effect of the first wave of COVID-19 with respect to the second wave of COVID-19. The percentage change is computed using the following equations:

$$\%\, change_{2020-2019} = \frac{(TTR_{2019} - TTR_{2020}) * 100}{TTR_{2019}} \quad (5)$$

$$\%\, change_{2021-2019} = \frac{(TTR_{2019} - TTR_{2021}) * 100}{TTR_{2019}} \quad (6)$$

$$\%\, change_{2021-2020} = \frac{(TTR_{2020} - TTR_{2021}) * 100}{TTR_{2020}} \quad (7)$$

where $\%\, change_{2020-2019}$ represents the percentage change in TTR and TTV measures for 2020 compared to 2019, $\%\, change_{2021-2019}$ represents the percentage change in TTR and TTV measures for 2021 compared to 2019, and $\%\, change_{2021-2020}$ represents the percentage change in TTR and TTV measures for 2021 compared to 2020. TTR_{2019}, TTR_{2020} and TTR_{2021} represent the value of TTR and TTV measures for 2019, 2020, and 2021, respectively. If TTR and TTV measures are compared between 2019 and 2020 and 2019 and 2021, a positive value of % change indicates that travel times are reliable for 2020 or 2021. A negative value of % change indicates that travel times are unreliable and uncertain for 2020 and 2021. In case TTR and TTV measures are compared between 2020 and 2021, a positive value of % change indicates that travel times are unreliable and uncertain for 2020, while a negative value of % change indicates that travel times are reliable and certain for 2020.

3.5 Time Series Analysis

For the time series analysis of the average daily travel time, it is necessary to check if there is any repetitive pattern or seasonality in the travel time for the link under consideration, as the travel time depends on various seasonal factors and can show weekly, biweekly, monthly, or yearly trends. Preliminary test results concerning seasonality were performed and revealed the presence of seasonality at different frequencies. Unlike simpler models such as Autoregressive (AR) or Moving Average (MA), SARIMA considers both the autoregressive and moving average terms, allowing it to capture the patterns and dependencies present in the data. Additionally, SARIMA incorporates the seasonal component, which is crucial for accurately modeling and forecasting time series data with repeating patterns. This makes SARIMA particularly suitable for datasets that exhibit seasonality, such as monthly or quarterly data. Furthermore, SARIMA can handle non-stationary data by incorporating the differencing components, enabling it to capture trends and eliminate seasonality or other patterns that might exist. SARIMA's comprehensive approach to modeling time series data, capturing both seasonality and non-seasonality, makes it a powerful and preferred choice over other models.

A SARIMA model is denoted as

$$ARIMA\ (p,d,q)(P,D,Q)m \qquad (8)$$

where "p" is the autoregressive order, "d" is the integrated order, and "q" is the moving average order. Likewise, "P" is the seasonal autoregressive order, "D" is the seasonal integrated order, and "Q" is the seasonal moving average order. m represents the frequency of seasonality in the data.

Equation 8's parameters were estimated using a Hyndamn–Khandakar algorithm, which combines unit root tests, a minimization of the Akaike Information Criteria (AIC), and a maximum likelihood estimation to obtain the optimal SARIMA model.

As the raw data had discontinuity, they were converted into daily average travel time data. The following steps were employed to evaluate the effect of COVID-19 on average daily travel time patterns. First, a SARIMA model using 2019 travel time data was developed. Second, the developed model was validated using Jan 2020 to Feb 2020 travel time data. Third, the validated SARIMA model was then employed to forecast the travel time for different phases of the COVID-19 pandemic. Fourth, the forecasted travel time was compared to the observed travel time for the different phases of the COVID-19 pandemic. The percentage difference between the forecasted and observed travel time is estimated to comprehend the effect of COVID-19 on average daily travel time patterns. The % difference in travel time is computed using Equation (9).

$$\%\ difference\ = \frac{(\text{Actual Travel Time} - \text{Forecasted Travel Time}) * 100}{\text{Actual Travel Time}} \qquad (9)$$

A box plot of the percentage difference in travel time for all three phases of COVID-19 was developed to see the trend in travel times over the phases. It is essential to mention that separate SARIMA models are developed for trucks and cars for the selected links from Buncombe County and Mecklenburg County.

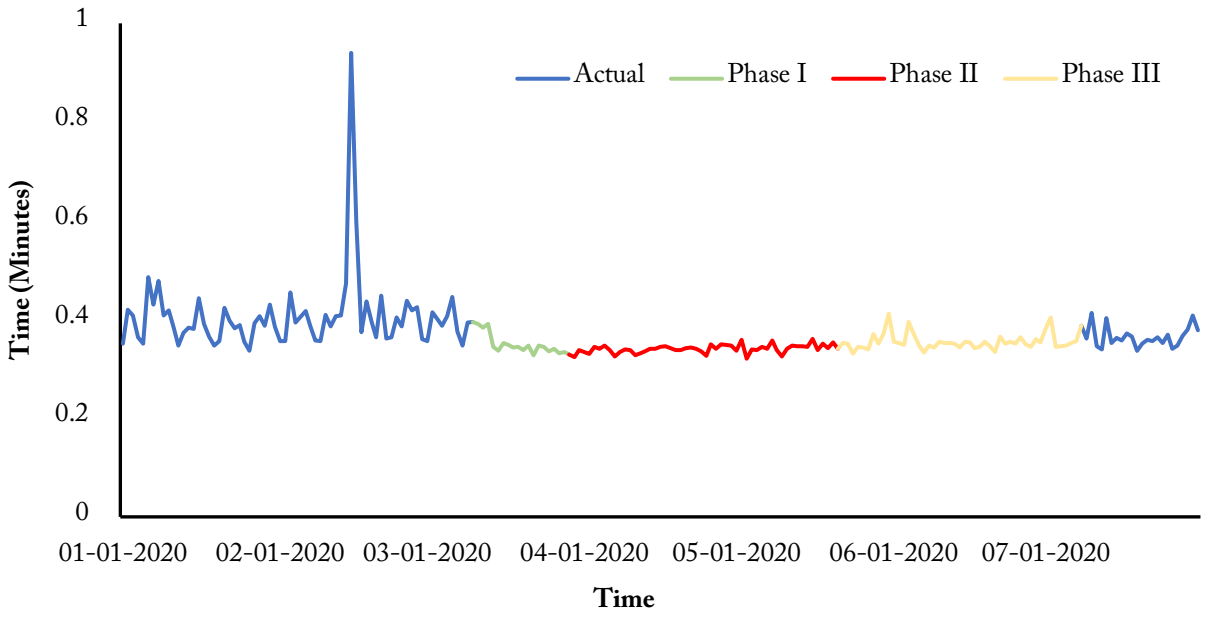
4. Results

This chapter discusses the results regarding the effect of different phases of COVID-19 on (a) TTR and TTV, and (b) average daily travel time patterns.

4.1 Preliminary Analysis

Figure 3 depicts the variation in travel time during various phases of the COVID-19 pandemic for one link and shows a reduction in travel times for the pandemic's different phases to pre-COVID-19 conditions. Within these different phases, a decrease in travel time was commonly observed during Phase II; however, variation in the patterns for Phase I and Phase III exists. Moreover, relative to the pre-COVID-19 conditions and different phases of COVID-19, stable travel time patterns (lesser variation in average daily travel times) can be noted for Phase II.

Figure 3. Example of Travel Time Variation (TTV) During COVID-19



To probe further, the variation in travel time between different phases of COVID-19 is studied by developing box plots, as shown in Figures 4 and 5. These plots are developed for one sample link as an example. Separate plots were developed for cars and trucks. Figures 4 and 5 show that the average travel time for 2020 and 2021 is less than that in 2019. Moreover, the variation in travel time (the interquartile range) is also less for 2020 and 2021 compared to 2019. Consistent observations can be made for cars and trucks during different phases of the COVID-19 pandemic. From the above discussion, it can be noted that the pandemic's different phases have changing effects on travel time and its variation. Such analysis gives a preliminary idea regarding the effect of different phases of COVID-19 on travel times.

Figure 4. Buncombe County Phase-Wise Travel Time Box Plot

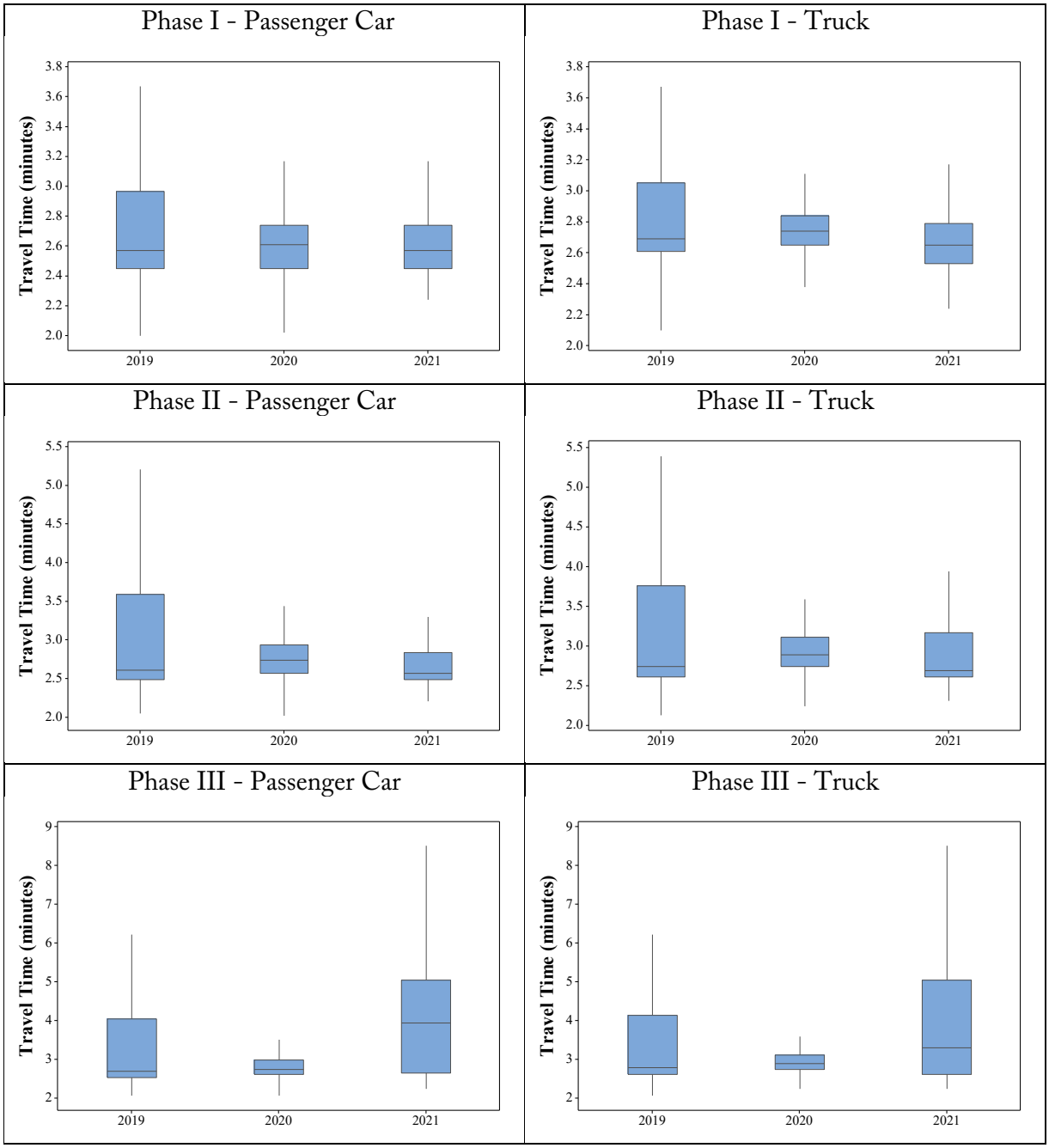
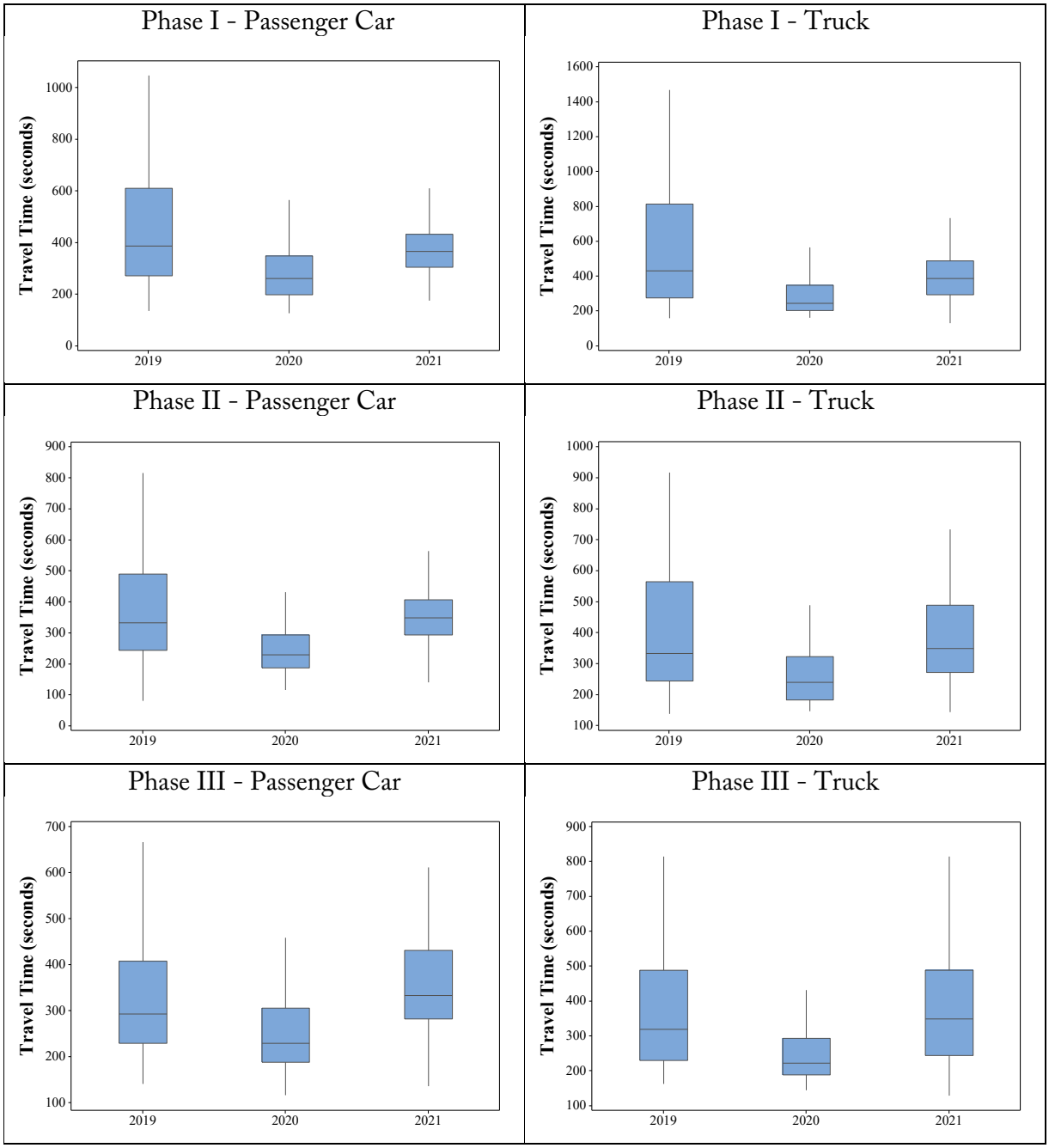


Figure 5. Mecklenburg County Phase-Wise Travel Time Box Plot



4.2 Effect of COVID-19 on Travel Time Reliability (TTR) and Travel Time Variation (TTV)

From the preliminary investigation of the data, the effect of different phases of COVID-19 varied for each link. The percentage change in TTR and TTV for different periods (2019, 2020, and 2021), and phases varied between -50% and 75%. This implies that unreliable and uncertain travel times were observed for a few links during the pandemic. Therefore, to investigate the effect of

different phases of COVID-19 from a network perspective and derive robust conclusions, the percentage of links with varying percentage change in TTV and TTR measures are computed, and the results are summarized in Tables 3 to 12. Separate tables are developed for speed limits and vehicle types. The range for percentage change in TTV and TTR measures was decided based on the results obtained. Moreover, based on the number of links and their speed limits, two speed-limit classes were defined for Buncombe County, i.e., <50 mph and ≥50 mph. For Mecklenburg County, three speed-limit classes were defined, i.e., ≤35 mph, >35 to ≤55 mph, and >55 mph. It is essential to mention that some links do not have data for a certain time of the day. Therefore, the percentage of links for a particular phase and time of day may not add up to 100%.

4.2.1 Buncombe County (Rural)

The results for Buncombe County are summarized in Tables 3 to 6. Separate tables are developed for different speed-limit classes and vehicle types.

Comparing 2020 with 2019

The TTV and TTR for 2019 and 2020 were compared by the time of day, phases of the COVID-19 pandemic, and speed limits. The percentage change in TTR and TTV measures was computed using Equation 5. A positive sign indicates a reduction in TTV or TTR for 2020, implying that travel times are reliable and certain. A negative sign indicates an increase in TTV or TTR, implying that travel times are unreliable and uncertain.

For links with speed limits <50 mph, it was observed that for most links (50–75% of the links), travel times are unreliable and uncertain during off-peak hours, i.e., the percentage change in TTV and TTR measures is negative. This implies that COVID-19 had a significant effect on trip patterns. However, for most links, travel times are reliable and certain during morning and evening peak hours. Consistent observations were noted for different phases of the COVID-19 pandemic. Directives to stay at home and travel for essential and business trips were issued. As a result, work-purpose trips, which are primarily in the morning and evening peak hours, were reduced, and therefore, travel time during peak hours was observed to be reliable and certain. Moreover, most of the trips were scheduled during off-peak hours to avoid crowds, so travel times were unreliable and uncertain during off-peak hours. For links with a speed limit ≥50 mph, it was observed that travel times are reliable and certain for most links (60–75%). Consistent observations were noted by the time of the day and for different phases of the COVID-19 pandemic.

For Phase III, the percentage links with positive change in TTR and TTV decreased compared to Phase II. Consistent observations were noted for varying speed limits. During Phase II, directives such as the stay-at-home order were released, which directed people to stay home except to visit essential businesses, exercise outdoors, or help a family member. This order had a huge impact on TTR and TTV. In Phase III, relaxations were made by reopening businesses, relaxing stay-at-home orders, and resuming certain activities. The effect of this relaxation can be witnessed in the

reduction of the percentage of links with a positive change in TTR and TTV for Phase III compared to Phase II. Overall, reliable and certain travel times were observed for most links (70–80%), which is attributed to stricter restrictions during Phase II.

For trucks and links with a speed limit <50 mph, it was observed that travel times are unreliable and uncertain for off-peak and peak hours for most links. Links showing improvement (positive value of % change) in TTV and TTR increased more in Phase II than in Phase I. Moreover, travel times were unreliable and uncertain in Phase III for a considerable percentage of links. Overall, the trends of truck travel times are similar to those of car travel times for links with a lower speed limit. However, the results showed that most links are reliable for all three phases for links with a higher speed limit, regardless of the time of the day.

There is a marginal change in the TTR and TTV for Phases I and III. The number of reliable links within different phases increased in Phase II compared to Phase I and III. There is a marginal change in the TTR and TTV for Phase III with respect to Phase II, which also indicates that the back-to-normal tendency of the truck traffic patterns is slow.

Comparing 2021 with 2020

The TTV and TTR for 2020 and 2021 were compared by the time of day, phases of the COVID-19 pandemic, and speed limits. The percentage change in TTR and TTV was computed using Equation 6. A positive sign indicates a reduction in TTV or TTR in 2021, implying that travel times are reliable and certain. A negative sign indicates an increase in TTV or TTR measures, implying that travel times are unreliable and uncertain in 2021.

For links with a speed limit <50 mph, it was observed that for most of the links travel times are reliable and certain for off-peak and peak (morning peak and evening peak) hours. Moreover, there is a significant improvement in the TTV and TTR in Phase II compared to Phase I. The percentage of reliable links decreased in Phase III compared to Phase II. This can be attributed to the stay-at-home directive imposed by the local agency in 2020. As the COVID-19 restrictions were relieved, everything started returning to normal, and reliability was restored to pre-pandemic conditions. The comparison of Phase III revealed that links are more reliable during the morning peak hours and less reliable during the evening peak and off-peak hours in 2021. This shift in reliability can be due to the work-from-home policy adopted by various organizations.

From Table 5 showing the results of TTV and TTR for the trucks it is clear that for Phase I, most links were unreliable during the morning and off-peak hours in the year 2020 compared to the year 2021. However, a marginal difference was noted for the evening peak hours. The cross-phase comparison results are the same as the passenger cars, which is consistent over the time of the day.

For the links with a speed limit greater than 50 mph, it was observed that for most links, travel times are reliable and certain during off-peak and evening peak hours for 2020 compared to 2021. Consistent observations were noted for different phases of COVID-19. Moreover, the number of

links showing improvement in TTV and TTR increased during Phase II compared to Phase I but decreased in Phase III. The results for truck travel times followed a similar trend as for cars.

Overall, as the restrictions were lifted in 2021, morning peak hours were observed to be more reliable. Furthermore, the effect of strict orders during Phase II on the TTV and TTR was consistent.

Comparing 2021 with 2019

The TTV and TTR for 2019 and 2021 were compared by the time of day, phases of the COVID-19 pandemic, and speed limits. The percentage change in TTR and TTV was computed using Equation 7. A positive sign indicates a reduction in TTV or TTR in 2021, implying that travel times were reliable and certain. A negative sign indicates an increase in TTV or TTR, implying that travel times were unreliable and uncertain in 2021.

For links with a speed limit <50 mph, it was observed that for most of the study links, travel times were unreliable and uncertain during off-peak hours, i.e., the percentage change in TTV and TTR measures is negative. However, travel times were reliable and certain during the morning and evening peak hours for most of the study links. On the contrary, it was observed that travel times were reliable and certain for most of the study links with a speed limit of ≥50 mph. Consistent observations were noted by the time of the day and for different phases of the COVID-19 pandemic. In the post COVID-19 phase, the trend in TTR and TTV is similar to that of during the COVID-19 conditions. However, the percentages of links with improved TTR and TTV decreased in 2021 compared to 2020.

These results for the trucks (Table 5 and Table 6) remain the same except for the morning peak hours at the lower speed limit. The shift in reliability was again observed for the morning peak hours as more links were observed to be reliable.

Table 3. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit <50 mph for Buncombe County for Passenger Cars

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	38.9	27.8	38.9	11.1	16.7	11.1	5.6	5.6	11.1	33.3	22.2	27.8
	MP	-15-0	5.6	22.2	11.1	33.3	44.4	50.0	44.4	50.0	61.1	27.8	16.7	22.2
	MP	0-15	44.4	44.4	44.4	44.4	38.9	38.9	44.4	44.4	27.8	22.2	27.8	27.8
	MP	>15	5.6	0.0	5.6	5.6	0.0	0.0	0.0	0.0	0.0	11.1	27.8	22.2
	EP	<-15	33.3	22.2	38.9	33.3	11.1	27.8	16.7	0.0	27.8	44.4	27.8	50.0
	EP	-15-0	22.2	11.1	22.2	22.2	33.3	22.2	66.7	55.6	50.0	0.0	11.1	5.6
	EP	0-15	38.9	44.4	22.2	38.9	27.8	33.3	16.7	38.9	11.1	33.3	22.2	0.0
	EP	>15	5.6	22.2	16.7	5.6	27.8	16.7	0.0	5.6	11.1	22.2	38.9	44.4
	OP	<-15	50.0	33.3	38.9	27.8	27.8	38.9	11.1	11.1	27.8	44.4	50.0	50.0
	OP	-15-0	22.2	33.3	11.1	27.8	38.9	16.7	55.6	50.0	38.9	11.1	5.6	5.6
	OP	0-15	11.1	22.2	33.3	38.9	33.3	44.4	27.8	38.9	27.8	33.3	33.3	11.1
	OP	>15	11.1	5.6	16.7	0.0	0.0	0.0	0.0	0.0	5.6	5.6	5.6	33.3
2021 Compared to 2020	MP	<-15	33.3	27.8	27.8	16.7	22.2	5.6	0.0	5.6	0.0	38.9	55.6	38.9
	MP	-15-0	22.2	22.2	16.7	33.3	44.4	27.8	44.4	72.2	50.0	33.3	16.7	22.2
	MP	0-15	27.8	44.4	33.3	44.4	27.8	55.6	55.6	16.7	38.9	16.7	0.0	22.2
	MP	>15	16.7	5.6	22.2	5.6	5.6	11.1	0.0	5.6	11.1	11.1	27.8	16.7
	EP	<-15	27.8	44.4	38.9	16.7	33.3	11.1	5.6	16.7	5.6	50.0	44.4	27.8
	EP	-15-0	38.9	22.2	11.1	33.3	33.3	44.4	44.4	61.1	55.6	16.7	11.1	16.7
	EP	0-15	22.2	11.1	22.2	44.4	22.2	22.2	50.0	16.7	22.2	22.2	11.1	16.7
	EP	>15	11.1	22.2	27.8	5.6	11.1	22.2	0.0	5.6	16.7	11.1	33.3	38.9
	OP	<-15	22.2	38.9	22.2	11.1	33.3	0.0	5.6	16.7	5.6	38.9	50.0	16.7
	OP	-15-0	5.6	5.6	11.1	38.9	44.4	38.9	50.0	77.8	55.6	16.7	22.2	22.2
	OP	0-15	61.1	38.9	33.3	44.4	22.2	38.9	38.9	5.6	16.7	16.7	22.2	27.8
	OP	>15	11.1	16.7	33.3	5.6	0.0	22.2	5.6	0.0	22.2	27.8	5.6	33.3
2021 Compared to 2019	MP	<-15	38.9	38.9	55.6	11.1	27.8	16.7	5.6	22.2	11.1	44.4	50.0	44.4
	MP	-15-0	5.6	38.9	5.6	33.3	55.6	38.9	27.8	50.0	50.0	16.7	11.1	16.7
	MP	0-15	44.4	16.7	33.3	50.0	16.7	44.4	61.1	27.8	33.3	27.8	11.1	16.7
	MP	>15	5.6	0.0	5.6	0.0	0.0	0.0	0.0	0.0	5.6	5.6	22.2	22.2
	EP	<-15	33.3	27.8	44.4	33.3	16.7	22.2	33.3	11.1	16.7	44.4	27.8	44.4
	EP	-15-0	22.2	0.0	11.1	22.2	44.4	50.0	50.0	66.7	55.6	11.1	11.1	11.1
	EP	0-15	38.9	66.7	27.8	38.9	27.8	11.1	16.7	16.7	16.7	33.3	33.3	11.1
	EP	>15	5.6	5.6	16.7	5.6	11.1	16.7	0.0	5.6	11.1	11.1	27.8	33.3
	OP	<-15	50.0	44.4	44.4	33.3	38.9	44.4	11.1	33.3	16.7	55.6	55.6	44.4
	OP	-15-0	22.2	33.3	0.0	33.3	50.0	22.2	50.0	55.6	72.2	11.1	16.7	0.0
	OP	0-15	11.1	11.1	33.3	22.2	11.1	33.3	27.8	11.1	11.1	16.7	11.1	27.8
	OP	>15	11.1	5.6	22.2	5.6	0.0	0.0	5.6	0.0	0.0	11.1	11.1	27.8

Table 4. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit ≥50 mph for Buncombe County for Passenger Cars

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	14.3	14.3	7.1	0.0	0.0	0.0	0.0	0.0	7.1	21.4	7.1	21.4
	MP	-15-0	7.1	21.4	21.4	35.7	21.4	21.4	50.0	57.1	35.7	35.7	21.4	28.6
	MP	0-15	64.3	57.1	35.7	64.3	78.6	78.6	50.0	42.9	57.1	35.7	57.1	21.4
	MP	>15	14.3	7.1	35.7	0.0	0.0	0.0	0.0	0.0	0.0	7.1	14.3	28.6
	EP	<-15	14.3	14.3	57.1	7.1	0.0	14.3	0.0	0.0	0.0	21.4	7.1	57.1
	EP	-15-0	14.3	21.4	0.0	42.9	21.4	42.9	85.7	57.1	85.7	14.3	35.7	7.1
	EP	0-15	57.1	64.3	35.7	42.9	78.6	42.9	14.3	42.9	14.3	28.6	28.6	21.4
	EP	>15	14.3	0.0	7.1	7.1	0.0	0.0	0.0	0.0	0.0	35.7	28.6	14.3
	OP	<-15	28.6	28.6	21.4	14.3	0.0	21.4	7.1	0.0	7.1	28.6	14.3	28.6
	OP	-15-0	21.4	7.1	7.1	35.7	14.3	21.4	85.7	64.3	57.1	14.3	21.4	28.6
	OP	0-15	42.9	57.1	50.0	50.0	85.7	57.1	7.1	35.7	35.7	35.7	42.9	7.1
	OP	>15	7.1	7.1	21.4	0.0	0.0	0.0	0.0	0.0	0.0	21.4	21.4	35.7
2021 Compared to 2020	MP	<-15	21.4	0.0	7.1	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	28.6
	MP	-15-0	14.3	14.3	7.1	7.1	7.1	7.1	14.3	28.6	28.6	42.9	50.0	14.3
	MP	0-15	50.0	64.3	35.7	92.9	92.9	92.9	85.7	71.4	64.3	28.6	35.7	21.4
	MP	>15	14.3	21.4	50.0	0.0	0.0	0.0	0.0	0.0	7.1	14.3	14.3	35.7
	EP	<-15	35.7	35.7	57.1	14.3	7.1	28.6	0.0	0.0	14.3	42.9	50.0	50.0
	EP	-15-0	21.4	21.4	0.0	35.7	57.1	28.6	64.3	71.4	71.4	21.4	28.6	14.3
	EP	0-15	42.9	21.4	21.4	50.0	35.7	42.9	35.7	28.6	14.3	21.4	21.4	7.1
	EP	>15	0.0	21.4	21.4	0.0	0.0	0.0	0.0	0.0	0.0	14.3	0.0	28.6
	OP	<-15	21.4	21.4	42.9	21.4	14.3	28.6	21.4	0.0	28.6	42.9	42.9	28.6
	OP	-15-0	7.1	7.1	0.0	28.6	35.7	21.4	57.1	78.6	57.1	7.1	21.4	14.3
	OP	0-15	64.3	64.3	42.9	42.9	50.0	50.0	21.4	21.4	14.3	21.4	14.3	35.7
	OP	>15	7.1	7.1	14.3	7.1	0.0	0.0	0.0	0.0	0.0	28.6	21.4	21.4
2021 Compared to 2019	MP	<-15	14.3	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.6	14.3	14.3
	MP	-15-0	7.1	0.0	14.3	14.3	14.3	0.0	14.3	42.9	14.3	28.6	7.1	14.3
	MP	0-15	64.3	64.3	35.7	85.7	85.7	100.0	85.7	57.1	85.7	28.6	64.3	42.9
	MP	>15	14.3	21.4	50.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	14.3	28.6
	EP	<-15	14.3	35.7	64.3	14.3	0.0	42.9	0.0	0.0	14.3	35.7	21.4	64.3
	EP	-15-0	14.3	21.4	7.1	42.9	57.1	28.6	92.9	100.0	85.7	21.4	28.6	0.0
	EP	0-15	57.1	42.9	21.4	35.7	42.9	28.6	7.1	0.0	0.0	14.3	50.0	28.6
	EP	>15	14.3	0.0	7.1	7.1	0.0	0.0	0.0	0.0	0.0	28.6	0.0	7.1
	OP	<-15	28.6	21.4	28.6	35.7	14.3	28.6	28.6	7.1	28.6	35.7	28.6	28.6
	OP	-15-0	21.4	21.4	7.1	21.4	28.6	21.4	57.1	71.4	42.9	7.1	14.3	7.1
	OP	0-15	42.9	57.1	35.7	42.9	57.1	50.0	14.3	21.4	28.6	35.7	42.9	28.6
	OP	>15	7.1	0.0	28.6	0.0	0.0	0.0	0.0	0.0	0.0	21.4	14.3	35.7

Table 5. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit <50 mph for Buncombe County for Trucks

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	27.8	11.1	33.3	16.7	5.6	16.7	0.0	0.0	5.6	33.3	22.2	11.1
	MP	-15-0	16.7	0.0	22.2	22.2	27.8	22.2	38.9	16.7	44.4	11.1	16.7	50.0
	MP	0-15	22.2	38.9	33.3	33.3	38.9	61.1	33.3	55.6	50.0	27.8	11.1	38.9
	MP	>15	11.1	22.2	11.1	5.6	5.6	0.0	5.6	5.6	0.0	5.6	22.2	0.0
	EP	<-15	38.9	38.9	33.3	16.7	11.1	33.3	11.1	5.6	27.8	55.6	50.0	27.8
	EP	-15-0	22.2	5.6	16.7	44.4	44.4	16.7	38.9	50.0	50.0	0.0	11.1	22.2
	EP	0-15	5.6	27.8	27.8	16.7	16.7	38.9	27.8	27.8	16.7	11.1	11.1	33.3
	EP	>15	11.1	11.1	22.2	5.6	11.1	11.1	5.6	0.0	5.6	11.1	11.1	16.7
	OP	<-15	50.0	38.9	50.0	22.2	11.1	38.9	22.2	0.0	27.8	66.7	55.6	38.9
	OP	-15-0	16.7	0.0	16.7	55.6	44.4	22.2	50.0	44.4	50.0	0.0	5.6	16.7
	OP	0-15	11.1	16.7	22.2	5.6	22.2	38.9	11.1	33.3	22.2	11.1	5.6	44.4
	OP	>15	5.6	27.8	11.1	0.0	5.6	0.0	0.0	5.6	0.0	5.6	16.7	0.0
2021 Compared to 2020	MP	<-15	16.7	11.1	11.1	11.1	5.6	11.1	16.7	5.6	0.0	16.7	11.1	5.6
	MP	-15-0	0.0	22.2	27.8	16.7	27.8	22.2	27.8	38.9	55.6	16.7	16.7	27.8
	MP	0-15	33.3	33.3	38.9	61.1	55.6	55.6	44.4	44.4	38.9	16.7	16.7	55.6
	MP	>15	38.9	22.2	22.2	0.0	0.0	11.1	0.0	0.0	5.6	38.9	44.4	11.1
	EP	<-15	44.4	27.8	27.8	22.2	27.8	0.0	16.7	22.2	5.6	38.9	44.4	11.1
	EP	-15-0	22.2	16.7	22.2	22.2	27.8	50.0	44.4	33.3	55.6	16.7	11.1	44.4
	EP	0-15	22.2	16.7	27.8	38.9	27.8	27.8	27.8	33.3	22.2	16.7	5.6	22.2
	EP	>15	0.0	22.2	22.2	5.6	5.6	22.2	0.0	0.0	16.7	16.7	22.2	22.2
	OP	<-15	16.7	27.8	16.7	5.6	22.2	0.0	0.0	22.2	5.6	27.8	38.9	0.0
	OP	-15-0	22.2	27.8	16.7	33.3	44.4	33.3	27.8	50.0	55.6	22.2	22.2	38.9
	OP	0-15	33.3	11.1	22.2	50.0	27.8	44.4	55.6	22.2	22.2	5.6	11.1	38.9
	OP	>15	16.7	16.7	44.4	5.6	0.0	22.2	11.1	0.0	16.7	33.3	11.1	22.2
2021 Compared to 2019	MP	<-15	22.2	5.6	33.3	22.2	11.1	16.7	0.0	0.0	11.1	38.9	22.2	16.7
	MP	-15-0	11.1	16.7	22.2	16.7	22.2	27.8	27.8	22.2	33.3	0.0	5.6	38.9
	MP	0-15	27.8	22.2	27.8	38.9	38.9	55.6	50.0	55.6	55.6	27.8	5.6	44.4
	MP	>15	16.7	27.8	16.7	0.0	5.6	0.0	0.0	0.0	0.0	11.1	38.9	0.0
	EP	<-15	55.6	61.1	61.1	38.9	22.2	16.7	22.2	16.7	16.7	61.1	55.6	22.2
	EP	-15-0	5.6	5.6	5.6	27.8	50.0	50.0	27.8	61.1	66.7	5.6	16.7	50.0
	EP	0-15	5.6	16.7	11.1	11.1	11.1	27.8	27.8	5.6	11.1	0.0	11.1	11.1
	EP	>15	11.1	0.0	22.2	5.6	0.0	5.6	5.6	0.0	5.6	11.1	0.0	16.7
	OP	<-15	55.6	44.4	38.9	27.8	22.2	33.3	11.1	27.8	16.7	50.0	55.6	44.4
	OP	-15-0	16.7	11.1	11.1	44.4	38.9	38.9	61.1	33.3	66.7	16.7	5.6	22.2
	OP	0-15	11.1	22.2	33.3	11.1	22.2	27.8	11.1	22.2	16.7	11.1	5.6	33.3
	OP	>15	0.0	5.6	16.7	0.0	0.0	0.0	0.0	0.0	0.0	5.6	16.7	0.0

Table 6. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit ≥50 mph for Buncombe County for Trucks

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	64.3	35.7	7.1	7.1	0.0	0.0	7.1	0.0	7.1	28.6	21.4	0.0
	MP	-15-0	0.0	0.0	0.0	28.6	28.6	21.4	57.1	28.6	21.4	21.4	35.7	21.4
	MP	0-15	35.7	50.0	71.4	64.3	71.4	78.6	35.7	71.4	71.4	35.7	7.1	78.6
	MP	>15	0.0	14.3	21.4	0.0	0.0	0.0	0.0	0.0	0.0	14.3	35.7	0.0
	EP	<-15	42.9	28.6	42.9	14.3	0.0	14.3	0.0	0.0	0.0	50.0	21.4	14.3
	EP	-15-0	14.3	21.4	7.1	50.0	28.6	28.6	78.6	64.3	78.6	7.1	21.4	42.9
	EP	0-15	42.9	42.9	42.9	28.6	71.4	57.1	21.4	35.7	21.4	28.6	21.4	42.9
	EP	>15	0.0	7.1	7.1	7.1	0.0	0.0	0.0	0.0	0.0	14.3	35.7	0.0
	OP	<-15	64.3	14.3	50.0	21.4	0.0	21.4	14.3	0.0	7.1	42.9	21.4	21.4
	OP	-15-0	14.3	14.3	0.0	50.0	21.4	21.4	71.4	57.1	57.1	21.4	7.1	21.4
	OP	0-15	21.4	64.3	28.6	28.6	78.6	57.1	14.3	42.9	35.7	7.1	42.9	57.1
	OP	>15	0.0	7.1	21.4	0.0	0.0	0.0	0.0	0.0	0.0	28.6	28.6	0.0
2021 Compared to 2020	MP	<-15	0.0	0.0	21.4	0.0	0.0	0.0	0.0	0.0	0.0	42.9	0.0	0.0
	MP	-15-0	0.0	0.0	0.0	7.1	0.0	0.0	7.1	42.9	14.3	28.6	21.4	7.1
	MP	0-15	71.4	57.1	35.7	85.7	100.0	100.0	85.7	57.1	78.6	7.1	35.7	92.9
	MP	>15	28.6	42.9	42.9	7.1	0.0	0.0	7.1	0.0	7.1	21.4	42.9	0.0
	EP	<-15	42.9	50.0	28.6	14.3	7.1	14.3	0.0	0.0	14.3	50.0	64.3	28.6
	EP	-15-0	7.1	7.1	0.0	35.7	71.4	50.0	64.3	85.7	71.4	7.1	14.3	28.6
	EP	0-15	42.9	35.7	57.1	50.0	21.4	35.7	35.7	14.3	14.3	28.6	14.3	42.9
	EP	>15	7.1	7.1	14.3	0.0	0.0	0.0	0.0	0.0	0.0	14.3	7.1	0.0
	OP	<-15	42.9	35.7	28.6	14.3	21.4	28.6	14.3	0.0	28.6	42.9	28.6	28.6
	OP	-15-0	0.0	7.1	0.0	50.0	42.9	35.7	64.3	92.9	57.1	28.6	21.4	21.4
	OP	0-15	42.9	57.1	57.1	28.6	35.7	35.7	21.4	7.1	14.3	7.1	28.6	50.0
	OP	>15	14.3	0.0	14.3	7.1	0.0	0.0	0.0	0.0	0.0	21.4	21.4	0.0
2021 Compared to 2019	MP	<-15	50.0	7.1	28.6	0.0	0.0	0.0	0.0	0.0	0.0	28.6	7.1	0.0
	MP	-15-0	0.0	0.0	0.0	35.7	7.1	0.0	14.3	28.6	0.0	42.9	14.3	0.0
	MP	0-15	42.9	64.3	21.4	64.3	92.9	100.0	85.7	71.4	100.0	14.3	21.4	100.0
	MP	>15	7.1	28.6	50.0	0.0	0.0	0.0	0.0	0.0	0.0	14.3	57.1	0.0
	EP	<-15	64.3	57.1	42.9	21.4	7.1	21.4	0.0	0.0	14.3	57.1	35.7	42.9
	EP	-15-0	0.0	14.3	7.1	64.3	64.3	57.1	78.6	100.0	78.6	28.6	28.6	28.6
	EP	0-15	28.6	28.6	42.9	7.1	28.6	21.4	21.4	0.0	7.1	0.0	14.3	28.6
	EP	>15	7.1	0.0	7.1	7.1	0.0	0.0	0.0	0.0	0.0	14.3	21.4	0.0
	OP	<-15	85.7	50.0	50.0	35.7	21.4	28.6	28.6	7.1	28.6	64.3	21.4	28.6
	OP	-15-0	0.0	7.1	7.1	50.0	21.4	21.4	50.0	78.6	35.7	7.1	21.4	21.4
	OP	0-15	14.3	28.6	21.4	14.3	57.1	50.0	21.4	14.3	35.7	14.3	28.6	50.0
	OP	>15	0.0	14.3	21.4	0.0	0.0	0.0	0.0	0.0	0.0	14.3	28.6	0.0

4.2.2 Mecklenburg County (Urban)

The results for Mecklenburg County are summarized in Tables 7 to 12. Separate tables are developed for different speed limit classes and vehicle types.

Comparing 2020 with 2019

The TTV and TTR for 2019 and 2020 were compared by the time of day for different phases of the COVID-19 pandemic and different speed limits. The percentage change in TTR and TTV was computed using Equation 5. A positive sign indicates a reduction in TTV or TTR for 2020, implying that travel times were reliable and certain. A negative sign indicates an increase in TTV or TTR, implying that travel times were unreliable and uncertain.

For links with speed limits <35 mph, travel times are reliable and certain during morning and evening peak hours compared to off-peak hours for most of the study links. However, travel times were unreliable and uncertain for off-peak hours (Table 7). Consistent observations were noted for different phases of COVID-19. For links with speed limits >35 or ≤55 mph, it was observed that travel times were uncertain and unreliable for most of the study links. Consistent observations were noted for off-peak and evening peak hours, and Phase I and III of COVID-19 (Table 8). However, travel times were reliable and certain for most of the study links with a speed limit of >55 mph (Table 9). Consistent observations were noted by the time of the day and for different phases of COVID-19. It is commonly observed that the percentage of links showing improvement in Phase II increased compared to Phase I. Moreover, it decreased in Phase III compared to Phase II. During Phase II, directives such as stay-at-home orders were released, which directed people to stay at home except to visit essential businesses, exercise outdoors, or help a family member. This order had a huge impact on TTR and TTV. In Phase III, relaxations were made in the form of the reopening of businesses, relaxation of stay-at-home orders, and resumption of certain activities. The effect of this relaxation can be witnessed in the reduction of the percentage of links with improved TTR and TTV for Phase III compared to Phase II.

From Table 10 summarizing truck travel time analysis results, it was observed that most links with speed limits <35 mph were unreliable during peak hours. Links showing improvements in TTR and TTV increased in Phase II compared to Phase I but then decreased in Phase III. The trends for truck travel times were similar to those of car travel times. For the trucks at higher speed limits (Table 11 and Table 12), the percentage of links showing improvement was less as there were no restrictions during Phase I of COVID-19. The number of links with improvement in TTR and TTV increased in Phase II when stay-at-home restrictions were imposed. There was a marginal change in the TTR and TTV in Phase III compared to Phase II. The results indicate that the back-to-normal tendency of truck travel times has been slow.

Comparing 2021 with 2020

The TTV and TTR for 2020 and 2021 were compared by the time of day for different phases of the COVID-19 pandemic and different speed limits. The percentage change in TTR and TTV was computed using Equation 6. A positive sign indicates a reduction in TTV or TTR in 2021, implying that travel times were reliable and certain. A negative sign indicates an increase in TTV or TTR, implying that travel times were unreliable and uncertain in 2021.

The TTV and TTR results for 2020, when compared to 2021, showed that travel times were reliable and certain for morning and evening peak hours for most links (>65%) compared to the off-peak hours. However, travel times were uncertain and unreliable during off-peak hours. Consistent observations were noted in different phases of COVID-19 and the speed limit.

Within different phases, reliable and certain travel times were observed during Phase II compared to other phases. The percentage of links showing improvement in TTV and TTR increased in Phase II compared to Phase I but then decreased in Phase III. The trends for truck travel times were similar to those of cars.

Comparing 2021 with 2020

The TTV and TTR for 2019 and 2021 were compared by the time of day for different phases of the COVID-19 pandemic and different speed limits. The percentage change in TTR and TTV was computed using Equation 7. A positive sign indicates a reduction in TTV or TTR in 2021, implying that travel times were reliable and certain. A negative sign indicates an increase in TTV or TTR, implying that travel times were unreliable and uncertain in 2021.

The results revealed that travel times were reliable and certain for most of the links in 2021 compared to 2019. Consistent observations were noted by the time of day, for different phases of COVID-19, and by the speed limit.

For the trucks (Tables 10, 11, and 12), TTV and TTR for 2021 were poor for most of the links. The shift in reliability was again observed for the morning peak hours, as most links were reliable during the morning peak hours. However, the evening peak and off-peak hours results are the same, which indicates that TTR and TTV are still poor for most of the links.

Table 7. Percentage of Links with Varying % change in TTR and TTV—Speed Limit ≤35 mph for Mecklenburg County for Passenger Cars

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	32.6	10.9	37.0	15.2	8.7	19.6	4.3	2.2	4.3	32.6	23.9	37.0
	MP	-15-0	26.1	15.2	17.4	43.5	13.0	32.6	45.7	13.0	47.8	32.6	21.7	15.2
	MP	0-15	21.7	23.9	30.4	32.6	43.5	37.0	50.0	63.0	47.8	21.7	19.6	23.9
	MP	>15	19.6	50.0	15.2	8.7	34.8	10.9	0.0	21.7	0.0	13.0	34.8	23.9
	EP	<-15	26.1	19.6	2.2	21.7	17.4	4.3	2.2	6.5	0.0	37.0	34.8	28.3
	EP	-15-0	15.2	17.4	32.6	26.1	15.2	37.0	39.1	13.0	39.1	23.9	15.2	23.9
	EP	0-15	30.4	26.1	45.7	30.4	45.7	52.2	47.8	69.6	60.9	10.9	28.3	26.1
	EP	>15	28.3	37.0	19.6	21.7	21.7	6.5	10.9	10.9	0.0	28.3	21.7	21.7
	OP	<-15	41.3	23.9	34.8	32.6	21.7	26.1	30.4	8.7	23.9	45.7	32.6	32.6
	OP	-15-0	23.9	17.4	23.9	34.8	17.4	34.8	47.8	32.6	50.0	17.4	26.1	17.4
	OP	0-15	28.3	26.1	28.3	26.1	41.3	23.9	21.7	45.7	21.7	17.4	19.6	23.9
	OP	>15	6.5	32.6	13.0	6.5	19.6	15.2	0.0	13.0	4.3	19.6	21.7	26.1
2021 Compared to 2020	MP	<-15	21.7	54.3	13.0	13.0	32.6	10.9	4.3	8.7	0.0	23.9	34.8	26.1
	MP	-15-0	15.2	17.4	32.6	28.3	26.1	26.1	45.7	73.9	50.0	23.9	21.7	17.4
	MP	0-15	41.3	21.7	39.1	41.3	37.0	54.3	45.7	15.2	45.7	15.2	26.1	30.4
	MP	>15	21.7	6.5	15.2	17.4	4.3	8.7	4.3	2.2	4.3	37.0	17.4	26.1
	EP	<-15	17.4	26.1	23.9	19.6	17.4	15.2	8.7	4.3	0.0	28.3	19.6	34.8
	EP	-15-0	28.3	30.4	28.3	19.6	50.0	32.6	26.1	67.4	50.0	13.0	41.3	37.0
	EP	0-15	23.9	28.3	37.0	43.5	28.3	47.8	63.0	28.3	50.0	19.6	23.9	10.9
	EP	>15	30.4	15.2	10.9	17.4	4.3	4.3	2.2	0.0	0.0	39.1	15.2	17.4
	OP	<-15	13.0	39.1	10.9	17.4	32.6	15.2	4.3	8.7	0.0	34.8	39.1	30.4
	OP	-15-0	34.8	26.1	45.7	28.3	37.0	34.8	32.6	67.4	60.9	26.1	28.3	28.3
	OP	0-15	28.3	23.9	37.0	37.0	23.9	43.5	60.9	21.7	39.1	17.4	15.2	26.1
	OP	>15	23.9	10.9	6.5	17.4	6.5	6.5	2.2	2.2	0.0	21.7	17.4	15.2
2021 Compared to 2019	MP	<-15	32.6	32.6	37.0	21.7	21.7	21.7	6.5	8.7	4.3	37.0	37.0	39.1
	MP	-15-0	26.1	8.7	17.4	21.7	19.6	30.4	37.0	30.4	50.0	19.6	17.4	15.2
	MP	0-15	21.7	17.4	28.3	47.8	32.6	34.8	54.3	47.8	41.3	15.2	13.0	23.9
	MP	>15	19.6	41.3	17.4	8.7	26.1	13.0	2.2	13.0	4.3	28.3	32.6	21.7
	EP	<-15	26.1	17.4	13.0	15.2	23.9	8.7	4.3	6.5	2.2	34.8	39.1	32.6
	EP	-15-0	15.2	23.9	28.3	32.6	21.7	43.5	37.0	47.8	39.1	13.0	15.2	32.6
	EP	0-15	30.4	37.0	32.6	26.1	34.8	39.1	47.8	41.3	58.7	26.1	19.6	15.2
	EP	>15	28.3	21.7	26.1	26.1	19.6	8.7	10.9	4.3	0.0	26.1	26.1	19.6
	OP	<-15	41.3	23.9	37.0	39.1	34.8	28.3	21.7	15.2	23.9	45.7	43.5	41.3
	OP	-15-0	23.9	23.9	28.3	28.3	26.1	37.0	47.8	39.1	47.8	21.7	23.9	19.6
	OP	0-15	28.3	34.8	19.6	23.9	28.3	26.1	30.4	39.1	26.1	13.0	13.0	15.2
	OP	>15	6.5	17.4	15.2	8.7	10.9	8.7	0.0	6.5	2.2	19.6	19.6	23.9

Table 8. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit >35 mph but ≤55 mph for Mecklenburg County for Passenger Cars

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	39.5	15.8	13.2	5.3	2.6	13.2	5.3	2.6	5.3	31.6	23.7	31.6
	MP	-15-0	36.8	15.8	34.2	31.6	23.7	28.9	26.3	7.9	34.2	28.9	26.3	10.5
	MP	0-15	15.8	34.2	15.8	52.6	47.4	36.8	65.8	78.9	55.3	26.3	13.2	15.8
	MP	>15	7.9	34.2	36.8	10.5	26.3	21.1	2.6	10.5	5.3	13.2	36.8	42.1
	EP	<-15	26.3	15.8	13.2	21.1	7.9	2.6	2.6	2.6	0.0	39.5	23.7	21.1
	EP	-15-0	42.1	15.8	31.6	42.1	39.5	28.9	52.6	39.5	26.3	21.1	18.4	26.3
	EP	0-15	13.2	39.5	28.9	18.4	31.6	60.5	36.8	52.6	73.7	18.4	21.1	18.4
	EP	>15	18.4	28.9	26.3	18.4	21.1	7.9	7.9	5.3	0.0	21.1	36.8	34.2
	OP	<-15	73.7	21.1	23.7	50.0	13.2	15.8	28.9	10.5	15.8	68.4	31.6	23.7
	OP	-15-0	18.4	15.8	18.4	44.7	7.9	34.2	68.4	7.9	68.4	21.1	13.2	15.8
	OP	0-15	5.3	31.6	31.6	5.3	71.1	47.4	2.6	81.6	15.8	5.3	31.6	36.8
	OP	>15	2.6	31.6	26.3	0.0	7.9	2.6	0.0	0.0	0.0	5.3	23.7	23.7
2021 Compared to 2020	MP	<-15	28.9	18.4	28.9	21.1	18.4	23.7	13.2	2.6	5.3	7.9	23.7	39.5
	MP	-15-0	2.6	26.3	23.7	13.2	36.8	21.1	23.7	73.7	47.4	21.1	28.9	18.4
	MP	0-15	23.7	31.6	36.8	57.9	36.8	52.6	57.9	21.1	47.4	23.7	18.4	28.9
	MP	>15	44.7	23.7	10.5	7.9	7.9	2.6	5.3	2.6	0.0	47.4	28.9	13.2
	EP	<-15	18.4	34.2	50.0	15.8	26.3	26.3	13.2	21.1	23.7	21.1	36.8	60.5
	EP	-15-0	18.4	31.6	21.1	10.5	55.3	44.7	13.2	63.2	36.8	10.5	13.2	13.2
	EP	0-15	28.9	18.4	28.9	47.4	10.5	28.9	68.4	15.8	39.5	13.2	18.4	23.7
	EP	>15	34.2	15.8	0.0	26.3	7.9	0.0	5.3	0.0	0.0	55.3	31.6	2.6
	OP	<-15	15.8	15.8	31.6	15.8	13.2	21.1	5.3	5.3	21.1	15.8	15.8	31.6
	OP	-15-0	10.5	39.5	7.9	2.6	52.6	15.8	13.2	81.6	34.2	5.3	21.1	23.7
	OP	0-15	34.2	36.8	55.3	57.9	28.9	63.2	78.9	13.2	42.1	26.3	28.9	36.8
	OP	>15	39.5	7.9	5.3	23.7	5.3	0.0	2.6	0.0	2.6	52.6	34.2	7.9
2021 Compared to 2019	MP	<-15	39.5	5.3	18.4	10.5	5.3	21.1	7.9	0.0	10.5	15.8	15.8	28.9
	MP	-15-0	36.8	13.2	18.4	15.8	18.4	23.7	13.2	21.1	31.6	18.4	10.5	21.1
	MP	0-15	15.8	47.4	39.5	60.5	55.3	36.8	76.3	65.8	57.9	26.3	34.2	10.5
	MP	>15	7.9	34.2	23.7	13.2	21.1	18.4	2.6	13.2	0.0	39.5	39.5	39.5
	EP	<-15	26.3	21.1	23.7	18.4	7.9	21.1	15.8	10.5	15.8	26.3	26.3	44.7
	EP	-15-0	42.1	23.7	39.5	21.1	57.9	44.7	28.9	73.7	44.7	10.5	15.8	21.1
	EP	0-15	13.2	47.4	28.9	39.5	28.9	28.9	47.4	13.2	36.8	23.7	15.8	28.9
	EP	>15	18.4	7.9	7.9	21.1	5.3	5.3	7.9	2.6	2.6	39.5	42.1	5.3
	OP	<-15	73.7	23.7	39.5	36.8	21.1	34.2	26.3	13.2	31.6	47.4	34.2	36.8
	OP	-15-0	18.4	15.8	13.2	26.3	28.9	26.3	52.6	44.7	39.5	13.2	13.2	21.1
	OP	0-15	5.3	34.2	23.7	36.8	47.4	36.8	21.1	42.1	28.9	13.2	21.1	15.8
	OP	>15	2.6	26.3	23.7	0.0	2.6	2.6	0.0	0.0	0.0	26.3	31.6	26.3

Table 9. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit >55 mph for Mecklenburg County for Passenger Cars

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	17.9	21.4	7.1	1.8	1.8	1.8	0.0	0.0	0.0	35.7	25.0	17.9
	MP	-15-0	39.3	23.2	21.4	35.7	21.4	14.3	32.1	16.1	26.8	19.6	23.2	16.1
	MP	0-15	30.4	32.1	53.6	53.6	60.7	80.4	64.3	69.6	73.2	25.0	16.1	25.0
	MP	>15	12.5	23.2	17.9	8.9	16.1	3.6	3.6	14.3	0.0	19.6	35.7	41.1
	EP	<-15	42.9	19.6	14.3	19.6	3.6	0.0	7.1	0.0	0.0	53.6	41.1	21.4
	EP	-15-0	32.1	44.6	21.4	57.1	48.2	46.4	58.9	41.1	57.1	21.4	23.2	17.9
	EP	0-15	16.1	19.6	51.8	14.3	37.5	50.0	23.2	51.8	42.9	14.3	17.9	41.1
	EP	>15	8.9	16.1	12.5	8.9	10.7	3.6	10.7	7.1	0.0	10.7	17.9	19.6
	OP	<-15	42.9	30.4	16.1	17.9	7.1	10.7	10.7	1.8	5.4	48.2	28.6	14.3
	OP	-15-0	30.4	26.8	16.1	50.0	17.9	32.1	51.8	10.7	73.2	23.2	33.9	21.4
	OP	0-15	21.4	35.7	42.9	28.6	71.4	51.8	33.9	85.7	21.4	17.9	21.4	30.4
	OP	>15	5.4	7.1	25.0	3.6	3.6	5.4	3.6	1.8	0.0	10.7	16.1	33.9
2021 Compared to 2020	MP	<-15	25.0	8.9	30.4	19.6	3.6	16.1	12.5	1.8	3.6	25.0	14.3	46.4
	MP	-15-0	21.4	28.6	26.8	17.9	30.4	37.5	25.0	60.7	55.4	16.1	19.6	30.4
	MP	0-15	41.1	53.6	37.5	60.7	64.3	46.4	62.5	37.5	41.1	30.4	46.4	19.6
	MP	>15	12.5	8.9	5.4	1.8	1.8	0.0	0.0	0.0	0.0	28.6	19.6	3.6
	EP	<-15	14.3	16.1	51.8	10.7	12.5	26.8	7.1	10.7	5.4	14.3	21.4	55.4
	EP	-15-0	16.1	37.5	26.8	17.9	48.2	62.5	30.4	60.7	75.0	8.9	26.8	30.4
	EP	0-15	35.7	42.9	17.9	55.4	35.7	8.9	60.7	26.8	19.6	28.6	32.1	12.5
	EP	>15	33.9	3.6	3.6	16.1	3.6	1.8	1.8	1.8	0.0	48.2	19.6	1.8
	OP	<-15	14.3	10.7	39.3	7.1	12.5	8.9	3.6	0.0	0.0	17.9	17.9	46.4
	OP	-15-0	30.4	21.4	17.9	21.4	21.4	48.2	23.2	80.4	57.1	25.0	10.7	25.0
	OP	0-15	41.1	57.1	33.9	64.3	66.1	42.9	71.4	19.6	42.9	26.8	51.8	17.9
	OP	>15	14.3	10.7	8.9	7.1	0.0	0.0	1.8	0.0	0.0	30.4	19.6	10.7
2021 Compared to 2019	MP	<-15	17.9	14.3	32.1	14.3	1.8	10.7	10.7	0.0	3.6	32.1	21.4	33.9
	MP	-15-0	39.3	12.5	16.1	28.6	10.7	28.6	25.0	12.5	39.3	26.8	21.4	23.2
	MP	0-15	30.4	50.0	44.6	46.4	76.8	60.7	58.9	78.6	57.1	10.7	25.0	28.6
	MP	>15	12.5	23.2	7.1	10.7	10.7	0.0	5.4	8.9	0.0	30.4	32.1	14.3
	EP	<-15	42.9	23.2	44.6	16.1	8.9	26.8	12.5	3.6	10.7	41.1	35.7	57.1
	EP	-15-0	32.1	46.4	23.2	41.1	62.5	55.4	39.3	67.9	69.6	21.4	26.8	21.4
	EP	0-15	16.1	21.4	26.8	28.6	25.0	16.1	39.3	28.6	19.6	16.1	19.6	10.7
	EP	>15	8.9	8.9	5.4	14.3	3.6	1.8	8.9	0.0	0.0	21.4	17.9	10.7
	OP	<-15	42.9	26.8	33.9	16.1	12.5	17.9	8.9	3.6	12.5	32.1	32.1	41.1
	OP	-15-0	30.4	19.6	17.9	28.6	16.1	28.6	28.6	28.6	66.1	33.9	16.1	12.5
	OP	0-15	21.4	42.9	28.6	51.8	67.9	51.8	58.9	66.1	21.4	17.9	33.9	21.4
	OP	>15	5.4	10.7	19.6	3.6	3.6	1.8	3.6	1.8	0.0	16.1	17.9	25.0

Table 10. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit ≤35 mph for Mecklenburg County for Trucks

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	43.5	30.4	37.0	45.7	26.1	34.8	34.8	13.0	15.2	41.3	34.8	45.7
	MP	-15-0	6.5	4.3	17.4	10.9	17.4	21.7	15.2	21.7	39.1	6.5	4.3	10.9
	MP	0-15	4.3	8.7	26.1	6.5	19.6	26.1	19.6	30.4	43.5	4.3	10.9	15.2
	MP	>15	13.0	23.9	19.6	15.2	13.0	17.4	8.7	10.9	2.2	15.2	17.4	28.3
	EP	<-15	23.9	15.2	37.0	30.4	30.4	32.6	4.3	19.6	17.4	43.5	23.9	43.5
	EP	-15-0	6.5	4.3	21.7	8.7	10.9	30.4	17.4	13.0	39.1	4.3	2.2	23.9
	EP	0-15	10.9	8.7	13.0	13.0	10.9	19.6	26.1	17.4	34.8	0.0	4.3	6.5
	EP	>15	19.6	13.0	28.3	10.9	13.0	17.4	15.2	15.2	8.7	13.0	10.9	26.1
	OP	<-15	45.7	37.0	52.2	47.8	39.1	50.0	37.0	19.6	37.0	52.2	39.1	47.8
	OP	-15-0	10.9	6.5	21.7	23.9	10.9	19.6	21.7	28.3	37.0	10.9	6.5	19.6
	OP	0-15	4.3	10.9	17.4	4.3	21.7	21.7	21.7	21.7	21.7	0.0	10.9	13.0
	OP	>15	13.0	21.7	8.7	10.9	15.2	8.7	6.5	17.4	4.3	10.9	19.6	19.6
2021 Compared to 2020	MP	<-15	21.7	34.8	26.1	30.4	37.0	26.1	19.6	19.6	2.2	30.4	37.0	39.1
	MP	-15-0	8.7	6.5	26.1	8.7	8.7	28.3	19.6	19.6	45.7	6.5	4.3	23.9
	MP	0-15	10.9	13.0	28.3	21.7	13.0	23.9	30.4	26.1	41.3	8.7	4.3	10.9
	MP	>15	37.0	15.2	19.6	30.4	17.4	21.7	21.7	10.9	10.9	32.6	23.9	26.1
	EP	<-15	39.1	45.7	28.3	28.3	39.1	26.1	21.7	26.1	6.5	30.4	43.5	41.3
	EP	-15-0	8.7	4.3	34.8	6.5	23.9	30.4	10.9	32.6	52.2	4.3	0.0	15.2
	EP	0-15	10.9	8.7	17.4	15.2	6.5	23.9	39.1	17.4	28.3	10.9	10.9	19.6
	EP	>15	28.3	15.2	19.6	37.0	13.0	19.6	15.2	6.5	13.0	41.3	19.6	23.9
	OP	<-15	37.0	43.5	21.7	32.6	43.5	23.9	19.6	34.8	4.3	37.0	41.3	32.6
	OP	-15-0	2.2	6.5	23.9	15.2	19.6	17.4	28.3	19.6	37.0	15.2	6.5	15.2
	OP	0-15	19.6	13.0	32.6	21.7	13.0	43.5	26.1	32.6	52.2	2.2	8.7	19.6
	OP	>15	30.4	23.9	21.7	23.9	15.2	15.2	19.6	4.3	6.5	34.8	30.4	32.6
2021 Compared to 2019	MP	<-15	39.1	41.3	50.0	43.5	34.8	43.5	28.3	26.1	15.2	41.3	43.5	58.7
	MP	-15-0	10.9	8.7	17.4	13.0	13.0	13.0	21.7	21.7	45.7	6.5	6.5	13.0
	MP	0-15	4.3	0.0	10.9	8.7	17.4	28.3	17.4	26.1	30.4	4.3	8.7	8.7
	MP	>15	15.2	23.9	21.7	17.4	13.0	15.2	15.2	4.3	8.7	17.4	15.2	19.6
	EP	<-15	26.1	21.7	50.0	17.4	39.1	43.5	10.9	30.4	15.2	34.8	30.4	52.2
	EP	-15-0	6.5	4.3	2.2	8.7	15.2	10.9	4.3	15.2	43.5	13.0	4.3	8.7
	EP	0-15	13.0	6.5	26.1	21.7	13.0	23.9	23.9	19.6	34.8	2.2	0.0	8.7
	EP	>15	15.2	8.7	21.7	15.2	6.5	21.7	23.9	8.7	6.5	10.9	6.5	30.4
	OP	<-15	52.2	41.3	50.0	58.7	47.8	54.3	37.0	32.6	34.8	52.2	41.3	50.0
	OP	-15-0	2.2	4.3	30.4	8.7	2.2	21.7	23.9	21.7	41.3	4.3	6.5	28.3
	OP	0-15	10.9	10.9	8.7	6.5	21.7	15.2	17.4	23.9	19.6	4.3	4.3	10.9
	OP	>15	8.7	17.4	10.9	13.0	15.2	8.7	8.7	8.7	4.3	13.0	21.7	10.9

Table 11. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit >35 mph but ≤55 mph for Mecklenburg County for Trucks

Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	34.2	7.9	34.2	10.5	5.3	21.1	2.6	2.6	10.5	52.6	13.2	34.2
	MP	-15-0	31.6	10.5	13.2	55.3	5.3	28.9	50.0	13.2	44.7	28.9	7.9	28.9
	MP	0-15	21.1	28.9	31.6	26.3	55.3	36.8	42.1	60.5	36.8	5.3	23.7	7.9
	MP	>15	7.9	44.7	21.1	5.3	28.9	13.2	2.6	18.4	7.9	7.9	47.4	28.9
	EP	<-15	34.2	21.1	23.7	28.9	5.3	13.2	7.9	5.3	5.3	42.1	28.9	34.2
	EP	-15-0	26.3	7.9	15.8	26.3	31.6	34.2	47.4	26.3	34.2	18.4	13.2	13.2
	EP	0-15	13.2	21.1	31.6	23.7	31.6	42.1	26.3	47.4	55.3	7.9	13.2	15.8
	EP	>15	21.1	44.7	28.9	18.4	28.9	10.5	15.8	18.4	5.3	26.3	39.5	36.8
	OP	<-15	71.1	7.9	34.2	47.4	2.6	26.3	28.9	5.3	15.8	71.1	7.9	36.8
	OP	-15-0	15.8	5.3	21.1	47.4	10.5	55.3	65.8	13.2	78.9	15.8	5.3	26.3
	OP	0-15	5.3	23.7	36.8	0.0	76.3	15.8	0.0	73.7	5.3	5.3	34.2	18.4
	OP	>15	2.6	55.3	7.9	2.6	5.3	2.6	2.6	2.6	0.0	2.6	44.7	18.4
2021 Compared to 2020	MP	<-15	10.5	21.1	31.6	13.2	10.5	21.1	7.9	5.3	5.3	10.5	26.3	28.9
	MP	-15-0	26.3	10.5	26.3	18.4	21.1	15.8	47.4	50.0	44.7	21.1	15.8	21.1
	MP	0-15	36.8	52.6	23.7	60.5	57.9	50.0	42.1	39.5	44.7	21.1	34.2	23.7
	MP	>15	26.3	15.8	18.4	7.9	10.5	13.2	2.6	5.3	5.3	47.4	23.7	26.3
	EP	<-15	36.8	60.5	52.6	26.3	31.6	28.9	18.4	28.9	23.7	31.6	52.6	60.5
	EP	-15-0	7.9	15.8	26.3	21.1	47.4	36.8	31.6	63.2	47.4	13.2	15.8	13.2
	EP	0-15	26.3	21.1	10.5	31.6	13.2	26.3	39.5	2.6	23.7	18.4	7.9	15.8
	EP	>15	28.9	2.6	10.5	21.1	7.9	7.9	10.5	5.3	5.3	36.8	23.7	10.5
	OP	<-15	31.6	68.4	28.9	23.7	26.3	23.7	2.6	15.8	21.1	39.5	65.8	39.5
	OP	-15-0	10.5	18.4	21.1	21.1	68.4	13.2	42.1	78.9	34.2	5.3	23.7	21.1
	OP	0-15	28.9	5.3	39.5	44.7	2.6	57.9	55.3	5.3	42.1	15.8	2.6	26.3
	OP	>15	28.9	7.9	10.5	10.5	2.6	5.3	0.0	0.0	2.6	39.5	7.9	13.2
2021 Compared to 2019	MP	<-15	31.6	7.9	31.6	13.2	7.9	26.3	7.9	0.0	13.2	34.2	10.5	36.8
	MP	-15-0	23.7	5.3	5.3	42.1	2.6	15.8	36.8	13.2	31.6	18.4	7.9	18.4
	MP	0-15	21.1	36.8	39.5	34.2	60.5	47.4	50.0	65.8	55.3	18.4	21.1	13.2
	MP	>15	18.4	42.1	23.7	7.9	23.7	10.5	2.6	15.8	0.0	23.7	52.6	31.6
	EP	<-15	31.6	36.8	52.6	28.9	18.4	31.6	18.4	18.4	18.4	39.5	44.7	60.5
	EP	-15-0	21.1	13.2	26.3	21.1	47.4	44.7	36.8	39.5	44.7	21.1	5.3	15.8
	EP	0-15	15.8	23.7	15.8	28.9	13.2	18.4	31.6	34.2	34.2	5.3	13.2	15.8
	EP	>15	26.3	21.1	5.3	18.4	18.4	5.3	10.5	5.3	2.6	28.9	31.6	7.9
	OP	<-15	55.3	21.1	50.0	47.4	21.1	36.8	26.3	15.8	31.6	57.9	31.6	57.9
	OP	-15-0	28.9	13.2	10.5	42.1	28.9	36.8	65.8	36.8	34.2	13.2	26.3	15.8
	OP	0-15	10.5	47.4	34.2	7.9	42.1	23.7	5.3	42.1	34.2	15.8	15.8	15.8
	OP	>15	0.0	10.5	5.3	0.0	2.6	2.6	0.0	0.0	0.0	7.9	18.4	10.5

Table 12. Percentage of Links with Varying % Change in TTR and TTV—Speed Limit >55 mph for Mecklenburg County for Trucks

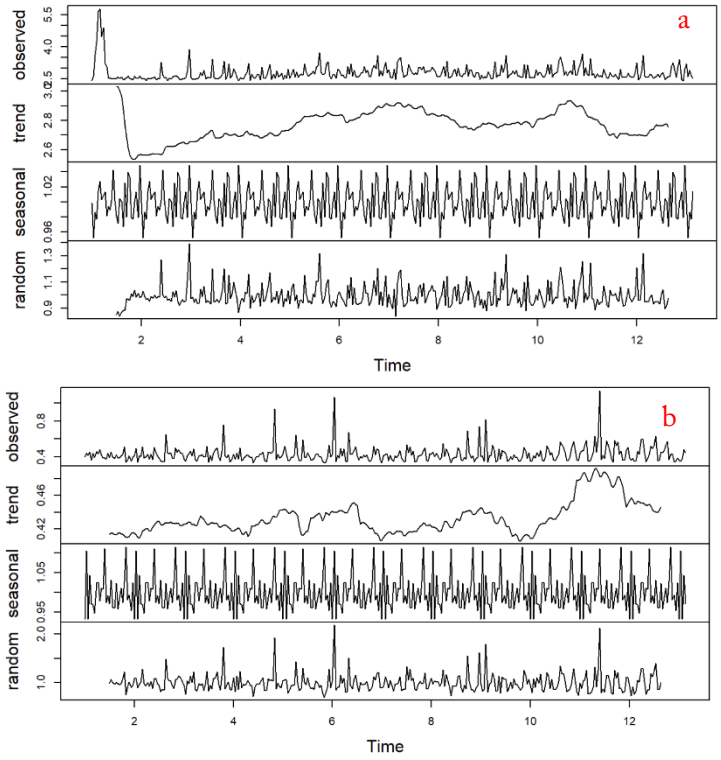
Comparison	Time	% change	TTV			PTI			TTI			BTI		
			Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III	Phase I	Phase II	Phase III
2020 Compared to 2019	MP	<-15	14.3	19.6	21.4	10.7	7.1	10.7	7.1	1.8	1.8	37.5	21.4	25.0
	MP	-15-0	32.1	14.3	23.2	39.3	12.5	17.9	39.3	21.4	26.8	21.4	8.9	23.2
	MP	0-15	35.7	25.0	37.5	42.9	67.9	67.9	51.8	67.9	71.4	16.1	28.6	25.0
	MP	>15	14.3	39.3	17.9	5.4	12.5	3.6	0.0	8.9	0.0	21.4	39.3	26.8
	EP	<-15	50.0	23.2	19.6	26.8	7.1	0.0	10.7	1.8	0.0	60.7	25.0	23.2
	EP	-15-0	14.3	17.9	25.0	42.9	19.6	33.9	60.7	37.5	37.5	12.5	17.9	21.4
	EP	0-15	17.9	33.9	42.9	16.1	62.5	55.4	17.9	48.2	57.1	5.4	26.8	26.8
	EP	>15	12.5	17.9	12.5	12.5	8.9	10.7	8.9	10.7	5.4	16.1	23.2	28.6
	OP	<-15	39.3	19.6	35.7	16.1	3.6	17.9	8.9	1.8	5.4	48.2	23.2	44.6
	OP	-15-0	17.9	14.3	21.4	58.9	10.7	46.4	64.3	16.1	73.2	21.4	10.7	17.9
	OP	0-15	32.1	30.4	39.3	21.4	80.4	35.7	25.0	76.8	21.4	12.5	23.2	28.6
	OP	>15	7.1	33.9	3.6	1.8	5.4	0.0	0.0	5.4	0.0	14.3	41.1	8.9
2021 Compared to 2020	MP	<-15	8.9	14.3	23.2	5.4	3.6	10.7	3.6	1.8	5.4	21.4	23.2	26.8
	MP	-15-0	16.1	14.3	41.1	21.4	28.6	33.9	37.5	35.7	42.9	19.6	21.4	42.9
	MP	0-15	51.8	53.6	28.6	58.9	64.3	53.6	53.6	60.7	50.0	21.4	28.6	25.0
	MP	>15	19.6	16.1	7.1	12.5	1.8	1.8	3.6	0.0	1.8	33.9	25.0	5.4
	EP	<-15	5.4	51.8	46.4	1.8	14.3	25.0	1.8	10.7	12.5	16.1	46.4	57.1
	EP	-15-0	32.1	28.6	25.0	32.1	66.1	62.5	48.2	71.4	64.3	26.8	23.2	23.2
	EP	0-15	42.9	8.9	19.6	53.6	12.5	12.5	44.6	12.5	21.4	26.8	10.7	14.3
	EP	>15	17.9	8.9	8.9	12.5	7.1	0.0	5.4	5.4	1.8	28.6	17.9	5.4
	OP	<-15	16.1	35.7	19.6	12.5	16.1	14.3	5.4	3.6	5.4	32.1	44.6	26.8
	OP	-15-0	16.1	19.6	19.6	25.0	46.4	28.6	37.5	82.1	53.6	14.3	19.6	19.6
	OP	0-15	55.4	33.9	57.1	55.4	37.5	55.4	53.6	14.3	39.3	33.9	25.0	30.4
	OP	>15	10.7	8.9	3.6	7.1	0.0	1.8	3.6	0.0	1.8	17.9	8.9	23.2
2021 Compared to 2019	MP	<-15	14.3	12.5	28.6	7.1	7.1	16.1	3.6	1.8	5.4	32.1	16.1	37.5
	MP	-15-0	25.0	16.1	26.8	35.7	8.9	23.2	32.1	12.5	21.4	12.5	16.1	19.6
	MP	0-15	39.3	33.9	37.5	42.9	71.4	60.7	60.7	78.6	73.2	32.1	32.1	19.6
	MP	>15	17.9	35.7	7.1	12.5	10.7	0.0	1.8	5.4	0.0	19.6	33.9	23.2
	EP	<-15	48.2	46.4	41.1	17.9	17.9	17.9	8.9	7.1	8.9	55.4	48.2	48.2
	EP	-15-0	14.3	33.9	23.2	51.8	60.7	51.8	60.7	71.4	53.6	7.1	19.6	28.6
	EP	0-15	16.1	12.5	28.6	14.3	16.1	25.0	17.9	14.3	32.1	12.5	7.1	8.9
	EP	>15	16.1	0.0	7.1	14.3	3.6	5.4	10.7	5.4	5.4	19.6	17.9	14.3
	OP	<-15	33.9	30.4	32.1	17.9	14.3	26.8	10.7	7.1	12.5	37.5	33.9	41.1
	OP	-15-0	16.1	17.9	28.6	46.4	19.6	23.2	66.1	30.4	58.9	32.1	14.3	26.8
	OP	0-15	42.9	32.1	39.3	33.9	60.7	50.0	21.4	57.1	28.6	19.6	21.4	21.4
	OP	>15	3.6	17.9	0.0	0.0	5.4	0.0	0.0	5.4	0.0	7.1	28.6	10.7

4.3 Effect of COVID-19 on Travel Time Patterns

As discussed earlier, to develop the SARIMA model, the five-minute data were converted to average daily travel time data. As this is a micro-level analysis, only a few links from both counties were selected. SARIMA models assume stationarity, meaning that the statistical properties of the time series remain constant over time. An Augmented Dickey–Fuller (ADF) test was conducted on each dataset to check for stationarity. The results revealed that the considered time series is stationary and suitable for SARIMA.

Visual seasonal patterns were observed to identify the seasonality. These seasonal patterns were checked from the multiplicative decomposition graphs of the time series. The multiplicative decomposition graph is used to visualize the components of a time series after decomposition. Time series decomposition is the technique that breaks down a time series into its underlying components, typically trend, seasonality, and residual components. Figure 6 shows an example of multiplicative decomposition graphs for two links.

Figure 6. Example of Multiplicative Decomposition Graph



The original time series is the first subplot in the multiplicative decomposition graph (Figure 6). This provides a visual reference and shows the overall behavior of the time series. The second subplot displays the estimated trend component, which represents the long-term behavior or direction of the time series. It shows the underlying pattern or tendency without the influence of seasonality or shorter-term fluctuations.

The third subplot displays the estimated seasonal component, which represents the repeating patterns that occur within a specific period, such as weekly or monthly. The fourth subplot represents the residual component, which represents the remaining variation in the time series after removing the trend and seasonal components. It represents random or unexplained fluctuations that cannot be attributed to the trend or seasonality.

Based on the results, it was observed that the seasonality in the time series varied for each link. For instance, seasonal variations were found weekly for some links, while seasonality patterns were observed monthly for other links. The frequency of seasonality was decided by developing the SARIMA model for different frequencies of seasonality, and the model with the minimum error was considered the final SARIMA model. The SARIMA model summary is presented in Table 13.

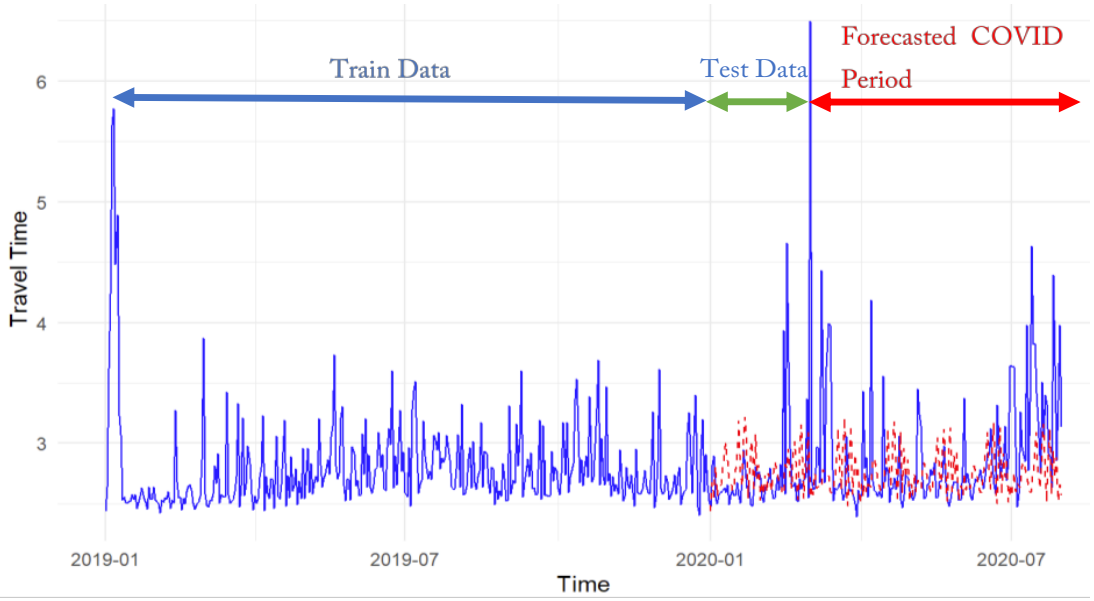
Table 13. SARIMA Model Results

Buncombe / Truck																	
Link	**p**	**d**	**q**	**P**	**D**	**Q**	**Frequency**	**ar1**	**ar2**	**ma1**	**sar1**	**sar2**	**sma1**	**sma2**	**drift**	**P-value**	**MAPE**
-5198	1	0	0	1	1	0	30	0.44	-	-	-0.41	-	-	-	-5.00E-04	<0.05	8.34
-5208	0	0	0	2	1	0	30	-	-	-	-0.67	-0.38	-	-	1.00E-04	<0.05	14.15
P05209	0	0	1	2	1	1	7	-	-	0	0.09	-0.04	0.05	-		<0.05	3.41
Buncombe / Car																	
Link	**p**	**d**	**q**	**P**	**D**	**Q**	**Frequency**	**ar1**	**ar2**	**ma1**	**sar1**	**sar2**	**sma1**	**sma2**	**drift**	**P-value**	**MAPE**
-5198	1	0	1	2	1	0	30	0.74	-	-0.29	-0.6	-0.41	-	-	-	<0.05	8.65
-5208	0	0	1	1	1	0	7	-	-	0.11	-0.44	-	-	-	0	<0.05	7.91
-9117	1	0	0	1	1	0	30	0.17	-		-0.52	-	-	-	0.0003	<0.05	19.07
Mecklenburg / Truck																	
Link	**p**	**d**	**q**	**P**	**D**	**Q**	**Frequency**	**ar1**	**ar2**	**ma1**	**sar1**	**sar2**	**sma1**	**sma2**	**drift**	**P-value**	**MAPE**
-4631	0	0	1	2	1	0	7	-	-	0.21	-0.64	-0.33	-	-	0.0001	<0.05	11.95
-4783	2	0	0	2	1	0	30	0.4	-0.23	-	-0.66	-0.37	-	-		<0.05	20.92
-10199	2	0	0	2	1	2	30	0.4	-0.22	-	-0.07	-0.3	-0.93	0.15	0.0001	<0.05	9.17

The *p*-values in Table 13 indicate that the models are significant. The SARIMA model was then validated for test data (Jan 2020–Feb 2020). The model's accuracy is gauged by the mean absolute percentage error (MAPE) value for the test dataset. The MAPE varied from 2.13% to 20.92%, highlighting that the SARIMA model can predict/forecast travel times with reasonable accuracy.

A SARIMA model using 2019 travel time data was developed to investigate the effect of COVID-19 on daily travel time patterns. The developed model was validated using Jan 2020 to Feb 2020 travel time data. The validated SARIMA model was then employed to forecast the travel time for different phases of the COVID-19 pandemic. The forecasted travel time was compared to the observed travel time for the different phases of the COVID-19 pandemic. Figure 7 shows the observed and forecasted travel time trends for one link. Here, the blue line represents the observed travel time, and the red line represents the forecasted travel time.

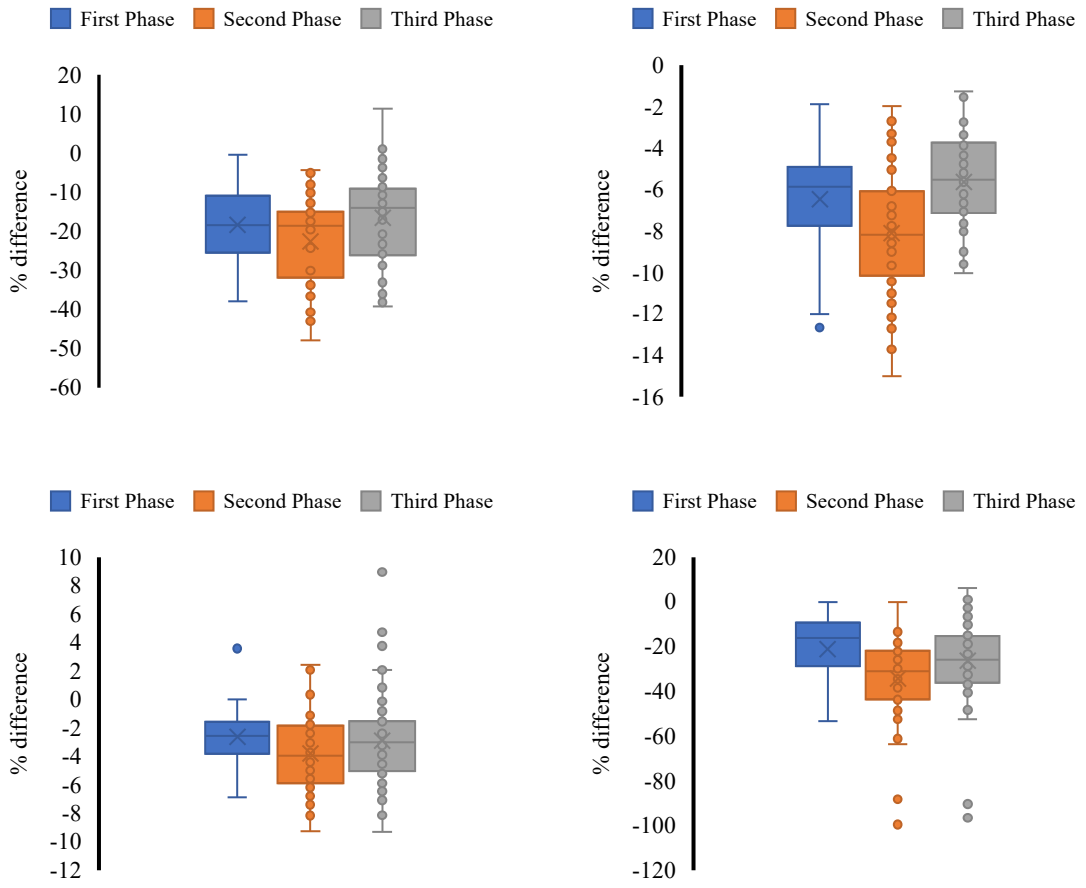
Figure 7. Actual and Forecasted Travel Time Trend



The percentage difference between the forecasted and observed travel time was estimated using Equation 9 to comprehend the effect of COVID-19 on average daily travel time patterns. A box plot of the percentage difference in travel time for all three phases of COVID-19 was developed to see the trend in the travel times over the phases. Figure 8 shows the box plot examples for some selected links. It can be inferred from the box plot that the percentage difference is negative, which indicates that the observed travel times are lower than the forecasted travel times. Consistent observations were made for different phases of the COVID-19 pandemic. Further, Phase II of the COVID-19 pandemic observed a higher percentage difference in travel times compared to other phases, apparently due to the strict restrictions from the government. In most cases, travel time patterns returned to normal (i.e., before the COVID-19 pandemic) after Phase II, attributed to the relaxation of restrictions.

Overall, from the time series analysis, different phases of COVID-19 significantly affected temporal trends and variations in travel times.

Figure 8. Box Plots of % Difference in Travel Times for All Three Phases



5. Summary and Conclusions

5.1 Summary

Global pandemics and pervasive events such as the COVID-19 pandemic disrupt day-to-day activities such as personal (home–work trips) and commercial trips (for shopping and freight transportation) due to safety, risk of becoming affected, or other associated concerns. The travel patterns during global pandemics or pervasive events differ from the normal travel patterns forecasted by the regional travel demand models. Over the past two years, numerous researchers have analyzed the effect of COVID-19 on travel and related metrics to understand the underlying patterns. While past research provides insights on the overall effect of COVID-19, they fall short of a deeper understanding of travel or travel time patterns during the various stages of such a pervasive event.

The focus of this study is on the travel time patterns during the COVID-19 pandemic and comparing these patterns during different stages of the pandemic. Road links or segments with varying functional class, road geometry, and speed limits were considered in Mecklenburg County (urban area) and Buncombe County (rural area). A total of 86 links were considered for the analysis. The different phases of the COVID-19 pandemic were identified based on the directives issued by the federal and state health agencies and three phases, Phase I, Phase II, and Phase III, were identified. Travel time data for the considered links were collected from the private data source for three years, i.e., 2019, 2020, and 2021. Globally, from April to July 2021, the number of COVID-19 cases spiked due to the emergence of mutated variants such as Delta and Omicron, and therefore, the travel time for 2021 was collected. The effect of different phases of the COVID-19 pandemic was investigated on TTR and TTV and average daily travel time patterns.

Different measures such as PTI, TTI, BTI, and TTV were computed for each of the selected links by time of the day and vehicle type and compared to investigate the effect of different stages of the COVID-19 pandemic on TTR and TTV. The comparison was made between three time periods (2019, 2020, and 2021) by time of the day, vehicle type, and different phases of COVID-19.

A SARIMA model was developed to investigate the effect of different phases of COVID-19 on average daily travel time patterns. Initially, the SARIMA model was developed using 2019 travel time data. The model was validated using the Jan 2020–Feb 2020 travel time data. The validated model was used to forecast the travel time for different phases of the COVID-19 pandemic. The forecasted values were compared with the observed values for the same period to comprehend the effect of different phases of the COVID-19 pandemic on travel time patterns.

5.2 Discussion

During COVID-19, i.e., 2020, off-peak hours are unreliable and uncertain for links with a lower speed limit. However, most links are observed to be reliable and certain for varying times of the

day for links with a higher speed limit. This result was consistent for passenger cars, trucks, and rural and urban counties. In the post COVID-19 pandemic period, TTR and TTV improved for the morning peak hours. Therefore, the COVID-19 pandemic significantly affected the scheduling of trips.

For Phase I, a marginal change in TTV and TTR was observed for 2020 compared to 2019. For Phase II, travel times were reliable and certain for most links compared to other phases. This can be attributed to the directives such as stay-at-home orders and travel only in case of emergency issued during Phase II. Therefore, the COVID-19 pandemic has had the most significant effect on TTR and TTV during Phase II. For Phase III (i.e., relaxation of restrictions), the number of links with reliable and certain travel times reduced compared to Phase II, highlighting that normality was slowly restored. However, the tendency to return to normal conditions was slow for the truck travel time. These results suggest that governmental rules and regulations significantly impact the TTR in case of pervasive events such as COVID-19.

Upon comparing links with different speed limits, it was observed that COVID-19 resulted in certain and reliable travel times for links with higher speed limits (speed limit greater than 50 mph) compared to links with lower speed limits (speed limit <35 mph).

The TTR and TTV during and after COVID-19 are similar for urban and rural counties. However, a difference in the magnitude of percent change in TTR and TTV measures can be seen, attributed to the difference in traffic flow conditions.

The time series analysis showed that SARIMA can be used to model the average daily travel time for passenger cars and trucks due to their ability to consider the seasonal variations in the model. Based on the SARIMA model, it can be concluded that COVID-19 significantly affected travel time patterns. The travel time patterns were stable (lesser variation in average daily travel times) for Phase II compared to the other phases. Phase II of the COVID-19 pandemic observed a higher percent difference in travel times compared to other phases, apparently due to the strict restrictions from the government. In most cases, travel time patterns returned to normal (i.e., before the COVID-19 pandemic) after Phase II, attributed to the relaxation in the restrictions.

The effect of pervasive events such as COVID-19 on travel time patterns highly depends on governmental norms and regulations. It is difficult to identify the effect of only COVID-19 without governmental laws as the seriousness and damage caused by the pandemic, to a considerable extent, needs the government to interfere just as in other pandemics.

5.3 Conclusions

The following are the important conclusions drawn from the study.

- The COVID-19 pandemic significantly affected the scheduling of trips. Most of the trips during and after COVID-19 were scheduled during off-peak hours.

- COVID-19 resulted in certain and reliable travel times for links with higher speed limits compared to links with lower speed limits.

- Restrictions on travel and work-from-home improved the reliability of travel times during COVID-19, especially during Phase II of the pandemic. However, links started showing poor reliability after governmental restrictions were lifted.

5.4 Recommendations

For a comprehensive understanding of the effect of pervasive events such as COVID-19, it is recommended that an analysis should be performed concerning different phases of the events. Moreover, collecting and analyzing the data for the post event conditions is also recommended to comprehend whether and how the system restores to normality.

Multiple measures should be adopted for a holistic assessment of the effect of pervasive events on travel times. For instance, PTI enables an understanding of the effect of pervasive events on the worst travel conditions. TTV enables an understanding of the effect of pervasive events on TTV. Similarly, TTI enables an understanding of how pervasive events influence average travel conditions.

5.5 Limitations and Future Scope of Work

The effect on travel time is due to the norms provided by the government and restrictions imposed by the government as per the forecasted trend of the pandemic. Here, people are required to avoid contact with everyone. Other pandemics can have a different nature, and hence, the plan of action can be different for them. In such a case, it can be hard to predict the nature of the travel time patterns and how they will vary.

Moreover, this study did not consider non-recurrent events such as crashes and work zones. In addition, an increase in the traffic volume is also not considered during the analysis due to the unavailability of the data. Further detailed analysis by considering these factors can uncover more about travel time patterns and TTR.

Appendix

This appendix presents the details of all the links considered for this project.

Road	County	# of Through Lanes	AADT	Reference Speed
NC-49	MECKLENBURG	4	33295	19
I-77	MECKLENBURG	6	134831	55
WT HARRIS BLVD	MECKLENBURG	8	66000	55
NC-49	MECKLENBURG	4	33000	19
I-77	MECKLENBURG	6	118000	55
I-85	MECKLENBURG	8	138797	60
I-77	MECKLENBURG	6	152414	55
I-77	MECKLENBURG	8	130027	55
NC-49	MECKLENBURG	4	20803	26
NC-49	MECKLENBURG	4	19000	27
I-85	MECKLENBURG	8	127000	60
I-77	MECKLENBURG	8	164000	55
I-77	MECKLENBURG	8	174000	55
NC-49	MECKLENBURG	4	16000	19
NC-16	MECKLENBURG	4	31000	31
I-85	MECKLENBURG	8	151772	60
I-485	MECKLENBURG	6	90000	70
NC-16	MECKLENBURG	4	23276	26
I-77	MECKLENBURG	8	168257	55
NC-16	MECKLENBURG	4	32691	29
NC-49	MECKLENBURG	6	35581	60
NC-49	MECKLENBURG	4	32054	60
I-77	MECKLENBURG	6	146192	60
WT HARRIS BLVD	MECKLENBURG	4	63516	60
US-74	MECKLENBURG	4	24000	36
US-74	MECKLENBURG	6	26280	34
US-74	MECKLENBURG	6	30307	34
I-485	MECKLENBURG	8	124000	70
I-485	MECKLENBURG	6	97285	70
I-85	MECKLENBURG	8	121000	60
I-85	MECKLENBURG	8	151633	60
I-77	MECKLENBURG	6	136314	55
NC-24	MECKLENBURG	4	63751	55
NC-16	MECKLENBURG	4	23276	26

Road	County	# of Through Lanes	AADT	Reference Speed
I-85	MECKLENBURG	8	127000	60
I-77	MECKLENBURG	8	169460	55
I-77	MECKLENBURG	8	131354	55
I-85	MECKLENBURG	8	157876	60
I-77	MECKLENBURG	6	127962	55
I-85	MECKLENBURG	8	140672	60
UNIVERSITY CITY BLVD	MECKLENBURG	4	28131	60
I-85	MECKLENBURG	8	141431	60
US-74	MECKLENBURG	4	24000	37
US-74	MECKLENBURG	6	26279	33
I-85	MECKLENBURG	8	121000	60
I-485	MECKLENBURG	6	90000	70
US-74	MECKLENBURG	6	30342	36
I-77	MECKLENBURG	6	155328	55
NC-49	MECKLENBURG	4	16000	19
NC-49	MECKLENBURG	4	20803	26
NC-49	MECKLENBURG	4	19000	27
I-77	MECKLENBURG	6	118000	55
UNIVERSITY CITY BLVD	MECKLENBURG	4	27671	70
NC-49	MECKLENBURG	4	32233	55
NC-49	MECKLENBURG	6	35620	55
I-85	MECKLENBURG	8	128981	60
I-85	MECKLENBURG	8	127000	60
I-77	MECKLENBURG	8	174000	55
NC-49	MECKLENBURG	4	33271	19
NC-49	MECKLENBURG	4	33000	19
I-77	MECKLENBURG	8	164000	55
I-485	MECKLENBURG	6	116558	70
I-85	MECKLENBURG	8	153000	60
NC-16	MECKLENBURG	4	31000	33
NC-16	MECKLENBURG	4	32690	28
I-85	MECKLENBURG	8	127000	60
I-485	MECKLENBURG	6	95816	70
I-85	MECKLENBURG	8	129000	60
I-485	MECKLENBURG	6	116493	70
I-485	MECKLENBURG	8	124000	70
I-240	BUNCOMBE	4	80000	20
I-240	BUNCOMBE	4	80000	35

Road	County	# of Through Lanes	AADT	Reference Speed
I-240	BUNCOMBE	4	80000	35
I-240	BUNCOMBE	4	80000	35
I-240	BUNCOMBE	4	80000	35
US-25	BUNCOMBE	4	25213	35
I-240	BUNCOMBE	4	66000	35
US-23	BUNCOMBE	4	26462	35
US-23	BUNCOMBE	4	26462	35
I-240	BUNCOMBE	4	80000	50
I-240	BUNCOMBE	4	80000	60
I-240	BUNCOMBE	4	80000	60
US-25	BUNCOMBE	4	25213	60
US-25	BUNCOMBE	4	25213	60
US-25	BUNCOMBE	4	25213	60
US-19	BUNCOMBE	4	60671	60

Abbreviations and Acronyms

ADF	Augmented Dickey–Fuller
ARIMA	Autoregressive Integrated Moving Average
ATT	Average Travel Time
BT	Buffer Time
BTI	Buffer Time Index
FFTT	Free Flow Travel Time
IATA	International Air Transport Association
IMF	International Monetary Fund
MAPE	Mean Absolute Percentage Error
NCDOT	North Carolina Department of Transportation
NHTSA	National Highway Traffic Safety Administration
NPMRDS	National Performance Management Research Data Set
PT	Planning Time
PTI	Planning Time Index
RITIS	Regional Integrated Transportation Information Systems
SARIMA	Seasonal Autoregressive Integrated Moving Average
SME	Small and Medium-Sized Enterprise
TMC	Traffic Message Channel
TTI	Travel Time Index
TTV	Travel Time Variability

VMT	Vehicle Miles Traveled
WTO	World Trade Organization

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