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Abstract: The COVID-19 pandemic resulted in significant social and economic impacts throughout the world. In addition to the health consequences, the impacts on travel behavior have also been sudden and wide ranging. This study describes the drastic changes in human behavior using the analysis of highway volume data as a representation of personal activity and interaction. Same-day traffic volumes for 2019 and 2020 across Florida were analyzed to identify spatial and temporal changes in behavior resulting from the disease or fear of it and statewide directives to limit person-to-person interaction. Compared to similar days in 2019, overall statewide traffic volume dropped by 47.5%. Although decreases were evident across the state, there were also differences between rural and urban areas and between highways and arterials both in terms of the timing and extent. The data and analyses help to demonstrate the early impacts of the pandemic and may be useful for operational and strategic planning of recovery efforts and for dealing with future pandemics. **DOI: 10.1061/(ASCE)NH.1527-6996.0000409.** *© 2020 American Society of Civil Engineers.*

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Introduction

The COVID-19 pandemic brought unprecedented levels of disruption to countries throughout the world. As the disease spread globally, all countries were impacted to one extent or another. However, the response to the global pandemic declaration has been uneven and varied, depending on factors such as wealth, availability of health care, socialized medicine, public welfare, and the extent of authoritarianism in government.

Because the specific mechanisms for the transmission of the virus were largely unknown during its onset period in the United States and there was a limited ability to test for infection, public officials throughout the country had few options to limit the rapid spread of the virus other than to call upon people to maintain physical distancing from one another. In the United States, governmental directives varied over time, beginning with voluntary stay-at-home requests and restrictions on large public gatherings, then, later, virtual statewide lockdown quarantines. However, travel in various forms continued throughout the country. Most notable of these were activities deemed essential for the public good, such as for people to access food, medical care, and other basic life necessities for public health, welfare, and safety.

While the ultimate intent of these restrictions, to slow the progression of the virus and limit fatalities, will take time to assess, other effects of travel and social interaction restriction can already be studied. In this research, it was hypothesized that roadway traffic volume data could serve as a reflection of societal activity and, to an extent, the likelihood of personal interaction. Because traffic count data are objective, accurate, reliable, and collected continuously throughout cities and states, they provide a basis of comparison between conditions before, during, and after the period of the initial COVID-19 detection in the United States in early 2020. In this paper, the sudden and drastic changes in societal behaviors are described and assessed by using the same-day traffic volumes for 2019 and 2020 across Florida to compare spatial and temporal pattern changes resulting from the disease, fear of it, and statewide directives to limit its spread.

More specifically, the focus of the effort was to examine the temporal relationship of key governmental requests for public isolation and travel limitations both temporally and spatially. The assessment looked at differences in urban versus rural regions of the state over time as well as on different road functional classifications. Road functional class was included because it was recognized that some types or roads, urban arterials, for example, tend to serve local traffic, while others, like rural freeways, tend to serve more distant, intercity travel. Florida was thought to be a particularly interesting location to examine the travel impacts of the COVID-19 pandemic because of its enormous diversity and unique demographic and commercial characteristics. Among these are its numerous highly populated major metropolitan regions and rural

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regions, its significant percentage of elderly population, and its position as one of the most highly visited tourist and recreational locations in the world.

The paper includes several sections to highlight and summarize the primary components of this research study. First, a review of relevant literature is included to provide background and context to the study from the perspective of prior research and prior study of virus transmission, particularly through isolation as it related to means and modes of transportation. This is followed by a description of the data and methods used to carry out the study. Then, the data collection and analyses are discussed. In particular, the Florida Department of Transportation (FDOT) traffic count data collection system is described and how its output was used for this study. This is followed by a presentation and discussion of the analytical results of the research. Because of the enormous quantity of data recorded hourly over a statewide network of data recorders, the "Results" section focuses on key statistical findings at various high levels of aggregation. Finally, the paper concludes with a discussion of what these data and results may be suggesting, especially in terms of policy guidance—both existing and future and the public response to government guidance and recommendations.

Background

Broadly, pandemics are global disease outbreaks that spread quickly across the world. Often, they result from lack of immunity and an inability to develop and deliver vaccines to stop the disease. While the threat of pandemic has been well recognized (Yong 2018) and guidance for pandemic planning has been developed by the World Health Organization (2019) and the Centers for Disease Control and Prevention (2017b), pandemics are complex, difficult phenomena to manage. They are rare events. Only four have occurred in the last century, in 1918, 1957, 1968, and 2009 (Kilbourne 2006; Centers for Disease Control and Prevention 2017a).

There have been epidemics such as dengue, Ebola, and measles, which are disease outbreaks that are more limited than pandemics in that they are concentrated in a few countries or regions of the world. With pandemics, challenges arise from the lack of knowledge, experience, and readiness. The global scale overwhelms the capacity to manage, respond to, contain, mitigate, and recover from the disease outbreak. Characteristics of the 2019 novel coronavirus in terms of origin, transmission, contagion, lethality, containment, treatment, and recovery present challenges for emergency management. A vaccine will likely not be developed in time to prevent the spread of the disease and its health and social consequences. For this reason, nonpharmaceutical interventions (US Dept. of Health and Human Services 2017) such as quarantine, isolation, and social distancing are most needed. Pandemics differ from other natural hazards (Kim et al. 2018a) such as hurricanes, tornadoes, flooding, earthquakes, tsunamis, volcanoes, and wildfires that typically damage infrastructure as well as cause harm to people. With a pandemic, homes, buildings, roads, facilities, vehicles, and equipment are not damaged. Pandemics cause people to be sick, absent from work, and hospitalized, and some people die. Some infected individuals may not fully recuperate or may take many months to recover. The loss of income because of health care costs and not being able to work, pay taxes, or conduct business can impact households, firms, and governments. A pandemic can also affect social, cultural, educational, recreational, and other important activities. As such, a pandemic affects the health and well-being of people and communities.

Among the ways that governments and health officials attempt to limit the speed and extent of pandemics is to physically separate people. In particular, quarantines—the restriction of movement of healthy persons suspected of being infected with a contagious disease—attempt to isolate and treat individuals who are, or are suspected to be, infected. Social distancing involves actions by individuals, groups, and organizations to limit contact with others through actions such as the closure of schools and businesses and shutdown of services, travel, and activities and gatherings. Any particular pandemic response relies on the planning, coordination, and execution of actions involving governments (federal, state, local, tribal, and territorial), businesses and industry, nonprofit organizations, and community groups. Pandemic responses also rely on whole community approaches. In the United States, this is a part of the National Incident Management System (NIMS), which includes frameworks for emergency management and response.

While guidance, training, exercises, and systems for pandemic planning have been developed, there are reasons for focusing on transportation and managing travel demand. Transportation planning theories, research, methods, and technologies can be incorporated into pandemic response and recovery (Baxter 2001; Berkoune et al. 2012; Kim et al. 2018b; Matherly et al. 2014; Renne et al. 2020; Zheng and Ling 2013). It is particularly useful to apply the tactics and strategies from other events that have disrupted transportation systems (Douglass et al. 2014; Grayson and Noonan 2010; Hambridge et al. 2017; Houston 2006; Houston et al. 2009, 2010; Kim et al. 2019; Kontou et al. 2017; Litman 2006; Schwartz and Litman 2008; Reggiani 2013; Vasconez and Kehrli 2010; Wolshon et al. 2005). There are useful lessons for managing, recovering, and restarting transportation systems (Chen and Miller-Hooks 2012). While evacuation typically involves movement of people away from hazards and threats, planning and decision-making involve trade-offs between sheltering in place, travel through hazard zones, evacuating to safety, and reentry decisions; all pertinent to quarantine, isolation, and social distancing efforts.

Timely, accurate, and actionable data are required for planning and decision-making. Information on the spread of the disease across and within transportation systems (e.g., nodes, hubs, links, vehicles, operators, passengers, and users) and an understanding of risk, risk tolerance, and risk management (Flannery et al. 2015; Fletcher et al. 2014; Reggiani 2013) are critical for strategic and operational planning. The capabilities used with events such as hazardous material release (National Academies of Sciences, Engineering, and Medicine 2011), infectious disease outbreaks on transit systems (Henson and Timmons 2017), air travel (Gardner and Sakar 2015), or management of transportation agencies during emergencies (Krechmer et al. 2018) depend on many of the same systems, frameworks, protocols, operational procedures, and processes needed for the COVID-19 pandemic.

There are unique challenges with COVID-19. The disease has spread rapidly, forcing governments to implement historic lockdowns, shutdowns, and closures of schools and businesses. There have been significant bans on international travel with impacts on tourism, entertainment, and the cruise ship industry, impacting some states more than others. In terms of the cruise ship industry, Florida leads the nation (followed by Alaska, California, Puerto Rico, and the US Virgin Islands) with more than 3,000 port calls, with the largest number of jobs in this industry located in Miami (Congressional Research Service 2020). The cancellation of flights and the closure of beaches, parks, sporting events, conferences, conventions, and other activities because of the coronavirus has had significant impacts on travel behavior. The effects on the airline industry are even more dramatic than the terrorist attacks on September 11, 2001, or the Icelandic volcano eruption in 2010 (Ulfarsson and Unger 2014). Evidence of the change in transportation owing to the shutdown of travel has been captured by seismometers measuring planetary movements (Gibney 2020).

In the United States, the response to the COVID-19 pandemic has been difficult to coordinate because of the size of the country and the system of public health management. While the federal government may impose restrictions on international travel and take actions affecting airlines and cruise ships, for the most part state and local governments manage public health emergencies. Most emergencies, from motor vehicle crashes to fires to industrial accidents, are handled locally with mutual aid from neighboring jurisdictions. Large cities have relevant experience with managing special events and incidents, including mass shootings, severe weather, and more catastrophic events such as earthquakes and hurricanes. However, most jurisdictions are not well prepared for pandemics. New York, San Francisco, New Orleans, and Detroit initially asked residents to limit travel to only essential trips for food, medication, medical care, and work deemed to be essential (e.g., public safety, hospitals, utilities, manufacturing, food production, groceries, and drug stores).

A recent study of Seattle from February 2, 2020, to March 8, 2020, found that major employment centers experienced the largest declines in visits, followed by recreational and social hubs, but a decline in longer trips was replaced with more frequent short trips. Second, as commute and social trips reduced traffic, travel speeds on roadways increased and trip times fell correspondingly. Finally, the study found that visits to bulk retailers spiked while mall visits decreased. Somewhat surprisingly, the study found that visits to grocery stores decreased, perhaps because of the early nature of this study before restaurants were closed on Tuesday, March 17, 2020 (Reed and Hendrickson 2020).

Florida imposed statewide lockdowns, keeping beaches open in some parts of the state outside the epicenter in South Florida, considered as Broward, Miami-Dade, Monroe, and Palm Beach Counties in this study, during spring break but urging elderly and high-risk groups to shelter in place. An article published in the *New York Times* found that residents in South Florida had virtually no travel while residents in the northern part of the state maintained more regular patterns of travel (Glanz et al. 2020). Directives in Florida became more restrictive over time as confirmed cases increased. By late March 2020, most nonessential activities throughout the nation came to a halt. Most primary, secondary, and higher education institutions started online education and some extended spring breaks. Restaurants switched to pickup and delivery service. There has also been growth in online shopping, telework, and virtual meetings.

In this research, statewide traffic volume data collected by FDOT were used to assess regional surface mobility during the early onset of COVID-19. With more than 20 million residents, Florida has a large diverse population with a mix of large urban regions and small rural communities. In addition to examining different parts of the state and urban and rural locations, there are a mix of different roadway classes. As a narrow peninsula, the state provides a more comprehensible and coherent transportation network.

From an operations perspective, the data and analyses in this paper support greater understanding of how to implement quarantine and isolation controls (Graham et al. 2008), adding to research on slowing movement of infectious disease (Gardner and Sakar 2015; Gendreau 2015; Fletcher et al. 2014). If the duration of the pandemic is long, there may be need for other operational strategies, such as the prepositioning of supplies (Zheng and Ling 2013; Rawls and Turnquist 2010), including equipment and other goods necessary for response and relief efforts or to ensure populations can comply with stay-at-home orders. Data on travel behavior are also relevant to recovery efforts and planning for the return to normalcy (Matherly et al. 2014; Chen and Miller-Hooks 2012), training and overall preparedness (Dept. of Homeland Security 2013; Wallace et al. 2010), and longer-term community resilience.

Data and Methods

Traffic patterns before and during the COVID-19 crisis across the State of Florida were examined using a quasi-natural experimental design of before and after, featuring traffic volume as the key variable of interest. Traffic count data from FDOT for 262 sites were analyzed to answer the following research questions:

1. What have been the changes in overall traffic volume patterns across Florida owing to COVID-19?
2. Did traffic volumes decrease more in closer proximity to the epicenter of the outbreak in South Florida compared to other counties with fewer confirmed cases (at the end of the study period on March 22, 2020), or was the decrease in travel equally distributed across the state?
3. Did traffic decline equally in urban locations compared to rural locations?
4. Did traffic decline equally on arterials compared to interstates?
5. When did traffic change significantly? Did this vary by roadway classification or area?

The first research question was answered by examining the overall share of traffic volume growth or decrease statewide for all locations during the COVID-19 response in March 2020 compared to March 2019. The second question examined 2019 to 2020 differences in traffic counts for sites located in Broward, Miami-Dade, Monroe, and Palm Beach Counties compared with 2019 to 2020 differences to counties outside this area. The third question examined 2019 to 2020 differences in traffic counts for sites located in urbanized areas (as defined by FDOT) compared with 2019 to 2020 differences in rural locations. The fourth research question examined 2019 to 2020 traffic volume differences on arterial roads versus interstates. Finally, the fifth research question was addressed through an examination of the dates when statistically significant differences arose and remained consistently different between 2019 and 2020.

Data from this natural experiment helped to inform the role of state policy directives in limiting travel on actual traffic volume. Moreover, the study sought to understand if proximity to the outbreak reduced traffic greater than distant locations; everyone in the state was under the same directives from the governor. Examining urban versus rural traffic differences informed how travel varied in different contexts. For example, while travel volumes are typically lower in rural areas, the decrease in travel may not have been as great because people may not have been as concerned about the disease because of living in a less crowded environment. Finally, comparing arterials with interstates allows for a comparison of differences between long-distance and local travel.

Traffic volumes in March 2020 were compared to base year levels in March of 2019 using paired t-test statistics generated using SPSS version 22. The comparison dates were March 1–22, 2020, and March 3–24, 2019, with matched days of the week. Wednesday and Thursday of the third week in January for 2019 and 2020 were compared against each other to test for general traffic growth or contraction. The Tuesday of this week was discarded because it would have involved comparing the Tuesday after Martin Luther King Jr. Day in 2020 with the Tuesday before Martin Luther King Jr. Day in 2019 and the holiday traffic differences could have skewed the results.

The FDOT Transportation Data and Analytics Office gathers roadway data from across the state. Volume, speed, and vehicle classification are collected hourly using telemetric monitoring stations that transmit these data through telephone or wireless communications. Bidirectional hourly traffic counts were collected, cataloged, and processed from 262 telemetric monitoring stations, shown in Fig. 1. Data were collected for the 82-day period beginning January 1, 2020, and ending March 22, 2020. For comparative purposes, data were also collected for the 90-day period beginning January 1, 2019, and ending March 31, 2019. Totaled, the data set consisted of more than 2.1 million individual count observations (172 days $\times$ 24 h $\times$ 262 sites $\times$ 2 directions).

The data were reviewed for errors. A common error was missing data and/or sites reporting zero values. The zero values were attributable to road closures because of incidents, scheduled maintenance work, and malfunctioning roadway sensors. Sites with three or more consecutive observations of zero values were removed. Data from 2020 were linked to data from 2019, resulting in 212 sites with consistent and error-free information.

Results

The research results are presented in two parts. First, traffic volume trends are presented and discussed for the period corresponding to the early onset of the COVID-19 pandemic in Florida. Then, statistical comparisons are presented to illustrate the significance of the traffic decrease in 2020 compared to 2019.

Traffic Volume Trends

Fig. 2 provides the daily traffic totals collected from the monitoring stations between March 1, 2020, and March 22, 2020. Traffic counts

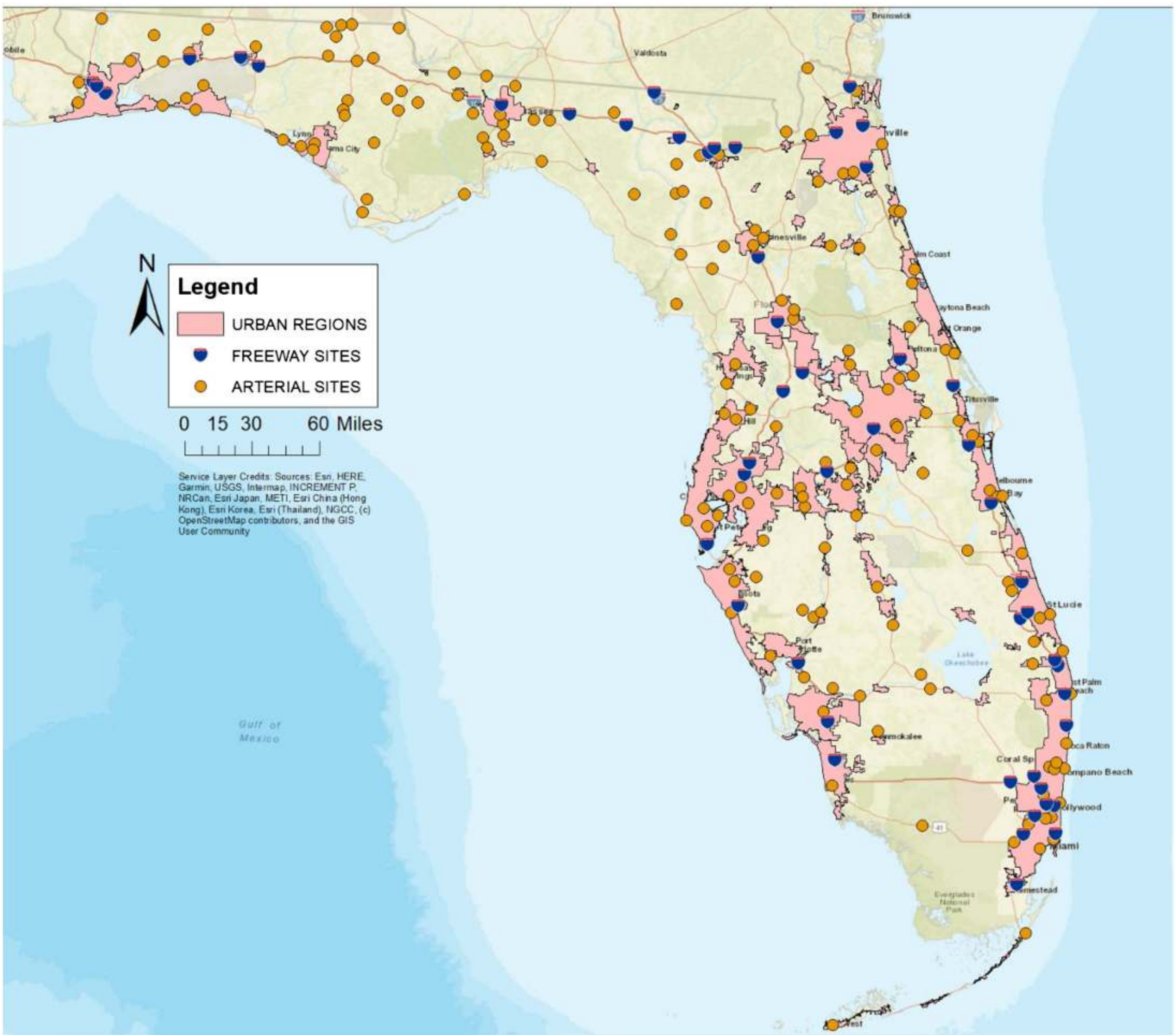

Fig. 1. FDOT telemetered traffic monitoring sites. [Base map sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community.]

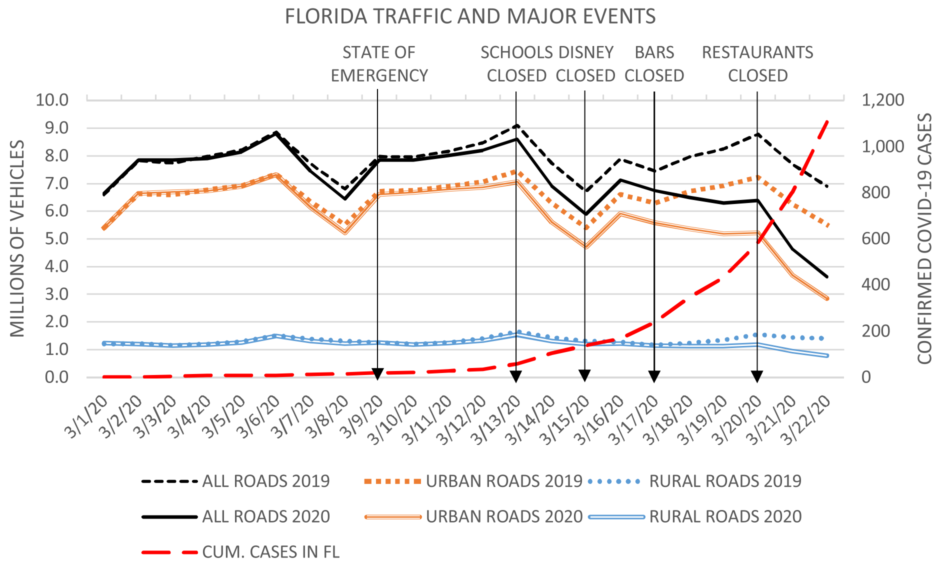

Fig. 2. Florida traffic, urban and rural roads, March 2020 and 2019 and COVID-19 reported cases.

are shown for urban roads (123 sites), rural roads (89 sites), and combined for all roads (212 sites). Daily traffic totals from these same sites are shown for a similar period in 2019, based on the first through the fourth Sunday in March for both years. Included in the figure are the cumulative confirmed cases of COVID-19 in Florida as well as the dates of statewide directives and actions (e.g., the emergency declaration, school closures, major theme park closures, bar closures, and restaurant closures). Traffic volumes for the first week of March 2020 remained consistent with the prior year. Governor Ron DeSantis declared a state of emergency on March 9, 2020, when the first two cases of COVID-19 were confirmed. By March 12, traffic volumes were reduced by 3.2% from their 2019 levels. The following day (March 13), the governor announced the closure of schools, and by Saturday, March 15, Disney World and Universal Studios' Orlando theme parks were closed. At that time, there were 50 confirmed case of COVID-19 and traffic was reduced by 12% compared to 2019. By March 17, the governor closed all bars and nightclubs, and on March 20, all restaurants were closed to dine-in service and traffic had decreased by 23%. On March 22, the last day of observation, traffic volumes across the 212 sites had dropped by an average of 47.5% when compared to 2019 levels and there were more than 1,100 confirmed cases of COVID-19 in the state.

Total urban traffic volume was approximately five times greater than rural volumes and constituted a larger proportion of the overall trend observed in Fig. 2. The figure reveals that urban traffic was subject to large weekday and weekend variations, ranging from a Friday high of more than 7 million vehicles per day (vpd) to a Sunday low of just 5.2 million vpd. The weekly variations in rural traffic were not as pronounced, ranging from a Wednesday high of 1.54 million vpd to a Sunday low of 1.15 million vpd. Urban traffic begins to decline from 2019 levels on March 7 with a 3% drop; however, the percent drop decreases to 1%–2% after March 8 (which had a 5.3% drop) until March 12. After March 12 (3% drop), the percent drop generally increased until reaching 48.3% on the last day of the study. In terms of percentage drops, decreases in traffic on rural roads began on March 12 (4.4% drop), with increasingly large percentage drops starting March 18, when rural roads showed a 9% decrease in traffic. By the end of the study period, rural roads had decreased by 44.3%.

Among the other findings from the analysis of traffic trends was that the 48 detector locations on freeways consistently carried more traffic than the 164 detector sites on arterial roadways. Overall, freeway traffic decreased by 52.4% when compared to 2019 traffic and arterials were reduced by 40.6%. The impact of COVID-19 on freeway traffic appeared to begin earlier than on arterial roadways.

Fig. 3 shows the percent decrease in traffic observed during the study period in 2020 compared to the same period from the prior year. The figure is partitioned to show total traffic and urban and rural roadways. The figure includes cumulative COVID-19 cases and major directives and actions taken to reduce travel. Overall, the figure suggests similar trends between decreases in traffic and confirmed cases of COVID-19 within the state. In general, the decrease in traffic was nominal until the governor's state of emergency declaration. The decreases, along with the confirmed cases of COVID-19, grew exponentially until the end of the study period. Furthermore, urban weekday and weekend variations narrowed over the study period. Starting on March 18, rural traffic rapidly reduced and the decrease aligned with urban traffic.

Statistical Analyses

To test for general traffic growth and contraction, traffic volumes on two days in January 2020 and 2019 were compared. These days were the Wednesday and Thursday of the third week January; Tuesday, Wednesday, and Thursday are the most similar (Rakha and Van Aerde 1995). In this study, Tuesday was excluded because of Martin Luther King Jr. Day falling in different weeks for 2019 and 2020. The results of the paired t-test among 226 sites indicated that the volumes were not statistically different ($p > 0.28$). This suggests that the differences in volumes were not attributable to an overall decreasing trend in traffic because of the COVID-19 pandemic event and associated responses.

All Roadways

Data for all roadways, including freeways and arterials (212 traffic count locations), across the state were analyzed with a paired t-test to compare traffic volumes for each day from March 1, 2020, to March 22, 2020, to a reference day in March 2019 corresponding to the same day of the week (i.e., March 1, 2020 was the first

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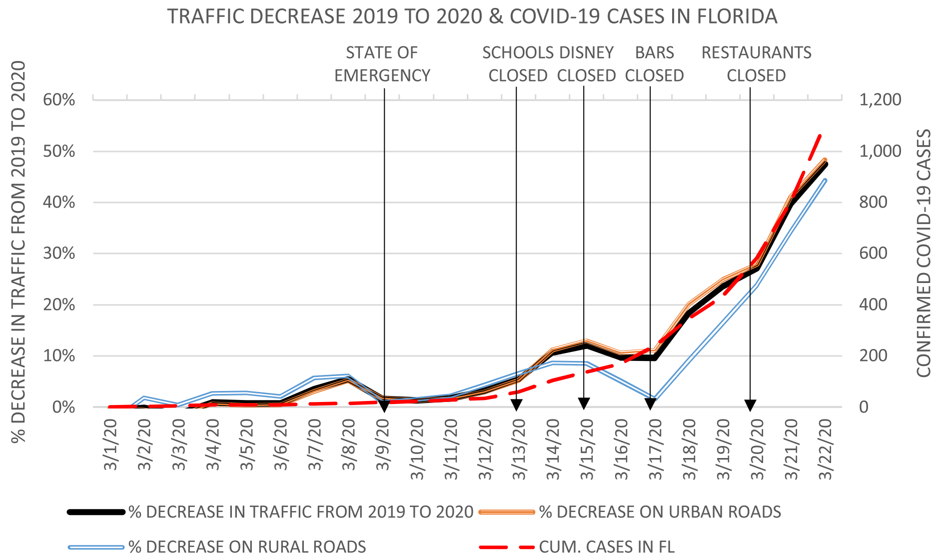

Fig. 3. Percentage of 2019 to 2020 traffic decrease and cumulative confirmed COVID-19 cases in Florida.

Sunday of the month compared to March 3, 2019, which was the first Sunday of March in that year).

As reported in Table 1, traffic on Sunday and Monday, March 1 and 2, showed no statistically significant differences compared to the reference days in 2019. March 3 and 4, 2020, were the first days that traffic volume declines were statistically significant compared to the 2019 reference days (Table 1). However, the p-values were 0.009 and 0.029, respectively, and the traffic decline was not statistically significant on March 5 and 6, 2020, compared to each of their reference days in the prior year. Starting on Saturday, March 7, 2020, and continuing to March 22, 2020, each day demonstrated a statistically significant difference compared to the reference day for 2019.

South Florida versus Outside of South Florida

The concentration of COVID-19 cases during this study period was located in Broward, Miami-Dade, Monroe, and Palm Beach Counties. As shown in Table 1, for all roadways combined, statistically significant volume changes were noted on March 7, 8, and 12–22 in South Florida. Outside of South Florida, statistically significant volume changes were present earlier and on more days: March 3, 5–8, and 10–22.

Urban versus Rural

Data for all roadways, including freeways and arterials, were examined and compared by urban versus rural location, as defined by FDOT (2018). All urban roadways (123 traffic count locations) showed no difference from the 2019 reference day for traffic volumes from March 1–6, 2020, with the exception of Tuesday, March 3, 2020. On that day, traffic decline was statistically significant. Starting Saturday, March 7, through the last day of the analysis on March 22, 2020, traffic decline was statistically significant for all urban roadways (Table 1).

The change in traffic for all rural roadways (89 traffic count locations) was not as clear. The t-test showed that traffic decline on all rural roadways was statistically significant on March 3, 4, 7, 8, 12–16, and 18–22, but no statistically significant differences were found on March 1–3, 6, 9–11, and 17 (Table 1).

The study examined urban freeways (33 traffic count locations), urban arterials (90 locations), rural freeways (15 locations), and rural arterials (74 locations). Tests of statistical significance between urban freeways and urban arterials failed to show a statistically significant difference with the exception of March 3 and 11, 2020. On March 3, 2020, traffic on urban arterials was less (statistically significant) than 2019, whereas traffic on urban freeways was not. On March 11, 2020, the opposite was the case, with traffic on urban freeways showing lower traffic compared to 2019 while urban arterials showed no statistically significant difference (Table 1).

The most striking difference in the analysis was apparent when comparing rural arterials to any other type of roadway classification. Rural arterials (74 traffic count locations) across Florida showed no statistically significant differences in traffic volume from March 1–15, 2020, compared to the reference days in 2019, with the exception of March 13 ($p = 0.046$). On March 16, 2020, declines in traffic volume became statistically significant on rural arterials and remained significant through the last day of the analysis on March 22, 2020. Data for rural freeways, which had the fewest number of traffic count locations ($N = 15$), showed a sporadic pattern of differences. Rural freeways showed significant declines on March 4–8, 10–15, and 19–22, 2020 compared to the reference days from 2019 (Table 1).

Freeways versus Arterials

Data for all freeways (48 traffic count locations) demonstrated the same pattern as all roadways with the exception of March 3, 2020. On that day, data for all freeways were not statistically significant compared to the reference day in 2019. Data for all arterials (164 traffic count locations) showed statistical significance on March 3; however, there was no significant difference in traffic on March 4–6, 2020, compared to the reference day in 2019. The data for Saturday and Sunday, March 7 and 8, 2020, demonstrate a statistically significant decrease in traffic compared to the previous year, but traffic for all arterials was not statistically different on March 9–11, 2020, compared to each of the prior reference year dates. Traffic decline for all arterials became statistically significant compared to the 2019 reference days March 12–22, 2020 (Table 1).

Date of Consistent Difference

For the purposes of this study, *consistently different* was considered at least three consecutive days of statistically significantly different traffic volumes with less than two consecutive days of not significantly different traffic volumes. Using this definition of consistently different, Table 1 indicates when the traffic volumes began to be consistently different. Any note indicates a statistically

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Table 1. Two-tailed significance of traffic volume differences

		All Florida			Urban			Rural		South Florida		Non-South Florida		
Comparison dates	Day	All	Freeway	Arterial	All	Freeway	Arterial	All	Arterial	All	Arterial	All	Freeway	Arterial
March 1, 2020 and March 3, 2019	Sunday	0.374	0.099	0.175	0.899	0.204	0.027[a]	0.125	0.134	0.594	0.313	0.136	0.016[a]	0.272
March 2, 2020 and March 4, 2019	Monday	0.741	0.660	0.973	0.305	0.244	0.874	0.140	0.662	0.643	0.591	0.990	0.915	0.900
March 3, 2020 and March 5, 2019	Tuesday	0.009[a]	0.391	0.000[a]	0.003[a]	0.150	0.000[a]	0.773	0.186	0.215	0.307	0.032[a]	0.773	0.000[a]
March 4, 2020 and March 6, 2019	Wednesday	0.029[a]	0.005[a]	0.782	0.163	0.057	0.675	0.049[a]	0.869	0.060	0.216	0.133	0.014[b]	0.399
March 5, 2020 and March 7, 2019	Thursday	0.117	0.316	0.144	0.486	0.998	0.098	0.041[a]	0.861	0.274	0.530	0.003[b]	0.015[b]	0.074
March 6, 2020 and March 8, 2019	Friday	0.115	0.063	0.917	0.360	0.510	0.504	0.159	0.197	0.640	0.960	0.018[b]	0.003[b]	0.789
March 7, 2020 and March 9, 2019	Saturday	0.000[b]	0.000[b]	0.002[a]	0.000[b]	0.000[a]	0.000[a]	0.010[a]	0.950	0.032[a]	0.133	0.000[b]	0.000[b]	0.007[a]
March 8, 2020 and March 10, 2019	Sunday	0.000[b]	0.000[b]	0.000[a]	0.000[b]	0.000[a]	0.000[a]	0.002[a]	0.064	0.002[a]	0.033[a]	0.000[b]	0.000[b]	0.000[a]
March 9, 2020 and March 11, 2019	Monday	0.020[b]	0.016[b]	0.777	0.026[b]	0.052	0.233	0.498	0.069	0.152	0.484	0.055	0.033[b]	0.775
March 10, 2020 and March 12, 2019	Tuesday	0.007[b]	0.011[b]	0.292	0.019[b]	0.063	0.153	0.168	0.341	0.400	0.998	0.002[b]	0.002[b]	0.203
March 11, 2020 and March 13, 2019	Wednesday	0.001[b]	0.002[b]	0.140	0.004[b]	0.015[b]	0.113	0.058	0.943	0.155	0.814	0.001[b]	0.002[b]	0.142
March 12, 2020 and March 14, 2019	Thursday	0.000[b]	0.000[b]	0.002[b]	0.000[b]	0.001[b]	0.003[b]	0.004[b]	0.314	0.024[b]	0.389	0.000[b]	0.000[b]	0.003[b]
March 13, 2020 and March 15, 2019	Friday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.001[b]	0.046[a]	0.003[b]	0.207	0.000[b]	0.000[b]	0.000[b]
March 14, 2020 and March 16, 2019	Saturday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.002[b]	0.123	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
March 15, 2020 and March 17, 2019	Sunday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.003[b]	0.523	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
March 16, 2020 and March 18, 2019	Monday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.012[b]	0.047[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
March 17, 2020 and March 19, 2019	Tuesday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.439	0.017[b]	0.000[b]	0.000[b]	0.000[b]	0.003[b]	0.000[b]
March 18, 2020 and March 20, 2019	Wednesday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
March 19, 2020 and March 21, 2019	Thursday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
March 20, 2020 and March 22, 2019	Friday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
March 21, 2020 and March 23, 2019	Saturday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
March 22, 2020 and March 24, 2019	Sunday	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]	0.000[b]
	N	212	48	164	123	33	90	89	74	33	23	176	37	139

Note: Results only reported when $N > 20$.
[a]Statistical significance at the $p < 0.05$ level.
[b]Statistical significance at the $p < 0.05$ level and the period of consistently significant differences.

significant difference at the $p < 0.05$ level. The superscript b indicates the consistently significantly different time period.

When considering all road types together for all of Florida, the first date of consistently different traffic was Saturday, March 7. The date was the same when considering just the freeways. However, while arterials show a statistically significant drop on that date, consistency did not arise until Thursday, March 12 (5 days later).

For all urban roadways, the first date of consistently different traffic was also Saturday, March 7, 2020. However, when considering only urban freeways, the first date was Wednesday, March 11, 2020. For arterials, the first date was a day later, March 12, 2020.

For all rural roadways, March 12, 2020, was the first date of consistently different traffic, later than that for urban areas. Freeways had less than 20 observations and are not discussed here because of low sample size. Rural arterials showed a noticeable 4-day lag in the start date of consistently different traffic (March 16).

Finally, the first date of consistency varied whether the roadways were located in South Florida or outside of this area. For South Florida, the start date is March 12, 2020, considering all road types, while outside of this area, the start date is a week earlier—March 5. Freeways are not compared here because low sample size within South Florida. For arterials, the start date outside of South Florida is March 12, 2 days earlier than within South Florida.

Conclusions

Five research questions were examined in this study. The first question indicated that traffic volumes by March 22, 2020, dropped by 47.5% of the volume that it was at the same point in 2019. Moreover, as shown in Fig. 2, traffic declined in March 2020 corresponding with the governor's state of emergency declaration and school, restaurant, and bar closures. Fig. 3 revealed that during the study period, the traffic decline followed similarly shaped trends with the increase in confirmed COVID-19 cases throughout the State of Florida.

The second research question found that the traffic decline outside of South Florida was statistically noticeable before that of South Florida. This finding indicates that people in the epicenter in South Florida continued to travel more early on despite being at a higher threat. However, traffic both inside and outside South Florida noticeably dropped after schools closed.

The third research question found significant variation between the decline. Urban areas across the state experienced significant decline several days before rural areas. Because the data are just based on traffic volume and not trip purpose, it is impossible to determine if the difference was related to a greater feeling of indifference, initially, among rural residents compared to urban dwellers. Another plausible explanation could be that college students and tourists needed to travel via rural locations on their way home to shelter. Further research should be conducted to identify when and why people traveled before they sheltered.

The fourth research question found that traffic on highways accounted for about two-thirds of the total volume and corresponding decline, but traffic decline on arterials was not consistently different until 5 days after freeways. This may indicate that people reduced travel for longer trip purposes, such as work trips, but continued to make local trips for nearly an extra week. However, again, the data from this study cannot draw conclusions on trip purpose; thus, such data should be collected in future research on this topic.

Finally, the fifth research question found that urban arterials experience consistently different volumes a day after urban freeways and rural arterials had a 4-day lag compared to urban arterials.

The analysis demonstrates that overall traffic volumes decreased significantly over the period with the greatest declines occurring later in the study period, suggesting that many factors including the start of spring break and decisions by local governments and employers contributed to the changes in travel behavior. In Florida, the issuance of the emergency declaration started the reductions in travel but other actions such as school closings, shutdown of theme park operations, and the shuttering of bars and restaurants were associated with increased travel reductions. Whether the reduction in travel demand was attributable to the closure of activities and trip generators or a function of increased fear arising from the increased lethality of COVID-19 requires further exploration.

The data and findings are useful in considering both the timing as well as the cumulative effects of orders and actions designed to increase social distance and limit contact to reduce the spread of the pandemic. It would be interesting to determine if starting some of the actions such as restaurant and bar closings earlier would have resulted in steeper increases in trip reduction. Clearly there was a lag between urban and rural areas and more investigation into reasons and motivations for the slower reaction is warranted. Such knowledge could be useful in messaging especially if the protective action decision-making is transferable to other hazards and threats.

Among the most important unanswered questions of this research pertain to the ultimate effect of reduced travel: was it successful in reducing sickness and fatalities from COVID-19? Time will tell. This will require more direct correlation between trip reduction and reduction in infection, transmission, and lethality for COVID-19. It requires additional data to better isolate those travelers who sheltered in place and reduced travel linked to health outcome data.

More research is needed with data and analytical tools for investigating the relationships between infectious disease, containment strategies, and travel behavior. Feedback mechanisms and systems that use traffic volume as a proxy for compliance with emergency orders would be useful to both strategic and operational planning and emergency management. Additional efforts to integrate traffic data systems to support response and recovery from pandemics beyond this initial analysis hold promising returns for transportation and community resilience.

Data Availability Statement

The authors assert that some or all data, models, or code used during the study were provided by a third party. Direct requests for these materials may be made to the provider as indicated in the "Acknowledgments" section of this paper.

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References

Baxter, D. H. 2001. "Utilization of Florida's existing and future intelligent transportation systems for enhancing statewide transportation system management during and after hurricane evacuations." In *Proc., ITS America 11th Annual Meeting and Exposition, ITS: Connecting the Americas*. Washington, DC: Intelligent Transportation Society of America.

Berkoune, D., J. Renaud, M. Rekik, and A. Ruiz. 2012. "Transportation in disaster response operations." *Socio-Econ. Plann. Sci.* 46 (1): 23–32. https://doi.org/10.1016/j.seps.2011.05.002.

Centers for Disease Control and Prevention. 2017a. "Community mitigation guidelines to prevent pandemic inflenza—United States, 2017." Accessed May 20, 2020. https://www.cdc.gov/mmwr/volumes/66/rr/rr6601a1.htm.

Centers for Disease Control and Prevention. 2017b. "Pandemic influenza plan: 2017 update." Accessed May 20, 2020. https://www.cdc.gov/flu/pandemic-resources/pdf/pan-flu-report-2017v2.pdf.

Chen, L., and E. Miller-Hooks. 2012. "Resilience: An indicator of recovery capability in intermodal freight transport." *Transp. Sci.* 46 (1): 109–123. https://doi.org/10.1287/trsc.1110.0376.

Congressional Research Service. 2020. *COVID-19 and the cruise ship industry*. CRS INSIGHT. Washington, DC: Congressional Research Service.

Dept. of Homeland Security. 2013. *National infrastructure protection plan (NIPP) 2013—Partnering for critical infrastructure security and resilience*. Washington, DC: Dept. of Homeland Security.

Douglass, S. L., B. M. Webb, R. Kilgore, and C. Keenan. 2014. *Highways in the coastal environment: Assessing extreme events*. FHWA-NHI-14-006. Washington, DC: Federal Highway Administration.

FDOT (Florida Dept. of Transportation). 2018. "Urban boundaries and functional classification of roadways." Accessed April 1, 2020. http://fdotwp1.dot.state.fl.us/ProceduresInformationManagementSystemInternet/FormsAndProcedures/ViewDocument?topicNum=525-020-311.

Flannery, A., M. A. Pena, M. R. Katon, and J. F. Kennedy. 2015. "Risk and resilience analysis for emergency projects." *Transp. Res. Rec.* 2532 (1): 74–82. https://doi.org/10.3141/2532-09.

Fletcher, K., S. Amarakoon, J. Haskell, P. Penn, M. Wilmoth, D. Matherly, and N. Langdon. 2014. *A guide for public transportation pandemic planning and response*. NCHRP Rep. No. 769. Washington, DC: Transportation Research Board.

Gardner, L., and S. Sakar. 2015. "The risk of Dengue spread from the Philippines through international air travel." *Transp. Res. Rec.* 2501: 25–30.

Gendreau, M. 2015. "Halting the travels of infectious disease: Lessons from the Ebola epidemic" *TR News* 299: 40–42. https://doi.org/10.17226/23612.

Gibney, E. 2020. "Coronavirus lockdowns have changed the way Earth moves." Accessed May 20, 2020. https://www.nature.com/articles/d41586-020-00965-x.

Glanz, J., B. Carey, J. Holder, D. Watkins, J. Valentino-DeVries, R. Jojas, and L. Leatherby. 2020. "Where America didn't stay home even as the virus spread." Accessed April 2, 2020. https://www.nytimes.com/interactive/2020/04/02/us/coronavirus-social-distancing.html.

Graham, J. L., J. M. Hutton, S. Cao, M. Fagel, and W. Wright. 2008. *A guide to emergency quarantine and isolation controls of roads in rural areas*. NCHRP Project No. 20-59 (22). Washington, DC: National Academies Press. https://doi.org/10.17226/23078.

Grayson, M., and T. Noonan. 2010. *Optimization of resources for mitigating infrastructure disruptions study*. Washington, DC: National Infrastructure Advisory Council.

Hambridge, M., A. Howitt, and D. Giles. 2017. "Coordination in crises: Implementation of the national incident management system by surface transportation agencies." *Homeland Secur. Affairs* 13 (2): 38–42.

Henson, T., and M. Timmons. 2017. *Public transit emergency preparedness against Ebola and other infectious diseases: Legal issues*. Legal Research Digest 50. Washington, DC: Transportation Research Board.

Houston, N. 2006. "Using highways during evacuation operations for events with advance notice: Routes to effective evacuation planning primer series." Accessed May 20, 2020. https://ops.fhwa.dot.gov/publications/evac_primer/primer.pdf.

Houston, N., A. Vann Easton, E. A. Davis, J. Mincin, B. D. Phillips, and M. Leckner. 2009. *Evacuating populations with special needs. Routes to effective evacuation planning primer series*. Washington, DC: USDOT.

Houston, N., J. Wiegmann, R. Marshall, R. Kandarpa, J. Korsak, C. Baldwin, and A. Vann Easton. 2010. "Information-sharing guidebook for transportation management centers, emergency operations centers, and fusion centers." Accessed May 20, 2020. https://ops.fhwa.dot.gov/publications/fhwahop09003/tmc_eoc_guidebook.pdf.

Kilbourne, E. 2006. "Influenza pandemics of the 20th century." *Emerging Infect. Dis.* 12 (1): 9–14. https://doi.org/10.3201/eid1201.051254.

Kim, K., O. Francis, and E. Yamashita. 2018a. "Learning to build resilience into transportation systems." *Transp. Res. Rec.* 2672 (1): 30–42. https://doi.org/10.1177/0361198118786622.

Kim, K., P. Pant, and E. Yamashita. 2018b. "Integrating travel demand modeling and flood hazard risk assessment for evacuation and sheltering." *Int. J. Disaster Risk Reduct.* 31 (Oct): 1177–1186. https://doi.org/10.1016/j.ijdrr.2017.10.025.

Kim, K., P. Pant, E. Yamashita, and J. Ghimire. 2019. "Analysis of transportation disruptions from recent flooding and volcanic disasters in Hawaii." *Transp. Res. Rec.* 2673 (1): 194–208. https://doi.org/10.1177/0361198118825460.

Kontou, E., P. Murray-Tuite, and K. Wernstedt. 2017. "Commuter adaptation to Hurricane Sandy's damage." *Nat. Hazards Rev.* 18 (2): 04016010. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000231.

Krechmer, D., A. Samano III, P. Beer, N. Boyd, and B. Boyce. 2018. "Role of transportation management centers in emergency operations guidebook." Accessed May 20, 2020. https://ops.fhwa.dot.gov/publications/fhwahop12050/index.htm#toc.

Litman, T. 2006. "Lessons from Katrina and Rita: What major disasters can teach transportation planners." *J. Transp. Eng.* 132 (1): 11–18. https://doi.org/10.1061/(ASCE)0733-947X(2006)132:1(11).

Matherly, D., N. Langdon, P. B. Wolshon, P. M. Murray-Tuite, R. Thomas, J. Mobley, and K. Reinhardt. 2014. *A guide to regional transportation planning for disasters, emergencies, and significant events*. Washington, DC: Transportation Research Board.

National Academies of Sciences, Engineering, and Medicine. 2011. *A guide for assessing community emergency response needs and capabilities for hazardous materials releases*. Washington, DC: National Academies Press. https://doi.org/10.17226/14502.

Rakha, H., and M. Van Aerde. 1995. "Statistical analysis of day-to-day variations in real-time traffic flow data." *Transp. Res. Rec.* 1510 (1): 26–34.

Rawls, C. G., and M. A. Turnquist. 2010. "Pre-positioning of emergency supplies for disaster response." *Transp. Res. Part B: Methodol.* 44 (4): 521–534. https://doi.org/10.1016/j.trb.2009.08.003.

Reed, T., and K. Hendrickson. 2020. "Understanding the impact of COVID-19 on commuting and retail: An analysis of the U.S. epicenter." Accessed April 2, 2020. https://inrix.com/campaigns/coronavirus-impact-study/.

Reggiani, A. 2013. "Network resilience for transport security: Some methodological considerations." *Transp. Policy* 28 (Jul): 63–68. https://doi.org/10.1016/j.tranpol.2012.09.007.

Renne, J., B. Wolshon, P. Murray-Tuite, and A. Pande. 2020. "Emergence of resilience as a framework for state Departments of Transportation (DOTs) in the United States." *Transp. Res. Part D: Transp. Environ.* 82 (May): 102178. https://doi.org/10.1016/j.trd.2019.11.007.

Schwartz, M. A., and T. Litman. 2008. "Evacuation station: The use of public transportation in emergency management planning." Accessed May 21, 2020. https://www.vtpi.org/evacuation.pdf.

Ulfarsson, G., and E. Unger. 2014. "Impacts and responses of Icelandic aviation to the 2010 Eyjafjallajokull volcanic eruption: Case study." *Transp. Res. Rec.* 2214 (1): 144–151. https://doi.org/10.3141/2214-18.

US Dept. of Health and Human Services. 2017. "Pandemic influenza plan 2017 update." Accessed May 20, 2020. https://www.cdc.gov/flu/pandemic-resources/pdf/pan-flu-report-2017v2.pdf.

Vasconez, K. C., and M. R. Kehrli. 2010. "Highway evacuations in selected metropolitan areas: Assessment of impediments." Accessed May 20, 2020. https://ops.fhwa.dot.gov/eto_tim_pse/reports/2010_cong_evac_study/fhwahop10059.pdf.

Wallace, C., A. Boyd, J. Sergent, A. Singleton, and S. Lockwood. 2010. *Surface transportation security, volume 16: A guide to emergency response planning at state transportation agencies*. NCHRP Rep. No. 525. Washington, DC: Transportation Research Board.

WHO (World Health Organization). 2009. "Pandemic influenza preparedness and response: A WHO guidance document." Accessed May 20, 2020. https://www.who.int/influenza/preparedness/pandemic/publication/en/.

Wolshon, B., E. Urbina, C. Wilmot, and M. Levitan. 2005. "Review of policies and practices for hurricane evacuation. I: Transportation planning, preparedness, and response." *Nat. Hazards Rev.* 6 (3): 129–142. https://doi.org/10.1061/(ASCE)1527-6988(2005)6:3(129).

Yong, E. 2018. "The next plague is coming. Is America ready?" *The Atlantic*, July/August.

Zheng, Y. J., and H. F. Ling. 2013. "Emergency transportation planning in disaster relief supply chain management: A cooperative fuzzy optimization approach." *Soft Comput.* 17 (7): 1301–1314. https://doi.org/10.1007/s00500-012-0968-4.