TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FMRI-Y3R1- 19	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle ANALYSIS OF FREIGHT MOVEMENT WITHIN REGIONAL EVACUATION		5. Report Date: February 2024 6. Performing Organization Code:
7. Author(s) Evangelos Kaisar, Scott Parr, Katerina Koliou		8. Performing Organization Report No.
9. Performing Organization Name and Address Florida Atlantic University Boca Raton, Fl, 33431 Freight Mobility Research Institute		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 69A3551747120
12. Sponsoring Agency Name and Address Freight Mobility Research Institute Florida Atlantic University 777 Glades Rd., Bldg. 36, Boca Raton, FL 33431		13. Type of Report and Period: Final 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The movement of freight vehicles during hurricane evacuations remains an underexamined aspect of emergency transportation planning. While extensive research has been conducted on personal vehicle evacuations, freight movement patterns before, during, and after hurricanes have received limited attention. This study investigates vehicle movements by classification, with a focus on freight, during the evacuations and reentries associated with Hurricanes Irma (2017) and Michael (2018). The research utilizes traffic volume data from Florida's statewide continuous-count stations to analyze spatial and temporal travel patterns across vehicle classifications.

Key findings reveal that commercial vehicles exhibit distinct evacuation behaviors compared to personal-use vehicles. Notably, truck traffic patterns changed earlier and persisted longer than personal vehicle evacuations, suggesting that commercial operators respond differently to impending storms. Additionally, results indicate that commercial use vehicles may have underutilized or avoided rest areas, possibly due to closures or other operational constraints. This behavior could imply extended driving hours and distances for truck operators, potentially impacting safety.

Spatial analysis demonstrated that vehicle movement during Hurricane Irma was widespread across the state, with traffic flow predominantly northbound, whereas Hurricane Michael's evacuation effects were largely localized to the Florida Panhandle. Temporal analysis confirmed significant deviations in traffic patterns, with commercial traffic surging well before storm landfall and persisting longer into the reentry phase, particularly in post-storm recovery efforts.

The findings of this study underscore the need for evacuation plans that specifically account for freight movement. Future research should explore the safety implications of extended truck travel during evacuations and identify policy interventions to better accommodate commercial vehicles within evacuation frameworks. This research provides a foundational step toward integrating freight considerations into comprehensive evacuation planning.

17. Key Words Freight Transportation, Evacuation, Classification Data		18. Distribution Statement No restrictions. This document is available to the public through Fmri.fau.edu	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

FREIGHT MOBILITY RESEARCH INSTITUTE
College of Engineering & Computer Science
Florida Atlantic University

Project ID: FMRI Y3R1-2019

ANALYSIS OF FREIGHT MOVEMENT WITHIN REGIONAL EVACUATION

Final Report

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February, 2024

ACKNOWLEDGEMENTS

This project was funded by the Freight Mobility Research Institute (FMRI), one of the twenty TIER University Transportation Centers that were selected in this nationwide competition, by the Office of the Assistant Secretary for Research and Technology (OST-R), U.S. Department of Transportation (US DOT).

DISCLAIMER

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EXCUTIVE SUMMARY

The movement of freight vehicles during hurricane evacuations remains an underexamined aspect of emergency transportation planning. While extensive research has been conducted on personal vehicle evacuations, freight movement patterns before, during, and after hurricanes have received limited attention. This study investigates vehicle movements by classification, with a focus on freight, during the evacuations and reentries associated with Hurricanes Irma (2017) and Michael (2018). The research utilizes traffic volume data from Florida's statewide continuous-count stations to analyze spatial and temporal travel patterns across vehicle classifications.

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1.0 INTRODUCTION

As the number of emergency events throughout the world increase, there is an enhanced need to understand mass evacuations. Some of the most common events requiring an evacuation are wildfires, hurricanes, and local flooding. A key aspect of evacuations often overlooked by prior research is the critical role of freight vehicles. Freight is an inextricable part of disaster preparedness, response, mitigation, and recovery. Natural disasters significantly affect freight movements because these events disrupt the global supply-chain. The surface transportation of freight is particularly vulnerable to storm and hurricane disasters, while at the same time is the primary transportation mode for delivering medical supplies, generators, fuel, water, and other essential goods. There is a need to better understand the movement of surface freight transportation before, during, and after regional evacuations.

To better plan for commercial vehicles during an evacuation, it is necessary to understand how these vehicles travel during an evacuation and determine if this travel is different from the general public. The goal of this paper was to investigate the movement of vehicles, by classification, with an emphasis on freight during two major evacuation events; hurricanes Irma (2017) and Michael (2018). This research sought to identify where and when different classes of vehicles were traveling leading up to hurricane landfall and post-storm reentry. The research investigation used Florida statewide continuous-count-station traffic volumes, by vehicle classification, from 2017 and 2018. Traffic volumes for each class where then compared between years, to identify locations where traffic was moving differently during the evacuation. The data was then used to identify days on which, traffic was significantly different between years.

1.1 BACKGROUND

Hurricane Irma has been referred to as the largest evacuation in the history of the United States. The storm's path and "cone-of-uncertainty" encompassed nearly the entire state of Florida [1] and resulted in approximately 6.5 million Floridians being placed under either mandatory or voluntary evacuation orders [2]. Ultimately, Irma made two landfalls on September 10, 2017, the first on Cudjoe Key in the lower Florida Keys at approximately 9:10 AM and the second near Marco Island, just south of Naples, FL at approximately 3:35 PM [3]. The storm left 65 percent of homes without power statewide [4] and the lower Florida Keys remained closed to non-residents for approximately three weeks following landfall [5]. The National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information (NCEI) estimates that wind and water damage caused by Irma totaled between $37.5 to $62.5 billion USD, making Irma the fifth-costliest hurricane in US history [6].

Hurricane Michael was the strongest storm by wind speed to strike mainland Florida in recorded history. Michael's landfall occurred near Mexico Beach, FL on October 10th at approximately 12:30 PM [7]. The NOAA National Centers for Environmental Information estimates the total damage from Michael in the US at approximately $25 billion [8]. Mandatory evacuation orders were issued on October 9, 2018 along Florida's Panhandle, Walton County, Wakulla County, Santa Rosa County also ordered voluntary evacuations [9]. Tragically, five Floridians drowned due to storm surge and another 43 indirect deaths in the state have been attributed to the storm.

2.0 LITERATURE REVIEW

The goal of an evacuation is to avoid injuries, loss of life and, to a lesser extent, property damage and economic loss. Thus, a primary objective is to move all evacuees outside of a threat area as safely and as quickly as possible [10]. Evacuation route planning (ERP) is an important component of emergency management that seeks to minimize the loss of life or harm to the public during natural disasters or terrorist attacks [11]. Important tasks during an evacuation are ensuring employee safety, supporting local community health, maintaining customer relationships, identifying strategy actions, and improving supply chain resilience. A well-organized logistics strategy can increase the system and supply chain resilience by helping with faster recovery [12].

The proposed methodologies for improving the efficiency of the mass movement include a wide variety of solutions. Contraflow freeway evacuation has been shown to be a successful method to move large numbers of people rapidly and efficiently during major hurricanes. Wolshon (2001) analyzed the efficiency of contraflow freeway evacuation [13]. Liu et al. (2006) used a two-level optimization system for the evacuation of Ocean City [14]. The optimization system effectively and efficiently generated a set of optimal emergency evacuation plans under available resources and the evacuation time windows. Triangle-Assignment-Transportation optimization was used by Na and Banerjee (2015), to route several classes of vehicles between staging areas and shelters [15]. He at al. (2015) designed a mixed integer linear program to allocate resources during an evacuation of a large scale network [16]. Chen et al. (2007) used simulation to identify the ideal solution of “infinite green time” for evacuation routes until queues dissipated [17]. Moreover, Vitetta et al.(2007) generated a path choice model for the simulation of emergency vehicles drivers [18]. Zhang et al. (2008) simulated the traffic flow during evacuation and reduce network clearance time [19] and in later study, Do and Noh (2016) conducted a microscopic simulation for the effects of predetermined evacuation routing methods [20]. Diversity in literature was also observed related to the investigation area, some projects used Traffic Analysis Zones (TAZs) as the most suitable subset of analysis [21] others were based on zip codes [22] and finally some investigate entire states or cities [23].

Supply chain resilience is defined as the adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of market position and control over structure and function [24]. In terms of freight transportation, disruptions can be defined as unplanned and unanticipated events (and in some cases planned events such as the planned shutdown of locks for maintenance) that affect the normal flow of goods and operations [25]. Emergency service vehicles operating in highly congested areas, during evacuation as well as non-evacuation conditions, are at higher risk for involvement in accidents and are subject to unpredictable delays in reaching the stricken or threatened area, potentially causing secondary supply-chain disruptions [26].

Prior studies have inspected the effects of interrupted freight transportation. For instance, Chang (2000) investigated the impact of natural disaster to freight transportation in the Port of Kobe [27]. Another worth mentioned study from Satoshi Tsuchiya (2007) presented the impact of transportation network disruptions and the transport-related losses based on two different scenarios [28]. Research by Grenzeback and Lukmann (2008) examined the economic impacts on the transportation sector during Hurricanes Katrina and Rita and focused on freight transportation [29]. Brown (2009) concluded that evacuation routes and emergency preparedness were necessary when examining the transportation sector in the event of a natural disaster, but found that little or no attention had been paid to freight transportation at either the state or county level [30].

Analyzing traffic data from detectors is a methodology applied to a variety of natural disasters. For instance, Chang et al. used traffic data to analyze the restoration of the highway system and recovery after the Kobe earthquake [31]. Wolshon used detector data from Louisiana collected during Hurricane Katrina to assess how well the maximum capacities suggested by the Highway Capacity Manual matched the detector reported flows for different types of roadways [32]. These roadway types included freeways operating in the normal direction, contraflow freeway segments, four-lane arterial roadways, and two-lane arterials. Another worth mentioned work was the temporal-spatial analysis of hurricane Katrina evacuation [33] that summarized the evacuation across roadway infrastructure. Archibald et al. (2012) used traffic data from automated traffic counters to explore traffic patterns before, during and after an evacuation to investigate the behavior of residents and visitors [34]. The results of the analysis suggest that that in the case of Hurricane Irene in Delaware, the evacuation orders were effective, provided sufficient lead time, and reached the intended audience. Traffic count data were also used by Li et al. [35] to develop empirical response curves for Hurricane Irene for a single county in New Jersey. They also identified evacuation volumes and compared these to the volumes from the previous week.

3.0 METHODOLOGY

The methodology of the research was divided into three phases: the first phase consist of data collection and management, temporal-spatial analysis, and statistical temporal comparisons. Data collection and management obtained continuous- count- station data from the state of Florida for both 2017 and 2018, by vehicle classification. The data werewas then processed into a manageable format. The second phase used geographic information systems (GIS) to qualitatively display where and when traffic varied across the state. The third and final phase was a quantitative investigation into which vehicle classifications were statistically different and on which dates, statewide. This phase used a two-sample, two-tailed t-test to compare sensors volumes, by classification, on similar days, between years. Overall increases in freight movement between years prevented a more precise paired analysis.

3.1 DATA COLLECTION AND MANAGEMENT

As part of the national Highway Performance Monitoring System (HPMS), the Federal Highway Administration (FHWA) regulates state departments of transportation to submit annual traffic statistics [11]. State transportation agencies build, operate, and maintain permanent traffic monitoring stations to collect, among other measures, traffic count information. Referred to as continuous-count-stations, these traffic count detectors report hourly traffic counts continuously throughout the year, year-over-year, to meet the federal regulation requirement. Data for this research was provided by the Florida Department of Transportation (FDOT) from 230 continuous count stations located throughout the state. Traffic data was provided for August, September, and October both in 2017 and 2018.

FDOT provided hourly traffic volumes for each of the 13 FHWA vehicle classifications categories. These categories were [36]:

Category 1 - Motorcycles
Category 2 – Passenger Cars
Category 3 – Four tire, single unit (vans)
Category 4 – Buses
Category 5 – Two axle, six tire, single unit
Category 6 – Three axle, single unit
Category 7 – Four or more axle, single unit
Category 8 – Four or less axle, single trailer
Category 9 – Five axel tractor semitrailer
Category 10 – Six or more axle single trailer
Category 11 – Five or less axle multi-trailer
Category 12 – Six axle, multi-trailer
Category 13 – Seven or more axle, multi-trailer

Broadly, this research compared vehicle movements between years for similar days, i.e. the first Monday in September 2017 was compared to the first Monday in September 2018. Furthermore, this research investigated categories 2, 3, 5, 8 and 9, which accounted for over 96 percent of all traffic during the analysis years. In contrast, each of the categories not investigated (1, 4, 6, 7, 10, 11, 12, 13) individually constituted less than one percent of the daily traffic. Additionally, two broader groups of vehicles were identified in the study: vehicles for personal use, which included categories 2 and 3; and vehicles for commercial use, categories 5, 8, and 9.

More specific due to the fact that a weekly pattern was noticed to be followed with week frequency, during the second phase was important to be compared data from the same date of the week. For 2017 as begging was set Monday August 7th and as of last day Sunday, October 29th, as the first day of the week was determined Monday. The first day for 2018 was Monday, August 6th and last day Sunday, October 28th. In total were analyzed 84 days for 202 detectors. The reduction of the number of detectors came as a result of data cleansing, by removing all the incomplete, inaccurate, or unpaired records.

The initial data were classification was based on Federal Highway Administration Classification that group vehicles in 13 categories. The analysis used only the categories that had a considerable impact on the annual average daily traffic (AADT), category 2, 3, 5, 8, and 9. In category 2 are classified all passenger cars, in category 3 are classified pickups, panels, and vans, in category 5 are all the single-unit 2-axle trucks, in category 8 are single trailer 3-or 4 axle trucks and in category 9 are classified single trailer 5-axle trucks. Based on the useless personal or personal two more subgroups were created by joining category 2 and category 3 and category 5 with 8 and 9. Furthermore, detectors were organized based on the district that they belong to or as one group for the whole state of Florida.

3.2 SPATIAL ANALYSIS

The impact of evacuation in vehicle movement was investigated in two levels simultaneously. The first level aims to understand the changes in trips in these two year as entities in the geographic space. The second one considers them as two different datasets and investigates whether the differences for the period before during and after the evacuation were significantly important.

The spatial analysis was made conducted in at the state level with aby investigating the difference in detector volumes for similar days between years. G geographic information system (ArcGIS) based) was used to project this data on to a base map for visual comparison. The spatial analysis applied to movement of vehicles for personal use and the movement of vehicles for commercial use, but not to the individual vehicle categories. On the location of the detector and the values for vehicles for personal use separately from the vehicle for commercial use. The way that values were calculated is presented in equation 1. The spatial comparison was conducted in accordance with Equation 1:

$$u_i = u_{i,a}^{t_2} - u_{i,a}^{t_1} \tag{1}$$

Where: u_i is the difference in total daily traffic at location *i*, between years t_2 (2018) and t_1 (2017) on day *a*.

The difference in volume calculated in Equation 1 was projected on to a base map and spatially weighted to generate a raster image for the generation of spatial heat maps. A spatial heat map is a data visualization technique to represent the density of geographic features. Inverse Distance Weighting (IDW) was used to interpolate the volumes between data sensor locations. The IDW is a multivariate interpolation and the value for each location was calculated based on Equation 2:

$$u(x) = \begin{cases} \frac{\sum_{i=1}^{N} w_i(x) u_i}{\sum_{i=1}^{N} w_i(x)} & if\ d(x, x_i) \neq 0\ for\ all\ i \\ u_i & if\ d(x, x_i) \neq 0\ for\ all\ i \end{cases} \tag{2}$$

Where u was the interpolation value for location x, $u_i = u(x_i)$ was the samples for $i = 1,2, \dots, N$ and N was the total number of detectors. Also, weights were different for each location based on distance d between the detectors and the points in the p represented the power parameter and was calculated with Equation 3.

$$w_i(x) = \frac{1}{d(x,x_i)^p} \tag{3}$$

3.3 TEMPORAL COMPARISON

To determine when the traffic pattern changed leading up to the evacuation and hurricane landfall, a t-test was conducted of the 202 detectors, for each day. Using an independent, two-tailed student t-test, total daily traffic volumes at each detector were compared for similar days between years. Days were considered significantly different when the critical t-scores resulted in p-values less than 0.05. Overall, during the three-month investigation period, Aug, Sept., and Oct. 2018 saw a 19 million-vehicle increase over the same period in 2017 for vehicle categories 2 and 3. Whereas categories 5, 8 and 9 saw a surge of nearly 1 million vehicles in 2018 during this same period. As a result, the two datasets were considered as unique and independent events. The two tail independent t-test used Equation 4 and Equation 5:

$$t_a = \frac{\overline{u_{a,t_2}} - \overline{u_{a,t_1}}}{\sqrt{\frac{s_a^2}{N_{a,t_2}} + \frac{s_a^2}{N_{a,t_1}}}} \tag{4}$$

$$s_a^2 = \frac{\sum(u_i - \overline{u_{a,t_2}})^2 + \sum(u_i - \overline{u_{a,t_1}})^2}{N_{a,t_2} + N_{a,t_1} - 2} \tag{5}$$

$\overline{u_{a,t_2}}$: represents the mean value from 2018 dataset in day a
$\overline{u_{a,t_1}}$: represents the mean value from 2017 dataset in day a
s_a^2 : is an estimator of the pooled variance of two groups
N_{a,t_2}: represent the size of 2018 dataset in day a
N_{a,t_1}: represent the size of 2017 dataset in day a

4.0 RESULTS

The multi-level analysis revealed that the effect of a hurricane on transportation started 2-3 days before landfall and return to pre-storm levels after 3-4 days. Significant differences in volumes were observed on landfall days across all vehicle classifications.

4.1 SPATIAL ANALYSIS

The results from IDW were presented in 4 figures separated for the two hurricanes, Irma and Michael, Moreover, two other subcategories were divided for personal use vehicles (categories 2 and 3) and commercial use vehicles (category 5, 8, and 9). These four figures each show eight consecutive days of traffic, encompassing landfall. These days were selected after examining all days in the dataset and determining this eight-day window approximately encompasses the storm events. The low values represent locations where the number of cars were more in 2017 compared to 2018 and the high value locations are where the volumes were higher in 2018. Therefore, brown/red colors signify more cars in 2017, whereas blue colors represent more cars in 2018.

Figure 1 shows personal use vehicles (categories 2 and 3) beginning Thursday September 7, 2017 through Thursday September 14, 2017. This period of traffic was compared to Thursday September 6, 2018 through Thursday September 13, 2018. During the first two days of the analysis period (Figure 1 (a) and Figure 1 (b)), the number of personal use vehicles began to increase across the state and traffic appeared to be moving from South to North. However, small areas encompassing high population cities did see some instances where traffic was greater in 2018. The day before landfall, September 9, 2017 (Figure 1 (c)), traffic levels were substantially higher in 2017. Traffic appears to increase yet again on September 10 (landfall) and the following day (Figures 1 (d) and Figure 1 (e). This increase likely signifies the start of the evacuation reentry. Two days after landfall (Figure 1 (f), small areas in the southeast were observed to have fewer trips in 2017 than 2018 (indicated by the blue regions). This trend continued for the next two days until a general return to pre-storm levels on September 14, 2017 (Figure 1 (h)).

Evacuation orders for hurricane Irma generated a remarkable number of trips for personal use vehicles. It appears vehicles were generated from nearly every region of the state and were generally travelling north. The figure suggest changes in traffic between years for South Florida, was less severe and returned to pre-evacuation values sooner than other regions. The investigation also suggest that people started reentry as soon as possible, beginning on the same day as landfall. Finally, while the maps have a smooth surface, some areas stand out. In the North, regions with darker shading suggest these locations experienced more vehicles in 2017, while lighter shading was seen in the south and center of the state; suggesting more vehicles in 2018. These locations may distinguish rest areas. It appears that drivers chose not to use these areas with some exceptions near the state borders.

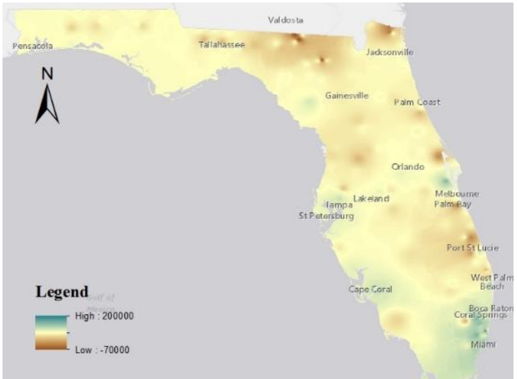


Figure 1(a) Personal Use Vehicles, 9/7/17

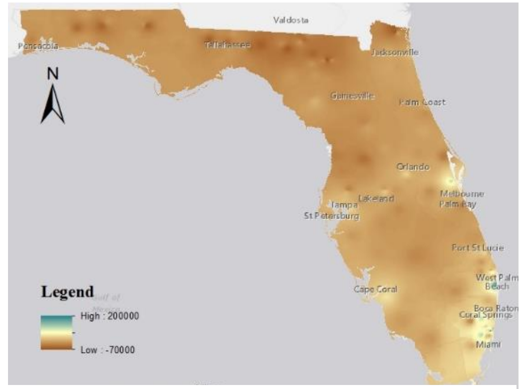


Figure 1(b) Personal Use Vehicles, 9/8/17

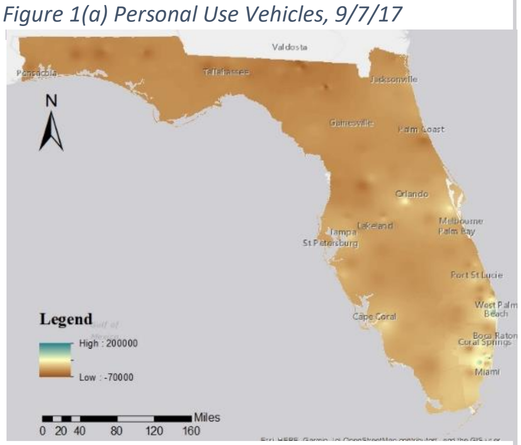


Figure 1 (c) Personal Use Vehicles, 9/9/17

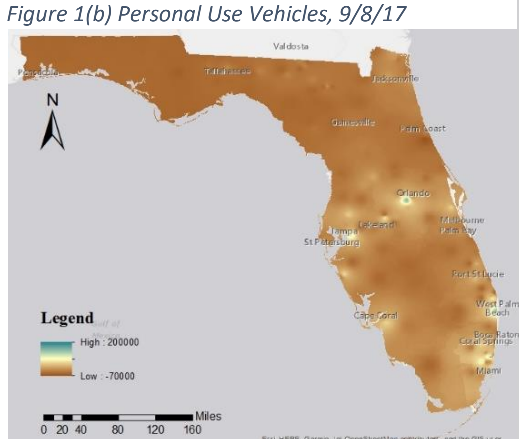


Figure 1(d) Personal Use Vehicles, 9/10/17

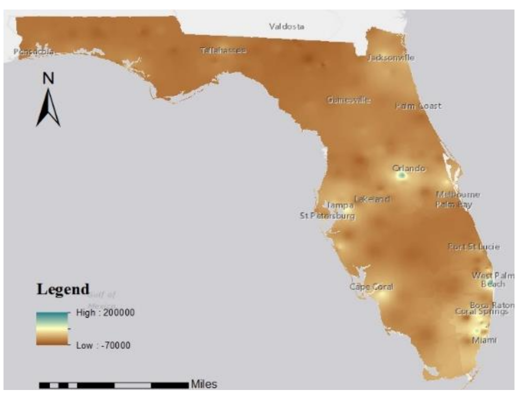


Figure 1(e) Personal Use Vehicles, 9/11/17

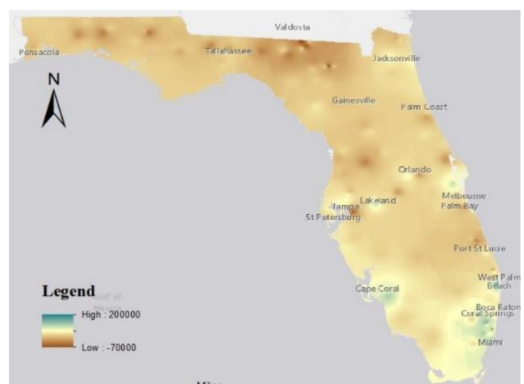


Figure 1(f) Personal Use Vehicles, 9/12/17

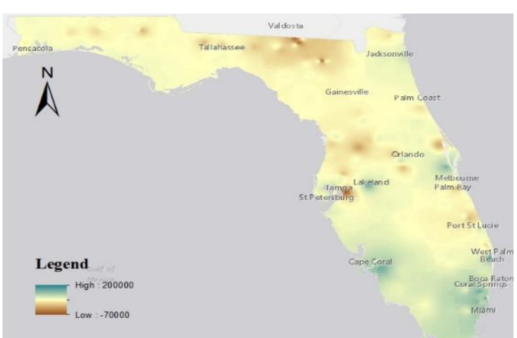


Figure 1(g) Personal Use Vehicles, 9/13/17

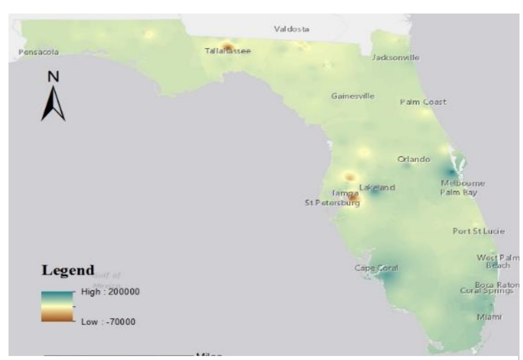


Figure 1(h) Personal Use Vehicles, 9/14/17

Figure 2 shows the personal use vehicles in the state of Florida starting Monday October 8, 2018 through Monday October 15, 2018. This period was compared with Monday October 9 – Monday October 16, 2017. In general, it would appear that Hurricane Michael was more of a local event, affecting mainly the Panhandle region, whereas Irma influence traffic throughout the state. Statewide traffic on October 8, two days before landfall, remained consistent between years. The following day, traffic would appear to be greater in 2017. However, areas along the I-10 freeway, a major east/west evacuation route for the panhandle, show distinct blue locations. This signifies more vehicles were traveling in 2018 along that corridor. Landfall, October 10, 2018 shows fewer trips being made in the North and more trips being made in the southeast of the state. This stands in contrast to hurricane Irma, which saw more trips occurring on landfall day. However, Hurricane Irma occurred earlier in the day, leaving more time for reentry and with the exception of the lower Florida Keys, most evacuees were permitted to return home. The damage caused by Michael likely prevented an immediate return to the landfall region resulting in fewer vehicles on the road. For the remainder of the analysis period, the figure suggest more personal use vehicles were on the road in 2017 than 2018, statewide. Exceptions to this are evident, however, along the I-10 corridor and in the southeast of the state.

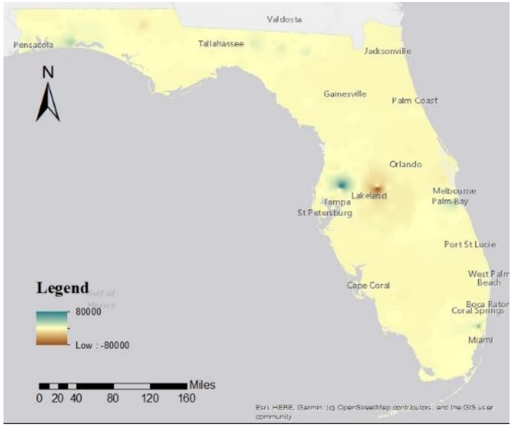


Figure 2 (a) Personal Use Vehicles, 10/8/18

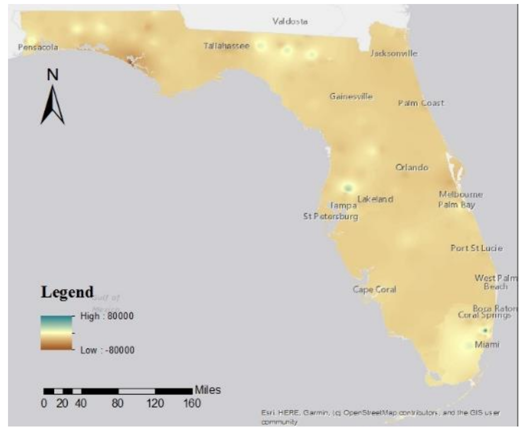


Figure 2 (b) Personal Use Vehicles, 10/9/18

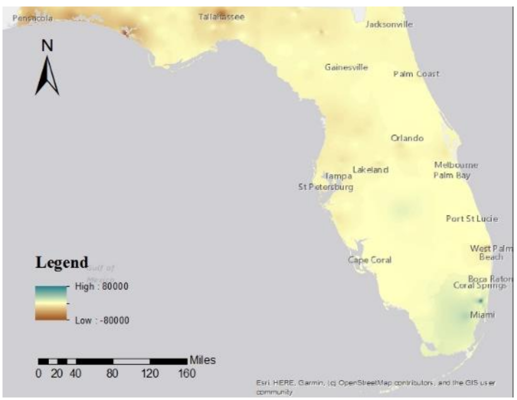


Figure 2 (c) Personal Use Vehicles, 10/10/18

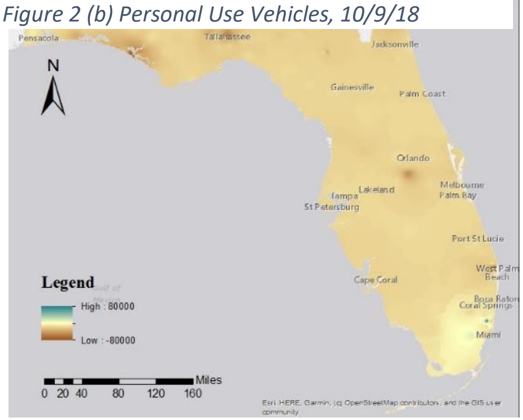


Figure 2 (d) Personal Use Vehicles, 10/11/18

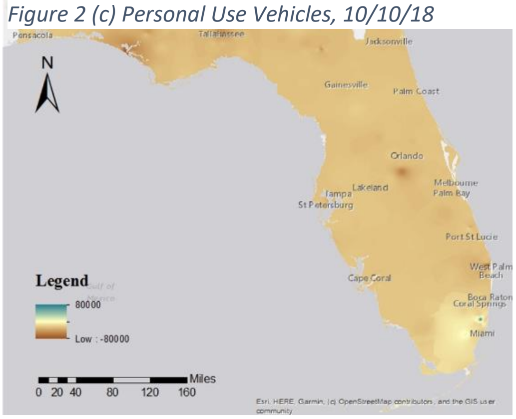


Figure 2 (e) Personal Use Vehicles, 10/12/18

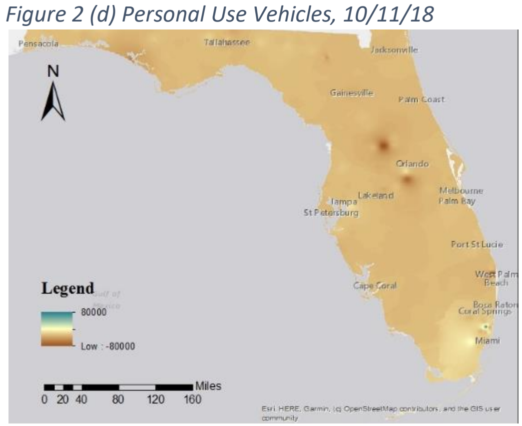
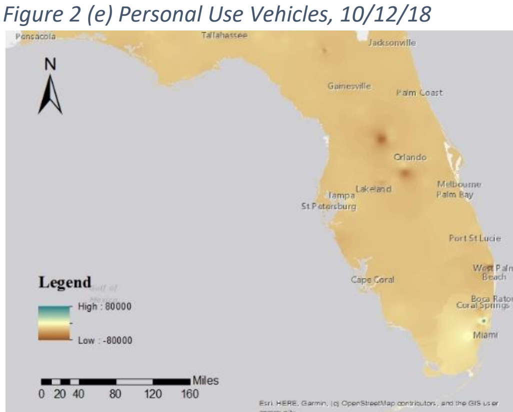


Figure 2 (f) Personal Use Vehicles, 10/13/18



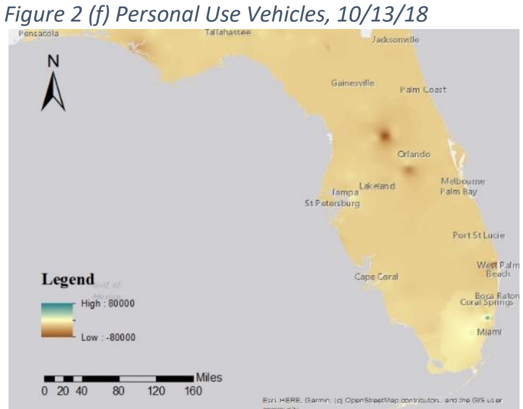


Figure 2 (g) Personal Use Vehicles, 10/14/18

Figure 2 (h) Personal Use Vehicles, 10/15/18

Figure 3 shows commercial use vehicles (categories 5, 9, and 10) beginning Thursday September 7, 2017 through Thursday September 14, 2017. This period of traffic was compared to Thursday September 6, 2018 through Thursday September 13, 2018. The first day of the analysis, September 7, 2017 shown in Figure 3 (a), suggest truck traffic was generally equivalent between years across the state, with slightly more trucks operating around cities in 2018. The northern portion of the state does show some regions were truck traffic was elevated in 2017 on this day. The following day, truck traffic in the north begins to increase, while truck traffic around rest areas and major population centers in the south, slow. This trend continues on September 9 (Figure 3 (c)), the day before landfall. September 10, 2017, Hurricane Irma made landfall and movement of trucks was higher in 2017 comparatively. Rest areas in Florida consist of the only locations where truck traffic was higher in 2018. This may suggest these areas were undesirable or otherwise closed. Increased truck volumes for 2017 were also noticed the following day (Figure 3 (e)) with a similar rest area pattern. By September 12, (Figure 3 (f)), truck traffic begins to decrease in the south and central parts of the state but is still elevated in northern region. Finally, on the last two days of the analysis period, truck traffic in 2018 dominates the figures as the region begins to return to pre-storm levels.

Overall, the results suggest that truck movement was strongly correlated with the evacuation orders. The number of trips was increased before the evacuation in the direction from South to North and peaking on landfall day. After which, truck traffic starts to decrease following the opposite direction from North to South. Exceptions to this were seen near rest areas, which saw more trucks in 2018.

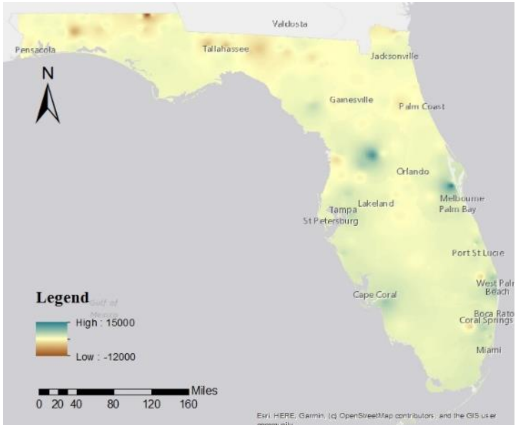


Figure 3 (a) Commercial Use Vehicles, 9/7/17

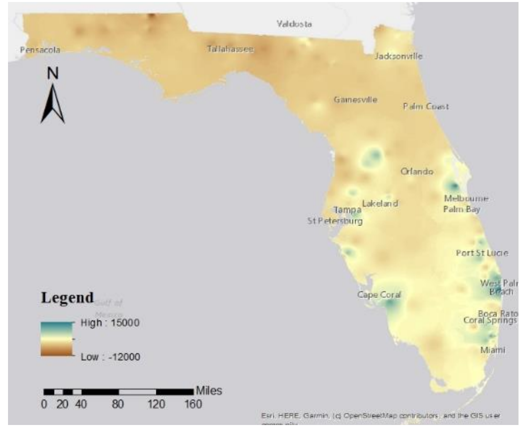
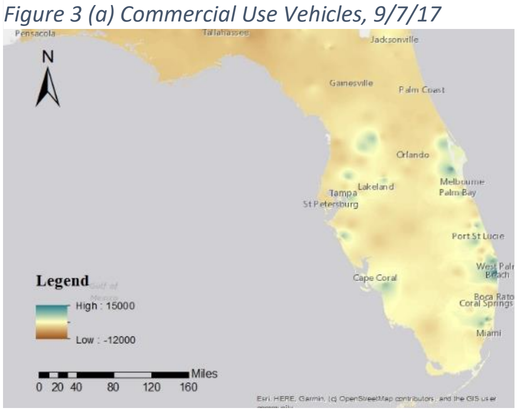


Figure 3 (b) Commercial Use Vehicles, 9/8/17



***Error! Reference source not found.** Figure 3 (c)*

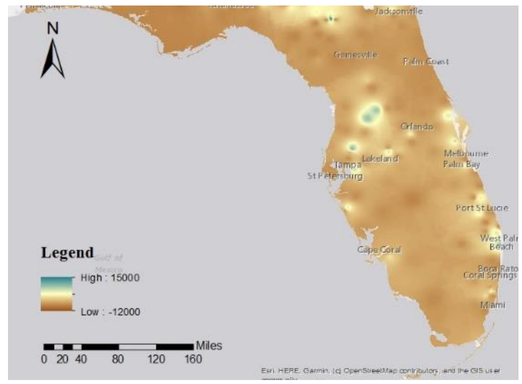


Figure 3 (d) Commercial Use Vehicles, 9/10/17

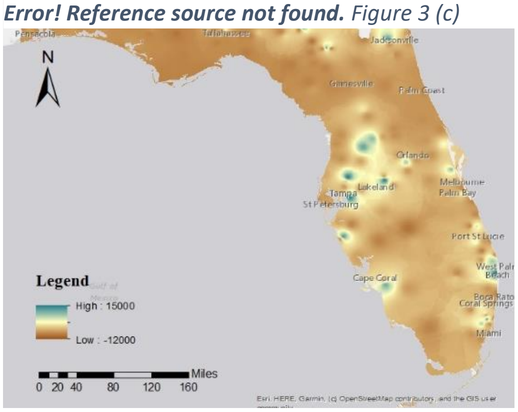


Figure 3 (e) Commercial Use Vehicles, 9/11/17

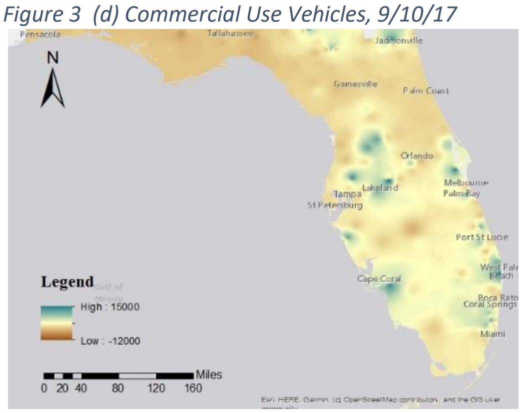


Figure 3 (f) Commercial Use Vehicles, 9/12/17

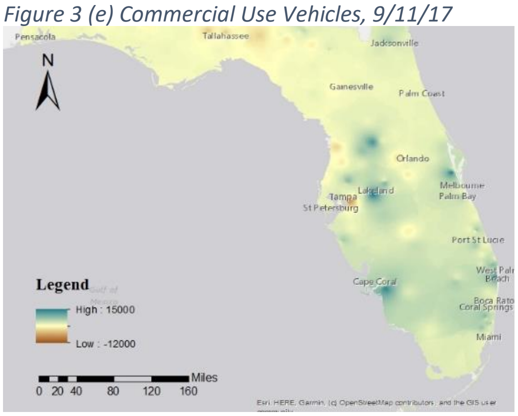


Figure 3 (g) Commercial Use Vehicles, 9/13/17

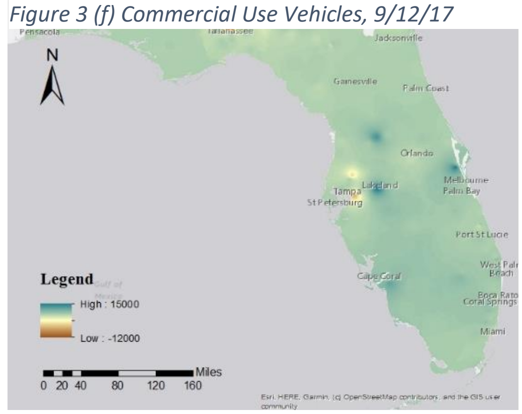
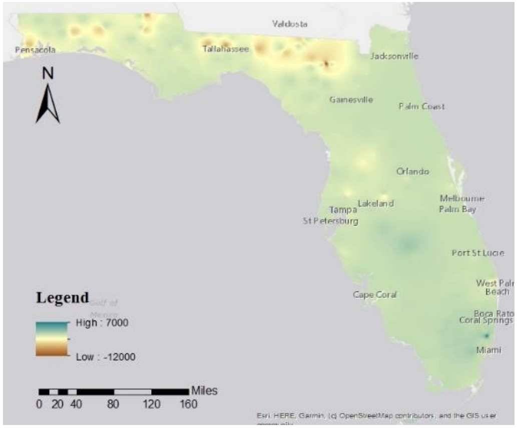


Figure 3 (h) Commercial Use Vehicles, 9/14/17

Figure 4 shows the commercial use vehicles in the state of Florida starting Monday October 8, 2018 through Monday October 15, 2018. This period was compared with Monday October 9 – Monday October 16, 2017. In general, the impact of Hurricane Michael on commercial use vehicles was predominately seen in the panhandle region, i.e. FDOT District 3, where the storm made landfall. Beginning October 8, 2018 (Figure 4 (a)), truck traffic across most of the state tended to show elevated levels for 2018. However, traffic was noticeably down along the I-10 corridor. A similar pattern was observed the following three days (Figure 4 (b), Figure 4 (c) and Figure 4 (d)). By October 12, two days after landfall, truck traffic was approximately equivalent across the state, with some exceptions near the I-10 corridor. October 13-14 saw elevated truck traffic in 2018 in the norther portion of the state and along I-10. However, by October 15 truck traffic had returned to pre-storm levels.

The result suggest a large number of trucks located in the northern portion of the state may have relocated to the south. The evacuation of the region from freight vehicles started three days before landfall and the reentry was denser two days later. The trucks required days for the state transportation system to recover from the effects of the evacuation.



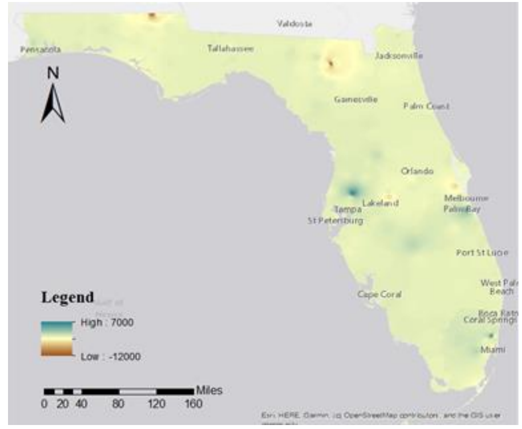
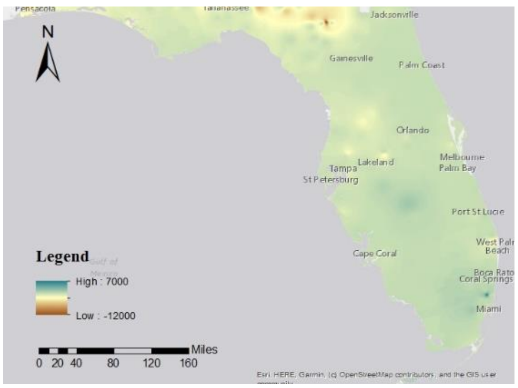


Figure 4 (a) Commercial Use Vehicles, 10/8/18

Figure 4 (b) Commercial Use Vehicles, 10/9/18



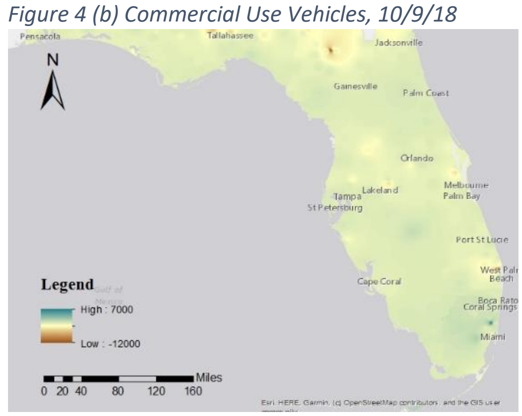
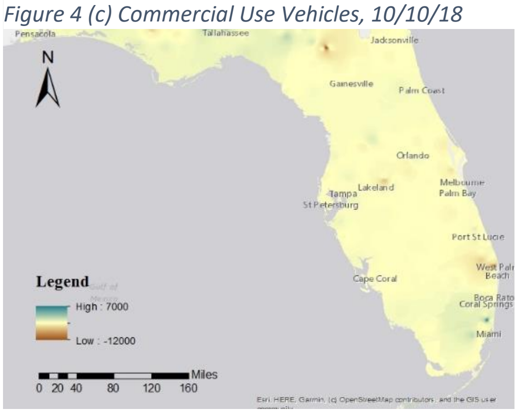


Figure 4 (c) Commercial Use Vehicles, 10/10/18

Figure 4 (d) Commercial Use Vehicles, 10/11/18



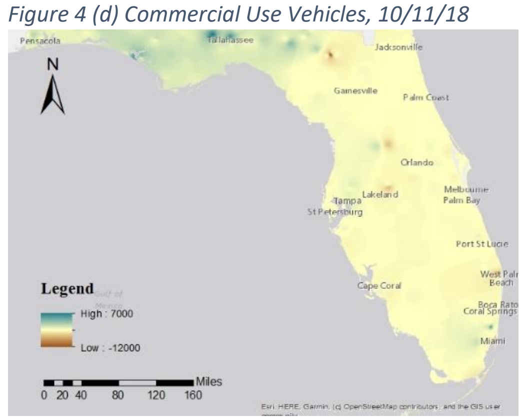
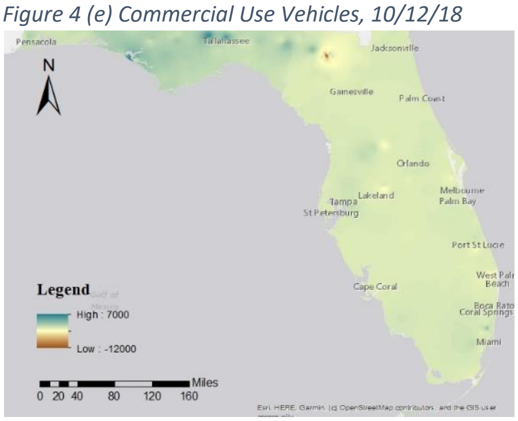


Figure 4 (e) Commercial Use Vehicles, 10/12/18

Figure 4 (f) Commercial Use Vehicles, 10/13/18



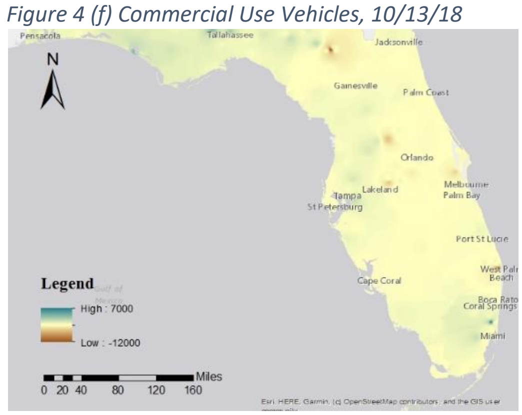


Figure 4 (g) Commercial Use Vehicles, 10/14/18

Figure 4 (h) Commercial Use Vehicles, 10/15/18

4.2 TEMPORAL ANALYSIS

The temporal analysis compared traffic volumes between years using an independent t-test of total daily traffic at each detector for similar days. For the analysis of Hurricane Irma, 202 (N=202) detectors statewide were investigated. Table 1 provides the t-test p-value results for eight days encompassing Hurricane Irma's landfall. The first column shows the analysis date in 2017, followed by their complementary dates in 2018. Then the table provides a comparison of personal use vehicles (classification 2 and 3 combined) and then commercial use vehicles (classifications 5, 8, and 9 combined). The table then shows the t-test results of each vehicle classification, independently. Personal use vehicle travel was significantly different on September 9-11, 2017, representing the day before, day of, and day after Irma's landfall. Hurricane Irma's impact on commercial use vehicles, however, began earlier and lasted longer. Commercial use vehicle travel was significantly different for the period of September 8-12, 2017. Vehicle classification 8 was significantly different on September 8, but not on September 9. Whereas classifications 3, 5, and 10 were different on September 8. Between the periods of September 9-11, all travel was significantly different between years, regardless of classification. By September 12, only classification 9 was significantly different and by September 13, 2017, traffic was indistinguishable from 2018 levels.

Table 1 P-values for hurricane Irma in Florida

2017	***2018***	***Class. 2 & 3***	***Class. 5 & 8 & 9***	***Class. 2***	***Class. 3***	***Class. 5***	***Class. 8***	***Class. 9***
9/7	9/6	0.400	0.960	0.400	0.800	0.800	0.020 [a]	0.700
9/8	9/7	0.090	0.012 [a]	0.100	0.030 [a]	0.005 [a]	0.600	0.010 [a]
9/9	9/8	0.000[a]	0.000 [a]	0.000 [a]	0.000 [a]	0.003 [a]	0.008 [a]	0.000 [a]
9/10	9/9	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]
9/11	9/10	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]
9/12	9/11	0.480	0.000 [a]	0.600	0.200	0.100	0.300	0.000 [a]
9/13	9/12	0.910	0.300	0.990	0.600	0.700	0.600	0.100
9/14	9/13	0.670	0.910	0.700	0.600	0.900	0.500	0.990

[a] Statistically significant at the $P < 0.05$ level

Table 2 provides the T-test results for the analysis of Hurricane Michael. This analysis only considered detectors located in FDOT District 3, where Hurricane Michael made landfall. A preliminary analysis of the statewide effects of Hurricane Michael was conducted and no meaningful impacts were found. This would suggest the evacuation from Hurricane Michael was a localized event. Table 2 results represent the analysis of 56 detectors (N=56). The first column provides the analysis dates in 2018. The second column provides their companion dates in 2017. The remainder of Table 2 follows the convention provided for Table 1. The results suggest that traffic was significantly different on October 10, 2018 (landfall day) for all vehicle classifications. No date, prior to landfall shows any significant changes for District 3. After landfall, traffic within the district was more or less unchanged for the next two days. However, beginning October 13 and lasting until at least October 15, 2018, travel for vehicle classification 5 was significantly different in 2018 when compared to 2017. Vehicle classification 5 represents two-axel, six tire, single unit vehicles and may represent utility and service vehicles traveling into the region as part of the recovery effort.

Table 2 P-values for hurricane Michael in District 3

2018	***2017***	***Class. 2 & 3***	***Class. 5 & 8 & 9***	***Class. 2***	***Class. 3***	***Class. 5***	***Class. 8***	***Class. 9***
10/8	10/9	0.400	0.700	0.400	0.300	0.300	0.300	0.900
10/9	10/10	0.900	0.900	0.900	0.900	0.600	0.900	0.700
10/10	10/11	0.000 [a]	0.000[a]	0.000 [a]	0.000 [a]	0.000 [a]	0.000 [a]	0.004 [a]
10/11	10/12	0.300	0.300	0.200	0.700	0.300	0.200	0.090
10/12	10/13	0.400	0.800	0.300	0.900	0.060	0.900	0.600
10/13	10/14	0.900	0.200	0.600	0.200	0.001 [a]	0.200	0.800
10/14	10/15	0.800	0.100	0.800	0.100	0.000 [a]	0.200	0.900
10/15	10/16	0.800	0.300	0.900	0.300	0.009 [a]	0.200	0.900

[a] Statistically significant at the $P < 0.05$ level

4.3 LIMITATIONS

This section discusses some of the limitations of the research that should be considered alongside the research results. One of the more significant limitations was data coverage. Data coverage was restricted to FDOT detectors that were in operation during both 2017 and 2018. FDOT detectors were generally located near areas of high population. Rural areas may therefore be underrepresented in the sample. Furthermore, this study investigated total daily traffic between years and did not consider hourly fluctuations. By aggregating the data by time, it was possible to investigate and present travel patterns over longer periods. However, this aggregation prevented a more detailed investigation in to departure and return times. Prior research has found that evacuees prefer morning departures [37]. The aggregation of data into 24-hour periods prevented an investigation into this phenomenon. Likewise, because of the 24-hour aggregation, evacuees departing on landfall day were indistinguishable from those returning afterward. The analysis also did not consider the direction of travel. By investigating sites as a whole (instead of by direction), it permitted a statewide analysis of both the evacuation and reentry. However, it did prevent an investigation into where vehicles were traveling and on which days.

5.0 CONCLUSION

The need for effective evacuation plans is critical. While the literature into auto-based evacuations for regional hurricanes is extensive, the consideration of freight on the surface transportation network is lacking. This study represents one of the first empirical investigations into the movement of trucks before, during, and after an evacuation event. This paper may also serve as the foundation for future research into commercial travel during evacuations and will hopefully lead to the inclusion of commercial use vehicles in evacuation planning.

Of the more significant findings, the research results showed that commercial use vehicles may have underutilized rest areas during the evacuation or perhaps these rest areas were closed. This may suggest that truckers are driving longer distances and possibly longer hours before hurricanes. An opportunity for future research would be to investigate crashes involving vehicle classifications 5, 8, and 9 during the periods before hurricanes to determine if the longer trips adversely affect driver safety. Furthermore, state planners could reconsider the role of rest areas in evacuation plans. Making these areas safer for truck parking during a storm or by repurposing these facilities to better serve evacuees, if truckers decided not to utilize these areas during an evacuation.

Another significant finding of this research was that changes in traffic patterns for commercial use vehicles occurred earlier and lasted longer than changes for personal use vehicles. In a very practical sense, commercial vehicles were reacting to the approaching storm differently. This finding suggest that commercial vehicles are perhaps evacuating in a fashion different from personal use vehicles. It would than stand to reason that if these two system users are operating in uniquely different ways during the evacuation, then commercial drivers should have evacuation plans tailored to meet their transportation requirements. Future research could investigate why commercial driving patterns were different from that of personal use vehicles and how evacuation planners could better accommodate their needs. After landfall, the need for utility vehicles and other large vehicles is generally necessary to facilitate the recovery effort. The results suggested that after Hurricane Michael, two-axel, six tire single unit trucks were still affected by the storm, several days after landfall. Given the devastation caused by the category 5 hurricane, it is likely these trucks represented utility and debris removal vehicles.

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