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Analysis of Roadway Traffic During Hurricane Irma

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ANALYSIS OF ROADWAY TRAFFIC DURING HURRICANE IRMA

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ABSTRACT

Hurricane Irma struck the United States in 2017 and caused a massive evacuation across the State of Florida. This research uses traffic data collected across Florida to investigate the evacuation pattern during Hurricane Irma.

Although many local governments issued evacuation orders before Hurricane Irma made landfall, the public may not follow the evacuation orders closely. They may choose to evacuate before the orders take effect. This thesis analyzes seven major regions, including the Florida Key, Southeast, Marco Island, Tampa, Hernando, Polk, and Orlando Regions. The objectives of this research are to (1) identify the evacuation start time, evacuation peak time and reentry time of each region and relate these times to information released time and Irma landfall time and (2) examine the road utilization by road types as Hurricane Irma approached.

For the first objective, this research uses the traffic volume data to study the evacuation traffic pattern. Two methods, cumulative volume comparison and Wilcoxon Signed-Rank test, are provided and they work together to identify the evacuation start time of different regions. Also, the evacuation peak time and traffic reentry time are identified for each region, based on traffic volumes.

For the second objective, this research calculates the volume to capacity ratio and density at different traffic count stations to examine the road utilization in three types of roads: Freeway, Multilane Highway and Two-lane Highway. The study explores the

reasons why the volume to capacity ratio is less than 1.0 when the density indicates level of service (LOS) F.

The results show that the evacuation started before evacuation orders took effect for the seven analysis regions. Volume to capacity and LOS analysis results show that Freeways were more frequently congested than Multilane highways and Two-Lane highways during evacuation.

DEDICATION

I would like to dedicate this thesis to my parents for their love and support all these years. I love you Mom and Dad!

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TABLE OF CONTENTS

Page

Table of Contents (Continued)

Page

Table of Contents (Continued)

Page

LIST OF TABLES

Table Page

List of Tables (Continued)

LIST OF FIGURES

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

Page

List of Figures (Continued)

CHAPTER 1:

INTRODUCTION

Hurricane Irma was a Category 5 hurricane that caused a massive evacuation in Florida. This research uses traffic detector data to study the evacuation traffic pattern in Florida during Hurricane Irma in 2017. This research mainly focuses on seven regions to conduct the analysis, including the Florida Key, Southeast, Marco Island, Tampa, Hernando, Polk and Orlando Regions.

In the first part, this research provides two methods that work together to identify the evacuation start time for each analysis region. The evacuation peak hour and reentry time of each region are also identified. Based on the result, this study shows the relationships between information release time, Irma landfall time, evacuation start time, evacuation peak time and reentry time.

Next this research examines the road utilization across Florida during the evacuation. Three types of roads are analyzed, which are Freeway, Multilane Highway and Two-lane Highway. The study uses the traffic data collected to identify which roads were over/under-utilized during evacuation. By analyzing the volume to capacity ratio and density together, this research also explores the reasons why the volume to capacity ratio is less than 1.0 when the traffic density reached Level of Service F based on the Level of Service Category provided by Highway Capacity Manual 6th edition (2016).

1.1 Background

Hurricane Irma originated from a tropical depression near the Cape Verde Islands on August 30, 2017 and it rapidly intensified into a Category 3 hurricane on August 31, 2017. In the next several days, Irma fluctuated between Categories 2 and 3 and it reached Category 5 on September 5, 2017 (Cangialosi et al, 2018).

According to the National Hurricane Center (NHC) Discussion on September 4th, 2017, there was a possibility that Hurricane Irma would impact southeastern Florida later that week (NHC, 2017). However, the path changed and Hurricane Irma made two landfalls in Florida. The first landfall hit Cudjoe Key in the lower Florida Keys as a Category 4 storm with 130 mph sustained winds on September 10th, 2017 at 9:00 AM EDT. Then Irma made the second landfall on Marco Island as a Category 3 storm with 115 mph wind on September 10th, 2017 at 3:30 PM EDT. After Irma passed over southwestern Florida and was influenced by the continent, it weakened quickly and kept moving north along the west coast of Florida. Irma passed east of Naples and Fort Myers as a Category 2 hurricane and passed between Tampa and Orlando as a Category 1 storm. Then Irma was reduced to a tropical storm before it entered Georgia on September 11th (Cangialosi et al, 2018).

According to the estimation from the National Oceanic and Atmospheric Administration (NOAA)'s National Centers for Environmental Information (NCEI), Hurricane Irma was the fifth-costliest hurricane that struck the United States and caused about 50.0 billion USD in losses due to wind and water damage. Hurricane Katrina in 2005, Hurricane Harvey in 2017, Hurricane Maria in 2017 and Hurricane Sandy in 2012 were ranked before Hurricane Irma (Cangialosi et al, 2018).

Within the large-scale impacted area, about 6.5 million residents in Florida evacuated to find shelters and other safer places, making it the most massive evacuation in Florida history (Florida House of Representatives, 2018). According to the Florida Department of Emergency Management's Updates, Governor Rick Scott declared a state of emergency in all counties within the State of Florida in response to Hurricane Irma on September 4th, 2017 (Florida Division of Emergency Management, 2017). In the next few days before Irma made landfall in Florida, 54 counties in Florida were given mandatory or voluntary evacuation orders. Visitors and most Floridian residents living in coastal areas, mobile homes, and low-lying areas were ordered to evacuate before Hurricane Irma arrived (Florida House of Representatives, 2018).

1.2 Problem Statement

The Government of Florida took a series of actions before Irma arrived to facilitate the evacuation of Floridians and visitors. For example, governments issued mandatory or voluntary orders to many counties several days before Hurricane Irma made the final landfall (Florida House of Representatives, 2018). Evacuees faced bumper-to-bumper traffic and a shortage of gas along the evacuation routes (Associated Press, 2017). These inconveniences, among others, are also the reason that many residents are not willing to evacuate even if they know that a hurricane is coming (Wong et. al, 2018). The decision not to evacuate when a hurricane approaches places the resident in danger.

Although many counties issued evacuation orders, evacuees may not follow the evacuation order closely. They may choose to evacuate before the evacuation order takes effect or after the evacuation order starts. There are also many other information items, e.g., alerts and media reports, that may influence the evacuation decision. It is important to study the evacuation decision relative to the timing of information distribution to help improve evacuation plans and operations.

During the evacuation, the public may choose different routes to evacuate; some routes may be overutilized while others may be underutilized. If evacuees exclusively used a certain type of road, severe evacuation congestion would occur. While congestion during an evacuation is expected, using all available routes would help mitigate it. Evaluating the traffic network during Hurricane Irma plays an important role in identifying which roads were over/under-utilized during evacuation. This analysis could help agencies identify alternative, underutilized routes to complement major evacuation routes.

1.3 Research Objectives

The research analyzed the traffic evacuation situation during Hurricane Irma from two major aspects as follows.

1.3.1 Evacuation and Re-entry Analysis

Before Hurricane Irma made its final landfall in Florida, several factors affected people's evacuation decisions. Among those factors, the media reports, alerts, and evacuation orders from the government play essential roles in influencing people's evacuation behavior (Baker, 1991), such as evacuation start time and evacuation peak time. This research used the traffic count data collected during Hurricane Irma from Aug 27th, 2017 to Oct 1st, 2017 to conduct the evacuation departure and re-entry analysis. This research focus on seven major regions to estimate the hour the evacuation noticeably started and find the evacuation peak time. Then the researchers analyzed the relationships of departures with media reports, alerts, and evacuation orders.

The thesis used the collected traffic data to find when the traffic re-entry happened in different regions. Analyzing re-entry timing would help the policymakers to better understand the residents' decision about when to return home. Accordingly, the government could provide more effective re-entry plans to the public so that it can reduce the reentry traffic loads.

1.3.2 Road Network Utilization

This research used the traffic data to examine the road utilization during Hurricane Irma's approach. The study focused on three types of roads - Freeways, Multilane Highways, and Two-lane Highways - to examine which roads were over/under utilized during the evacuation.

1.4 Thesis Organization

The thesis is structured in six chapters. Chapter 2 reviews the related research works that conducted hurricane traffic evacuation analysis. Chapter 3 discusses the data used for the research. Chapter 4 discusses the different methods used to address the research objectives. Chapter 5 presents and discusses the analysis results. Finally, Chapter 6 summarizes the whole research work and provides recommendations for future studies.

CHAPTER 2:

LITERATURE REVIEW

2.1 Overview

In the past few decades, many disasters like hurricanes and floods seriously threatened people's lives and caused evacuations. A series of research efforts focused on the analysis of traffic evacuation patterns for hurricanes. Several of these studies used data collected from traffic count stations to analyze these patterns. Other studies related to the types of roads used to evacuate were based on post-impact surveys. The literature reviewed below focuses on these two aspects to show the related research that had been done.

2.2 Real-event Traffic Data Analysis Literature

Before Hurricane Katrina happened in 2005, the Louisiana Department of Transportation and Development and the Louisiana State Police used the previous hurricane evacuation experience from Hurricane Georges in 1998 and Hurricane Ivan In 2004 to develop an evacuation plan to better serve the evacuation of Southeast Louisiana. Wolshon (2006) discussed the Katrina evacuation plan, which included implementation of contraflow and restricted access to freeways. This research summarized the success and failure of the evacuation during Hurricane Katrina. Wolshon and McArdle (2009) use hourly traffic count volume, collected across Louisiana to analyze how the evacuation plan affected the temporal and spatial traffic during Hurricane Katrina. The authors analyzed the traffic volume on several interstates and showed that there was a significant increase of outbound evacuation volume after the implementation of contraflow during Hurricane

Katrina. Also, compared with the total evacuation volume for Hurricane Ivan in 2004, the Hurricane Katrina evacuation, with the contraflow plan implemented, had a significant increase during the corresponding evacuation period. The authors used the traffic count stations that were located on the interstates to analyze the evacuation start time, duration of evacuation traffic and how the evacuation traffic propagated. The results showed that the duration of the evacuation for Hurricane Katrina with the new evacuation plan was significantly reduced when compared with the Hurricane Ivan evacuation in 2004 and more evacuees moved north instead of west and east.

Wolshon (2008) used hourly traffic counts collected during Hurricane Katrina in 2005 to analyze the traffic flow characteristics of different roadway types and areas types in Louisiana. This research classified the roads into three different types, such as freeways, four-lane arterial roadways and two-lane arterial roadways. Area types included urban or nonurbanized. Also, this research analyzed the contraflow traffic characteristics during evacuation. In this paper, maximum hourly flow rates and the theoretical capacity provided by Highway Capacity Manual (2000) were used to study the traffic patterns. The traffic flows on different road types did not exceed the theoretical capacity. Interestingly, the data showed that the contraflow traffic flow during evacuation is lower than the traffic flow on the normal lanes. But, the implementation of contraflow plays a crucial role in increasing the total evacuation flow during the same period. Also, Wolshon (2008) used the maximum traffic flows to identify the roadways that have the greatest peak flows.

Wolshon and McArdle (2011) studied the traffic volume data collected during Hurricane Katrina to analyze the evacuation traffic patterns of the secondary and low volume roadways in Louisiana. They classified the secondary and low volume routes that were used into four major types. First, secondary and low volume routes were used as primary evacuation routes for the coastal areas. Second, secondary routes were used as alternate routes in place of the freeways that were congested or access limited. Third, secondary routes were used as branch routes based on their orientation to freeways. Fourth, secondary and low volume routes are classified as routes of minimal impact where the routes are marginally affected. The results show that other than the major freeways, the secondary and low volume roadways also play critical roles in evacuation traffic (Wolshon and McArdle, 2011).

Archibald and McNeil (2012) used traffic detector data, hourly volume specifically, collected during Hurricane Irene in 2011 in Delaware to analyze the traffic behavior of communities before, during and after an evacuation. This study estimated the number of vehicles that evacuated from the coastal area in Delaware. Based on the vehicles that evacuated, this research estimated the number of evacuees. The authors used the census data to estimate the percentage of people who evacuated. The analysis showed that a significant number of residents and visitors evacuated from the beach communities. The traffic patterns during the evacuation were very similar to the traffic patterns that occur on summer weekends. The authors indicated that the capacity is able to support the evacuation traffic. However, in this study, the authors did not calculate the capacity. Archibald and McNeil (2012) also found that the route selection of evacuation traffic during Hurricane Irene differed from the evacuation plan's prescribed routes.

Dixit and Wolshon (2014) used the traffic volume and speed data collected during Hurricane Ivan in 2004, Hurricane Katrina in 2005 and Hurricane Gustav in 2008 to analyze the traffic characteristics during evacuation. The authors introduced two phenomena, the “maximum evacuation flow rate” and “maximum sustainable evacuation flow rate”. The results showed that the maximum evacuation flow rate during an evacuation was significantly different from the non-emergency peak traffic. The maximum evacuation flow rate can be used as capacity values in simulation models. The authors used speed data to study the temporal variation of traffic characteristics and found there was a difference between the maximum evacuation flow rate of contraflow and non-contraflow traffic. The research mentioned that the maximum sustainable evacuation flow rate can be used to analyze and determine the delays, queue length and estimate evacuation time.

Li et al. (2015) used the traffic data and event data to analyze the traffic pattern and highway disruptions in New Jersey when Hurricanes Irene and Sandy happened in 2011 and 2012, respectively. The traffic data included the hourly traffic volumes and travel time from different count stations. The event data included vehicle accidents, winds, and flooding, among others. The authors used the hourly traffic volume collected from Cape May county toll plazas to represent and study the evacuation patterns such as start time and peak evacuation time for Hurricane Irene and Hurricane Sandy. Also, the authors calibrated three models - Logit, Rayleigh, and Poisson distributions - to find the best model that fit the evacuation data observed. Li et al. (2015) also conducted a spatial analysis to show the evacuation pattern in different locations during Hurricane Irene and Sandy. Next the authors used the event data to analyze the disruptions during the evacuations. The travel times were used to identify the bottlenecks.

Srijith et al. (2020) used traffic speed data collected by roadside devices, Bluetooth sensors specifically, in Houston to study the traffic pattern during Hurricane Harvey, which happened in 2017. The authors translated the average link speed data into average link travel times and decomposed average link travel time into three different components using Seasonal-Trend Decomposition using Loess (STL) method. These three components include the trend component, seasonality component and the remainder component. According to the authors, the remainder component could be caused by traffic incidents. Then this study used the Generalized Extreme Studentized Deviate test to identify the extreme travel time observations of the traffic links based on the remainder component. The authors mentioned that the magnitude and frequency of extreme observations can be used to examine the hurricane effect on the traffic networks. The study results showed that this method could be used to examine the hurricane effect on the traffic network and quantify the resilience of the traffic network.

2.3 Post-impact Survey Analysis Literature

According to Dow and Cutter (2002), transportation problems are becoming more and more important in coastal areas when hurricanes approach. In 1999, when Hurricane Floyd happened in South Carolina, Dow and Cutter (2002) conducted a post-impact survey to analyze evacuation choices. They conducted a random telephone survey focused on the region that issued a mandatory evacuation order. This research showed that 25% of households took two or more cars. Analysis of evacuation departure time showed that most people chose to evacuate between 9 am and 3 pm and the result was verified with the traffic count data provided by the SCDOT. This research found that although many respondents carried road maps, they chose to stay on the interstate despite the congestion rather than switching to alternative routes. By analyzing the distance travelled, the authors found that many residents traveled longer to find shelters than in previous storms.

In a recent study on Hurricane Irma, Wong et al. (2018) conducted online post-impact surveys to analyze the travel behavior. The survey was distributed on both the east coast and west coast of Florida. The authors studied the data in two ways - descriptive statistics analysis and discrete choice analysis models. The descriptive analysis provided the overall results of evacuation decisions. The analyzed evacuation decisions included whether to evacuate or not, departure day, departure time of day, evacuation mode, route selection, destination selection, shelter type, and reentry. In the second analysis part, Wong et al. (2018) developed discrete choice models (binary or multinomial logit model) to determine the factors that influence the evacuation decisions.

2.4 Summary

It is evident from the literature that although many studies used traffic data or post-impact survey data to analyze the traffic evacuation pattern, few focused on studying the relationship between where and when evacuation departure occurred and alerts, orders and media reports. Although mandatory or voluntary order start times from the local government play important roles in evacuees' departure decisions, many people may not choose to follow the evacuation order closely. The evacuees may choose to evacuate several hours or several days before or after the orders are released to public. Tourists and some residents are more likely to evacuate after they get the information that there is an increasing possibility that the hurricane will make landfall on the continent (Fitzpatrick and Mileti, 1991). Also, there are few studies that examine the road type utilization for disasters.

This thesis addresses these gaps. It provides methods to determine the evacuation start time of analysis areas and find the relationship between the evacuation start time and the information released. In each analysis area, this thesis identifies when the traffic re-entry happened and when the evacuation peak happened. Finally, this research determines which routes and route types were over or underutilized.

CHAPTER 3:

DATA COLLECTION AND PROCESSING

3.1 Introduction

This chapter provides an overview of the data that are used in the analysis. It introduces three data types that are used and the source of each data. Also, it contains the data processing procedure of each data type.

3.2 Data Types

This research uses three major types of data. The first is the traffic data, including hourly traffic volume and average speed data, collected during Hurricane Irma in 2017. The second is the traffic count data that were collected in 2018 as a group of comparison data. The third contains related information (alerts, media report, evacuation orders) for Hurricane Irma to analyze the relationship between this information and evacuation traffic.

For the first type of data, the Florida Department of Transportation (FDOT) has implemented traffic count stations to collect the hourly traffic volume across the State of Florida. Each traffic count station provides bidirectional hourly volume for a whole day, 24 hours. When Hurricane Irma happened, there were 245 valid traffic count stations that collected the hourly traffic volumes. The data was collected from August 27, 2017 to October 1, 2017. Among the 245 valid traffic count stations, 60 also had average speed data. The speed data was collected from September 5, 2017 to September 15, 2017. A sample of the hourly volume data can be found in Appendix A.

Second, to compare the traffic pattern difference between Hurricane Irma and the normal traffic, this study utilized the hourly traffic count data in 2018 from the FDOT Website. “Florida Traffic Online” is a web-based mapping application (FDOT, 2020). The Telemetered traffic Monitoring Site layer shows the location of each traffic count station and the whole year’s hourly traffic volume. In our study, we used the traffic data from 2018 to represent the normal/historical traffic for the comparison in later analysis.

Third, information given to public several days before Hurricane Irma made landfall included alerts, media reports and evacuation orders. This information was provided by the National Hurricane Center (NHC), Florida State Government, and local counties. For example, Hurricane watches and warnings were issued and could be found on the National Hurricane Center’s website (Hurricane IRMA Advisory Archive, 2017). According to the National Oceanic and Atmospheric Administration (NOAA)‘s definition, Hurricane warnings indicate that hurricane conditions (sustained winds of 74 mph or higher) are **expected** somewhere within the specified area. A hurricane watch means that hurricane conditions (sustained winds of 74 mph or higher) are **possible** within the specified area (NOAA, 2018). Normally, the evacuation orders (mandatory or voluntary) could be issued by the Florida State Government or local counties. The channels by which the orders are distributed to the public include social media like Facebook and Twitter. This research also collected the related information from Facebook and Twitter. This information influences the public’s evacuation decisions which, in aggregate, translate into traffic patterns. A summary of information used in this study regarding Hurricane Irma’s approach are shown in Appendix B.

3.3 Data Processing

3.3.1 Hurricane Irma Data Processing

This research first uses ArcGIS to join the traffic data collected across Florida during Hurricane Irma with the location of the traffic count stations. There are 245 valid traffic count stations with hourly counts. Based on the location of traffic count stations, this research focused on seven major areas to study the evacuation traffic: Florida Key, Southeast, Marco Island, Tampa, Hernando, Polk and Orlando Regions. Each region contains one or several counties. A Geographic Information System (GIS) map below shows the location of each traffic count station and the analysis region (Figure 3.1). Table 3.1 shows the counties each region includes.

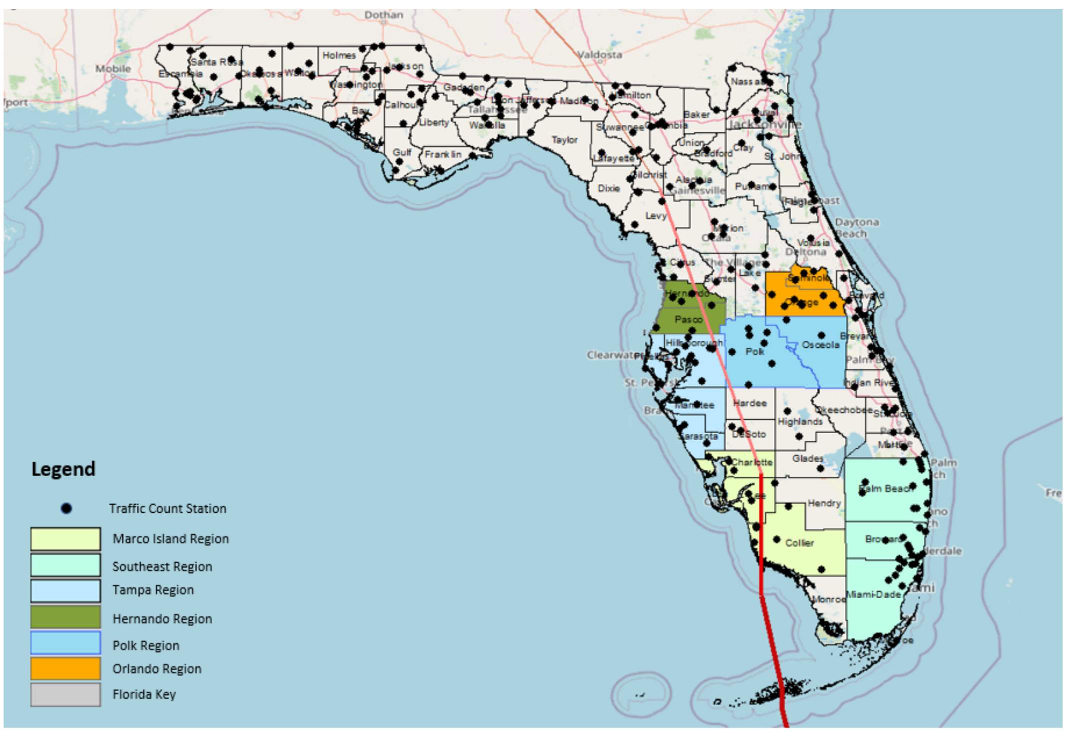

Figure 3-1: Location of Traffic Count Station and Analysis Region

Table 3-1: Analysis Region

Number	Analysis Region	Counties Included
1	Florida Key Region	Florida Key
2	Southeast Region	Miami-Dade, Palm Beach, Broward
3	Marco Island Region	Charlotte, Lee, Collier
4	Tampa Region	Hill Brough, Manatee, Pinellas, Sarasota
5	Hernando Region	Hernando, Pasco
6	Polk Region	Polk, Osceola
7	Orlando Region	Orange, Seminole

3.3.2 Normal Traffic Data Processing

To establish a traffic pattern baseline, this research gathered the traffic count data in 2018 from FDOT's Website. This research utilized the programming language Python to average the data from Aug 27, 2018 to Oct 1, 2018 to build an example week's data and matched with the same period during 2017 for each traffic count station. Due to the reason that seasonal factors may influence the daily traffic, the analysis period of 2018 is the same as the 2017 analysis period. One thing that needed to be checked before processing is that within the same period in 2018, there were no disasters that happened and it could be treated as the normal traffic. Labor day weekends happened in this period and they were treated separately. After averaging, a certain weekday in 2018 was compared with the matched weekday in 2017. For example, the average of Tuesday's data in 2018 at 1:00 am is matched with 2017 Tuesday's data at 1:00 am to conduct the comparison. After the hourly count volume for Hurricane Irma and normal traffic in 2018 were both processed, this research combined them together to conduct the later analysis. A sample of the combined data of one traffic count station can be found in Appendix C.

CHAPTER 4:

METHODOLOGY

4.1 Analysis Region

This research focuses on seven analysis regions, which include the Florida Key, Southeast, Marco Island, Tampa, Hernando, Polk and Orlando Regions. The determination of these analysis regions is based on the location of the traffic count stations. For an analysis region, the direction that goes into a region is counted as inbound. The opposite direction that leaves a region is viewed as outbound. If there are sufficient traffic count stations located at the border of a region and they can form a cordon line to encompass a region, they can be used to calculate the vehicles leaving or entering the region. The traffic count stations used for this study are mainly located on Freeways, Multilane Highways and Two-lane Highways. This research takes all the border traffic count stations, regardless of road type, into consideration to form an analysis region. Except for the Florida Keys region that has one traffic count station to represent the region, the other regions combine several counties together as an analysis region. The traffic count stations that are selected to form an analysis region are provided in the Appendix D.

4.2 Method for Evacuation Analysis

For each analysis region, this research uses the bidirectional traffic count volume to identify the evacuation start time, reentry time, and the evacuation peak time in a day as Hurricane Irma was approaching. Then this research finds the relationship between these information (alerts, orders, media reports) and the identified times.

Using the traffic count stations at the border of a region, the total number of vehicles that leave and enter an analysis region at a given hour can be determined with equation (1). When evacuation happens, more vehicles leave the region. And when the people start to return to their homes, more vehicles enter the region.

$$n_i = \sum_{all\ counters} (Inbound\ Volume_i - Outbound\ Volume_i) \quad (1)$$

Where *i* means a certain hour after the analysis period starts and (n_i) represents the vehicle change of a region for hour i. When $n_i > 0$, it means within a certain hour, there are more vehicles entering the area. When $n_i < 0$, it means within a certain hour, there are more vehicles leaving the area. For example, for normal daily commuting traffic, it can be expected that n_i could be greater than 0 when people are going to work in a region in the morning. When people are leaving an area and return to their homes in the afternoon, n_i will be less than 0. The following methods to obtain each objective are based on this equation.

4.2.1 Evacuation Start Time

This research provides two methods that work together to identify the evacuation start time precise to a certain hour. The first way is to calculate the cumulative changes in the number of vehicles in a region. This is complemented by a statistical test.

First, the cumulative vehicle changes reflect the net decrease or increase over time. For normal commuting traffic, the cumulative graph is expected to experience a vehicle increase and decrease in a day. After a normal day ends, the changes of the cumulative volumes are close to zero. If an evacuation happens in a region, the cumulative volume keeps decreasing. This research creates two graphs to show the cumulative change of vehicles. One graph shows the cumulative change of vehicles during Hurricane Irma and another shows the historical cumulative change of vehicles in normal traffic. By comparing these two graphs, the time that these two graph trends are different from each other can be identified. This time is the hour that evacuation noticeably starts for a region. Definitions used in later sections are provided in equations (2-5).

$$Volume_i = \sum_{all\ counters} (Inbound\ Volume_i - Outbound\ Volume_i) \tag{2}$$

$$History_i = \sum_{all\ counters} (Inbound\ Volume_i - Outbound\ Volume_i) \tag{3}$$

$$CUL.VOL_i = \sum_{j=0}^{i} Volume_j \tag{4}$$

$$CUL.HIS_i = \sum_{j=0}^{i} History_j \tag{5}$$

Where $Volume_i$ shows the vehicle changes in a certain hour during Hurricane Irma. $History_i$ shows the vehicle changes in a certain hour of the historical data for the comparison. $CUL.VOL_i$ and $CUL.HIS_i$ are cumulative vehicle changes of Hurricane Irma and historical data, respectively.

Second, this research conducts the Wilcoxon Signed-Rank test to identify the evacuation start time. The Wilcoxon Signed-Rank test is a nonparametric paired test that is valid for non-normally distributed data. When the sample size is small, it is more suitable to use a nonparametric test (Fagerland, 2012). Also, it is more robust to outliers when compared to a parametric test (Pappas and Depuy, 2004). This study takes two groups of values to conduct the Wilcoxon Signed-Rank test. The first group contains the volume differences of the inbound traffic and the outbound traffic of all the border traffic count stations for each region during Hurricane Irma in 2017. The second group contains the volume difference of the inbound traffic volume and the outbound traffic volume of the same border traffic count stations in 2018. The statistical tests are conducted for different regions separately. This study takes the same analysis hour's values of these two groups to compare and conduct the statistic test. The analysis period is from Sep 5th,2017 to Sep 10th, 2017, and it contains 144 hours. Sample test data of the Southeast region at hour 1 are provided in Table 4.1, where hour 1 is one hour after the analysis period starts for this region.

The hypotheses of the test are shown below.

Null Hypothesis (H_0): The median difference between the Hurricane Irma data and the historical data are equal to 0.

Alternative Hypothesis (H_a): The median difference between the Hurricane Irma data and the historical data are not equal to 0.

In this research, when the p-value is less than 0.1, it indicates that there is a significant difference between the two groups. It is the time that evacuation starts.

Table 4-1: Sample Wilcoxon Signed-Rank test of Southeast Region

Traffic Count Station	Volume difference at hour 1 during Hurricane Irma	Volume difference at hour 1 in 2018
357	67	-12
383	88	35
374	-19	-19
140	2	-13
164	18	-11
268	8	-6
217	30	-94
417	233	12
257	13	-3

These two methods, comparing the cumulative graph and conducting the Wilcoxon Signed-Rank test, work together to help identify the evacuation start time. Using these two methods separately faces individual limitations. For the cumulative graph, it is challenging to find exactly when the graphs are different from each other. For the nonparametric test, it may have outliers and this test itself is less powerful than a parametric test (Chin and Lee, 2008). By considering these two results together, it is more accurate to determine the evacuation start time.

4.2.2 Evacuation Reentry Time

The methodology to identify the evacuation reentry time is based on the cumulative vehicle changes of an analysis region. When the hurricane makes landfall, the cumulative vehicles changes will be fairly constant since many people choose to stay at home or they already evacuated to other places. After landfall, the evacuees start to return to their regions, leading to the increase of the cumulative graph of $Volume_i$. The hour that cumulative volume starts to increase is the time that the reentry starts. The result could be obtained from the graph of $CUL.VOL_i$.

4.2.3 Evacuation Peak Time

This research defines the evacuation peak time to have the biggest difference between $Volume_i$ and $History_i$ as in equation (6).

$$Difference_i = Volume_i - History_i \qquad (6)$$

This study draws the graph of $Difference_i$ to show the difference between the normal commuting traffic and the evacuation traffic. Between the time period that evacuation starts and landfall, each region may experience an evacuation peak time when $Difference_i$ reaches the smallest value (most negative) in each day.

4.2.4 Relationships

After obtaining the evacuation start time, evacuation peak time, and evacuation reentry time, this research examines their relationships to the information released. Equations (7-10) calculate the time differences.

$$Difference_1 = Evacuation\ start\ time - Information\ Release \qquad (7)$$

$$Difference_2 = Evacuation\ Peak\ Time - Information\ Release \qquad (8)$$

$$Difference_3 = Landfall\ Time - Evacuation\ Start\ time \qquad (9)$$

$$Difference_4 = Reentry\ Time - Landfall\ time \qquad (10)$$

4.3 Method for Road Utilization Analysis

In this part, this research uses the traffic data collocated from the Florida Department of Transportation to examine the road network utilization. The traffic count stations are mainly located on three types of roads across the State of Florida: Freeways, Multilane Highways and Two-lane Highways.

Two measures - volume to capacity ratio (v/c) and density are used to reflect the road utilization situation. For the volume to capacity ratio, when the volume to capacity ratio (v/c) is greater than 1, the traffic exceeds the capacity. When the volume to capacity ratio (v/c) approaches 1, the traffic on the road is near the capacity. According to the general v/c ratio ranges mentioned in CH2M Hill (2012), Table 4.2 shows three v/c ratio categories to represent the road utilization. With the speed data obtained from several traffic count stations, this research calculates the density. According to HCM (2016), a density greater than 45 pc/mi/ln is considered as Level of Service F and the traffic exceeds the capacity. Density less than 45 pc/mi/ln, including LOS A, LOS B, LOS C, LOS D and LOS E, indicates that the road is operating under its capacity. By analyzing the density and v/c ratio results together, this study also examines why the v/c ratio is low but the level of service is F.

Table 4-2: v/c ratio Category (created from CH2M Hill, 2012)

v/c Ratio	Utilization
0-0.80	Within Capacity
0.81-1.00	Near Capacity
Greater than 1.00	Exceed Capacity

According to Highway Capacity Manual 6th edition (2016), equation (11) is used to convert the hourly count volume into the 15-minute passenger-car equivalent peak flow rate.

$$v_p = \frac{V}{PHF \times N \times f_{HV}} \tag{11}$$

Where

v_p = 15-minute passenger-car equivalent peak flow rate (pc/h/ln),

V = hourly volume collected from the traffic count stations (vph),

PHF = peak hour factor,

N = number of lanes of the analysis direction, and

f_{HV} = heavy vehicle adjustment factor (HCM, 2016).

This research takes the default values of PHF from the HCM (2016) for different types of roads. It takes 0.94 for the basic freeway segments and 0.95 for multilane highway urban areas. f_{HV} values are calculated using equation (12) from HCM (2016). The State-Specific Default Values for percentage of heavy vehicles on freeways and multilane highways can be found in HCM (2016). In this study, it is assumed the percentage of heavy vehicle on freeways and multilane highways is 7%. The road terrain type is assumed to be level in this study and the value of E_T is 2.0, which can be found from HCM (2016).

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1)} \tag{12}$$

Where

f_{HV} = heavy vehicle adjustment factor (decimal),

P_T = proportion of SUTs and TTs in the traffic stream (decimal),and

E_T = passenger car equivalent of one heavy vehicle in the traffic stream (PCEs) (HCM, 2016).

According to HCM (2016), in practical terms, all the adjustment factors for a Two-lane Highway should be based on a flow rate greater than 900 veh/h. In this study, the capacity is assumed to be 1700 pc/h/ln to conduct the analysis. The capacity of basic freeway segment and Multilane Highway segment are calculated from the following equations (13-24) obtained from HCM (2016).

Basic Freeway Segment:

$$FFS = BFFS - f_{LW} - f_{RLC} - 3.22 \times TRD^{0.84} \quad (13)$$

Where

FFS = free-flow speed of the basic freeway segment (mi/h),

$BFFS$ = base FFS for the basic freeway segment (mi/h),

f_{LW} = adjustment for lane width (mi/h),

f_{RLC} = adjustment for right-side lateral clearance (mi/h), and

TRD = total ramp density (ramps/mi) (HCM, 2016).

$$BFFS = speed\ limit + 5 \quad (14)$$

$$FFS_{adj} = FFS \times SAF \quad (15)$$

$$c = 2200 + 10 \times \left(FFS_{adj} - 50\right) \quad (16)$$

$$55 \leq FFS \leq 75 \quad (17)$$

$$c \leq 2400 \quad (18)$$

$$c_{adj} = c \times CAF \quad (19)$$

Where

c_{adj} = adjusted capacity of segment (pc/h),

c = base capacity of segment (pc/h),

CAF = capacity adjustment factor (unitless), and

SAF = speed adjustment factor (unitless) (HCM, 2016).

Multilane Highway Segment:

$$FFS = BFFS - f_{LW} - f_{TLC} - f_M - f_A \quad (20)$$

Where

FFS = free-flow speed of the basic freeway segment (mi/h),

$BFFS$ = base FFS for the basic freeway segment (mi/h),

f_{LW} = adjustment for lane width (mi/h),

f_{TLC} = adjustment for total lateral clearance (mi/h),

f_M = adjustment for median type (mi/h), and

f_A = adjustment for access point density (mi/h) (HCM, 2016).

$$BFFS = speed\ limit + 5 \quad (21)$$

$$c = 1900 + 20 \times (FFS - 45) \quad (22)$$

$$c \leq 2300 \quad (23)$$

$$45 \leq FFS \leq 70 \quad (24)$$

Where c = base capacity of segment (pc/h) (HCM, 2016).

This research takes the level of Driver Familiarity to be "Most unfamiliar divers" (HCM 2016) for the evacuation traffic because evacuees may move through many regions during the evacuation process. This study takes 0.898 and 0.913 for CAF and SAF, respectively. The values for f_{LW} , f_{RLC} f_{TLC} and f_M can be found from Exhibits 12-20 to 12-23 of HCM (2016), respectively. This study assumes the access point density to be 25 access points/mile, which is a default value for the high-density suburban areas provided by HCM (2016), and f_A can be interpolated from Exhibit 12-24 of HCM (2016). The total ramp density is assumed to be 4 ramps/mile when there is one full cloverleaf per mile.

After getting the capacity and flow rate for each road, the volume to capacity ratios are calculated though the following equation obtained from HCM (2016).

$$\frac{v}{c}\, ratio = \frac{v_p}{c} \tag{25}$$

For the traffic count stations with speed data, the density is calculated using equation (26) from HCM (2016):

$$D = \frac{v_p}{S} \tag{26}$$

Where

D = density (pc/mi/ln),

v_p = 15-minute passenger-car equivalent peak flow rate (pc/h/ln), and

S = average speed of traffic stream (mi/h) (HCM, 2016).

CHAPTER 5:

RESULTS

This chapter presents and discusses the result in two parts. The first part shows the evacuation start time, evacuation peak time, reentry, and relationships results. The second part shows the analysis results for road utilization.

5.1 Evacuation Analysis Results

This research shows the results in different graphs and tables. The cumulative graph and Wilcoxon Signed-Rank test results table of each region are used to determine the evacuation start time. The cumulative graph covers the whole analysis period, including the reentry time of each region. The Wilcoxon Signed-Rank tests are focused on the analysis period before Hurricane Irma made landfall to identify the evacuation start time. The Wilcoxon Sign-Rank test results can be found in Appendix E. Evacuation peak time graphs are provided to focus on the analysis period before Hurricane Irma made landfall. It marks all the evacuation peak hours from evacuation start to the reentry start of each region. The relationship table of each region is provided to show the time difference result.

5.1.1 Florida Keys Region

The Florida Key region has just one traffic count station, which prohibits the use of the Wilcoxon Signed-Rank test. This research directly uses the cumulative graph (Figure 5.1) to identify the evacuation start time. The analysis period of this region is from Aug 27th, 2017 to Oct 1th, 2017. Figure 5.1 shows that the evacuation starts at 2:00 pm on Sep 5th, 2017. On Sep 4th, 2017, the first National Hurricane Center report indicated that there was an increasing chance of seeing impacts from Hurricane Irma in the Florida Peninsula later the following week and, rough surf and dangerous marine conditions were going to threaten the coastal areas (National Hurricane Center, 2017). Table 5.1 shows the evacuation started about 27 hours after the first National Hurricane Center report was issued. During the same day, the governor declared a state of emergency (CBS NEWS, 2017). Table 5.1 shows the evacuation started 20 hours after that. On the next day, the evacuation order was released and Table 5.1 shows the evacuation started 2 hours later. The mandatory start time of this region was issued to be 7:00 am and 7:00 pm on Sep 6th, 2017 for non-residents and residents, respectively (Monroe County Emergency management, 2017). Table 5.1 shows that the public did not follow the evacuation order closely and they started to evacuate 17 hours before the evacuation orders took effect.

Based on Figure 5.2, the Florida Keys experienced five peak hours in the following days from the evacuation start until Hurricane Irma made landfall. The evacuation peak hour occurred in the evening on the early days and in the morning when approaching the landfall day. Table 5.1 shows that more people evacuated at 8:00 am in the morning and 7:00 pm in the evening. The biggest evacuation peak happened on Sep 6th, 2017, four days before landfall. Table 5.1 shows that the evacuation started 115 hours before Hurricane Irma made the first landfall. The reentry traffic started 46 hours after Hurricane Irma made landfall, which was later than other regions. The local government prohibited people from returning to their homes early due to hurricane damage.

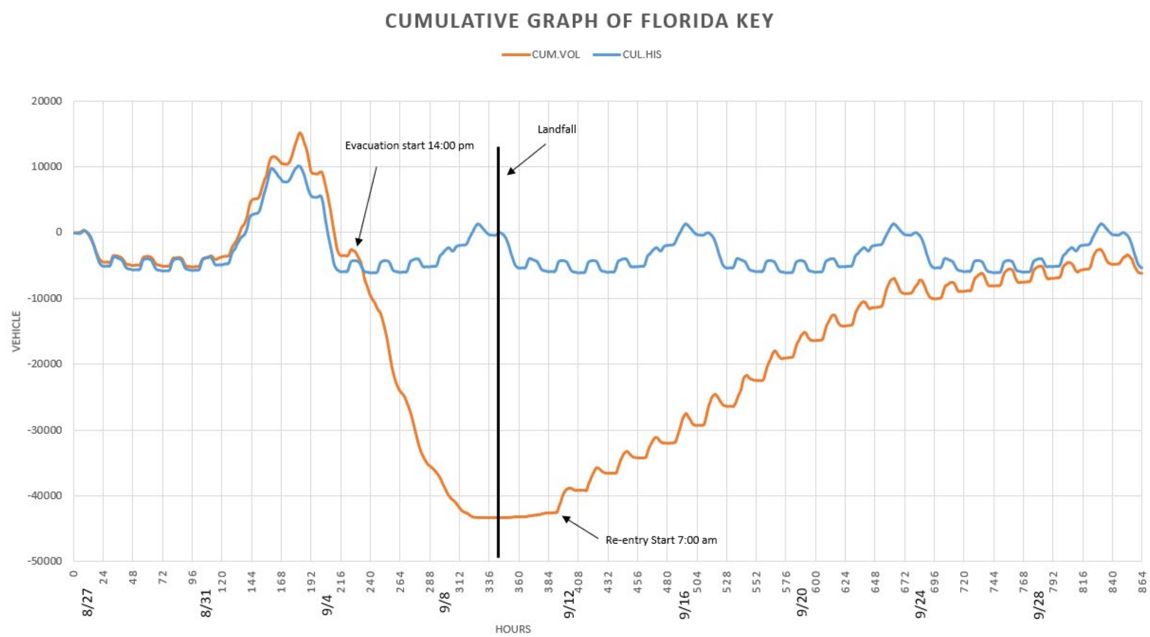

Figure 5-1: Cumulative Graph of Florida Key

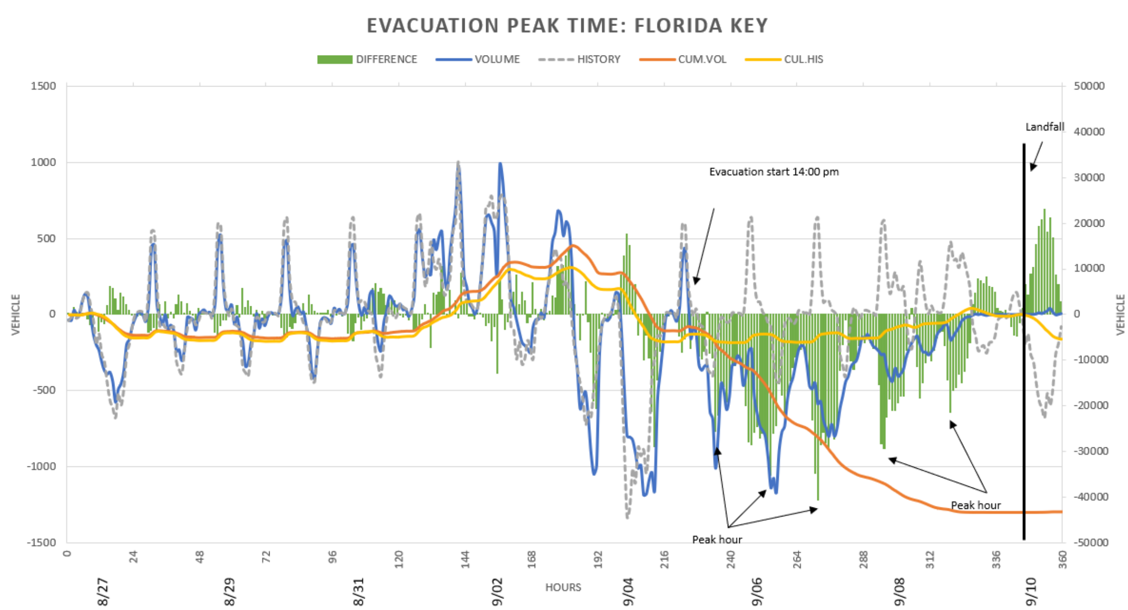

Figure 5-2: Evacuation Peak Time: Florida Key

Table 5-1: Relationship of Florida Key Timepoints

Florida Key										
Information	Information Time	Evacuation Start time	Difference 1 (Hours)	Evacuation Peak Time	Difference 2 (Hours)	Landfall	Difference 3 (Hours)	Reentry Time	Difference 4 (Hours)
First NHC Report	9/4/17 11:00	9/5/17 14:00	27	9/5/17 19:00	32	9/10/17 9:00	115	9/12/17 7:00	46
State of Emergency	9/4/17 18:00	9/5/17 14:00	20	9/5/17 19:00	25	9/10/17 9:00	115	9/12/17 7:00	46
Order Release	9/5/17 11:55	9/5/17 14:00	2	9/5/17 19:00	7	9/10/17 9:00	115	9/12/17 7:00	46
Mandatory Start 1	9/6/17 7:00	9/5/17 14:00	-17	9/6/17 15:00	8	9/10/17 9:00	115	9/12/17 7:00	46
Mandatory Start 2	9/6/17 19:00	9/5/17 14:00	-29	9/7/17 8:00	13	9/10/17 9:00	115	9/12/17 7:00	46
Hurricane Watch	9/7/17 11:00	9/5/17 14:00	-45	9/8/17 8:00	21	9/10/17 9:00	115	9/12/17 7:00	46
Hurricane Warning	9/7/17 23:00	9/5/17 14:00	-57	9/9/17 8:00	33	9/10/17 9:00	115	9/12/17 7:00	46

5.1.2 Southeast Region

The southeast region has nine detectors (see Table D.2). The analysis period is from Sep 5th, 2017 to Oct 1th, 2017. The evacuation start time is determined by examining Figure 5.3 and the Wilcoxon Signed-Rank Test (Table E.1) together. Figure 5.3 indicates that the evacuation started at 11:00 am on Sep 6th, 2017. The Wilcoxon Signed-Rank test result shows that on Sep 5th , 2017, there are p-values less than 0.1. They may not indicate the evacuation start time because the two cumulative graphs, CUL.VOL and CUL.HIS, on Sep 5th, 2017 are similar as shown in Figure 5.3. The cumulative volume changes of the Southeast Region did not decrease after these hours. When the two methods work together, the evacuation start time could be identified as 11:00 am on Sep 6th, 2017, where the first p-value is less than 0.1 at hour 35 after the analysis period starts (Table E.1). According to Table 5.2, the information items that were given before the evacuation start time includes the First National Hurricane report, State of Emergency declaration and the evacuation orders that Miami Dade county issued. The evacuation started 20 hours before the mandatory evacuation took effect and 101 hours before Hurricane Irma made landfall (Table 5.2). This region experienced three evacuation peak hours identified in Figure 5.4. In the early days before landfall, the evacuation peak hour happened in the evening, but closer to landfall, the evacuation peak time happened in the morning. The biggest evacuation peak happened three days before landfall on Sep 7th, 2017. As shown in Table 5.2, the reentry started 33 hours before landfall. This may be attributed to a change in Hurricane Irma's path. After people knew that Hurricane Irma was going to strike the southwestern part of Florida instead of the southeastern region, there were some people who entered this region. It may due to some people returning home or evacuees from other places choosing this area as their evacuation destination.

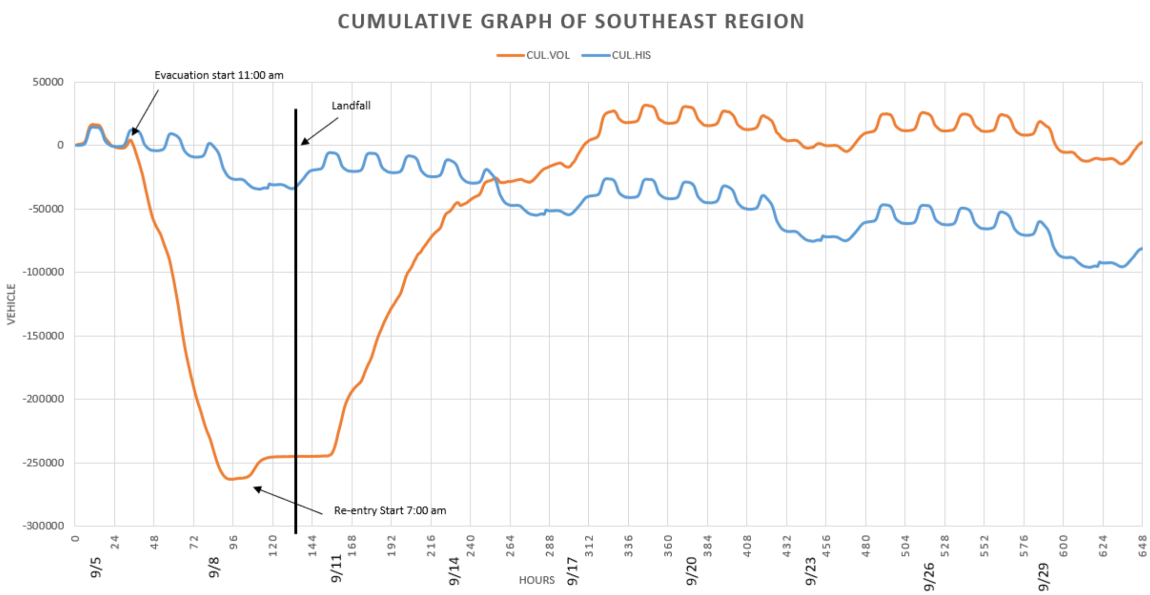

Figure 5-3: Cumulative Graph of Southeast Region

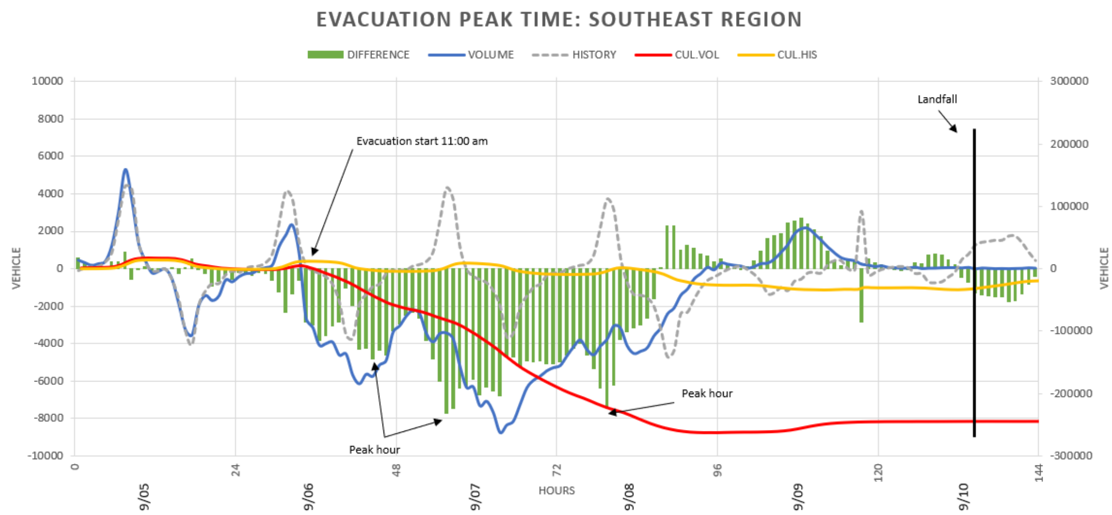

Figure 5-4: Evacuation Peak Time: Southeast Region

Table 5-2: Relationship of Southeast Region Timepoints

Southeast Region									
Information	Information Time	Evacuation Start time	Difference 1 (Hours)	Evacuation Peak Time	Difference 2 (Hours)	Landfall	Difference 3 (Hours)	Reentry Time	Difference 4 (Hours)
First NHC Report	9/4/17 11:00	9/6/17 11:00	48	9/6/17 21:00	58	9/10/17 15:30	101	9/9/17 7:00	-33
State of Emergency	9/4/17 18:00	9/6/17 11:00	41	9/6/17 21:00	51	9/10/17 15:30	101	9/9/17 7:00	-33
Order release 1	9/6/17 7:15	9/6/17 11:00	4	9/6/17 21:00	14	9/10/17 15:30	101	9/9/17 7:00	-33
Order release 2	9/6/17 15:00	9/6/17 11:00	-4	9/6/17 21:00	6	9/10/17 15:30	101	9/9/17 7:00	-33
Mandatory Start 1	9/7/17 7:00	9/6/17 11:00	-20	9/7/17 8:00	1	9/10/17 15:30	101	9/9/17 7:00	-33
Hurricane Watch	9/7/17 11:00	9/6/17 11:00	-24	9/8/17 8:00	21	9/10/17 15:30	101	9/9/17 7:00	-33
Mandatory Start 2	9/7/17 12:00	9/6/17 11:00	-25	9/8/17 8:00	20	9/10/17 15:30	101	9/9/17 7:00	-33
Order release 3	9/7/17 19:00	9/6/17 11:00	-32	9/8/17 8:00	13	9/10/17 15:30	101	9/9/17 7:00	-33
Hurricane Warning	9/7/17 23:00	9/6/17 11:00	-36	9/8/17 8:00	9	9/10/17 15:30	101	9/9/17 7:00	-33
Mandatory Start 3	9/8/17 10:00	9/6/17 11:00	-47	9/8/17 8:00	-2	9/10/17 15:30	101	9/9/17 7:00	-33

5.1.3 Marco Island Region

The analysis period of the Marco Island region is from Sep 5th, 2017 to Sep 14th, 2017. This smaller period is due to one important traffic count station, Site 39, failing after Sep 14th, 2017. From Figure 5.5, it is found that the evacuation starts on Sep 5th, 2017. Working together with the Wilcoxon Signed-Rank test result (Table E.2), the evacuation started at 12:00 pm on Sep 5th, 2017. The evacuation started before counties issued evacuation orders. The evacuation started around 124 hours before landfall (Table 5.3).

From Figure 5.6, this region experienced five evacuation peaks. In the early days before landfall, the evacuation peak time happened in the evening. For this region, there was one day that the evacuation peak happened in nighttime. The biggest evacuation peak happened two days before landfall on Sep 8th, 2017. Reentry started about 18 hours after landfall (Table 5.3).

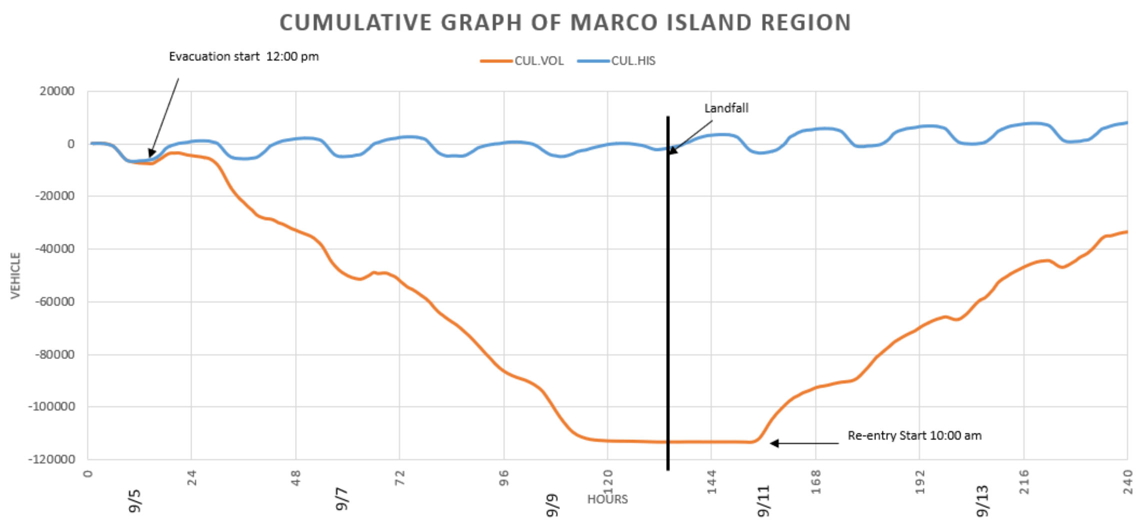

Figure 5-5: Cumulative Graph of Marco Island Region

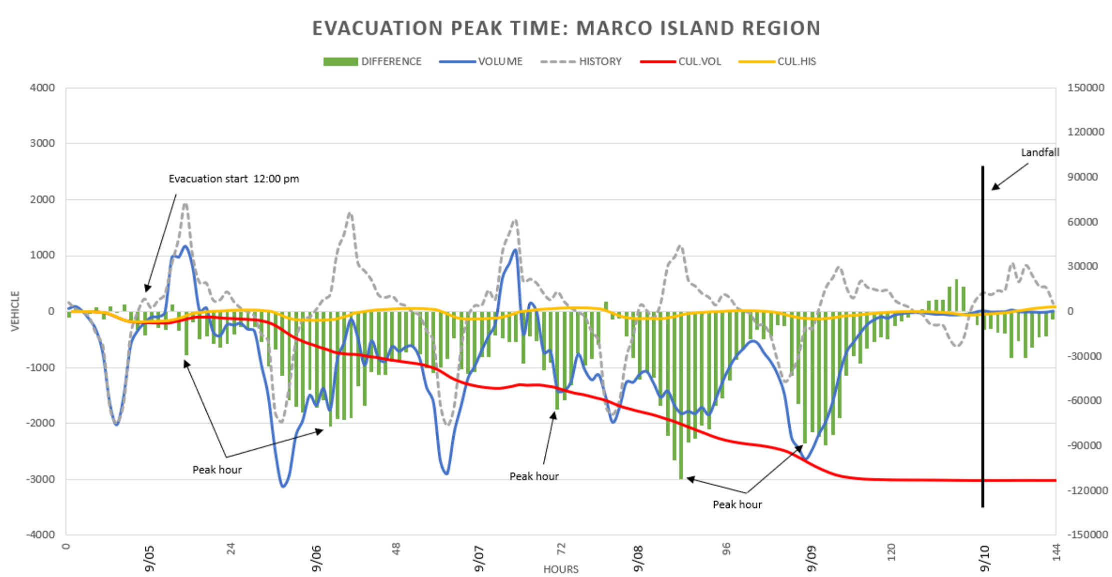

Figure 5-6: Evacuation Peak Time: Marco Island Region

Table 5-3: Relationship of Marco Island Region Timepoints

Marco Island Region									
Information	**Information Time**	**Evacuation Start time**	**Difference 1 (Hours)**	**Evacuation Peak Time**	**Difference 2 (Hours)**	**Landfall**	**Difference 3 (Hours)**	**Reentry Time**	**Difference 4 (Hours)**
First NHC Report	9/4/17 11:00	9/5/17 12:00	25	9/5/17 18:00	31	9/10/17 15:30	124	9/11/17 10:00	18
State of Emergency	9/4/17 18:00	9/5/17 12:00	18	9/5/17 18:00	24	9/10/17 15:30	124	9/11/17 10:00	18
Order release 1	9/5/17 17:00	9/5/17 12:00	-5	9/5/17 18:00	1	9/10/17 15:30	124	9/11/17 10:00	18
Hurricane Watch	9/7/17 11:00	9/5/17 12:00	-47	9/8/17 0:00	13	9/10/17 15:30	124	9/11/17 10:00	18
Order release 2	9/7/17 16:00	9/5/17 12:00	-52	9/8/17 0:00	8	9/10/17 15:30	124	9/11/17 10:00	18
Order release 3	9/7/17 17:00	9/5/17 12:00	-53	9/8/17 0:00	7	9/10/17 15:30	124	9/11/17 10:00	18
Hurricane Warning	9/7/17 23:00	9/5/17 12:00	-59	9/8/17 0:00	1	9/10/17 15:30	124	9/11/17 10:00	18
Mandatory Start 1	9/8/17 9:30	9/5/17 12:00	-70	9/8/17 18:00	8	9/10/17 15:30	124	9/11/17 10:00	18
Mandatory Start 2	9/8/17 13:00	9/5/17 12:00	-73	9/8/17 18:00	5	9/10/17 15:30	124	9/11/17 10:00	18
Order release 4	9/8/17 15:09	9/5/17 12:00	-75	9/8/17 18:00	3	9/10/17 15:30	124	9/11/17 10:00	18
Order release 5	9/9/17 8:23	9/5/17 12:00	-92	9/9/17 12:00	4	9/10/17 15:30	124	9/11/17 10:00	18

5.1.4 Tampa Region

The analysis period of the Tampa region is from Sep 5th, 2017 to Oct 1th, 2017. Considering Figure 5.7 and the statistical test result (Table E.3) together, the evacuation started at 7:00 am on Sep 8th, 2017, 57 hours before the hurricane made landfall. In this region, the information that were available to people before the evacuation start time included the First National Hurricane Report, State of Emergency declaration and the release of evacuation order from three counties (Manatee, Pinellas, and Hill Borough). This region experienced two evacuation peak hours, which all happened in the morning (Table 5.4). The biggest evacuation peak happened on Sep 9th, 2017, one day before landfall. The traffic reentry of this region happened 17 hours after Hurricane Irma made landfall (Table 5.4).

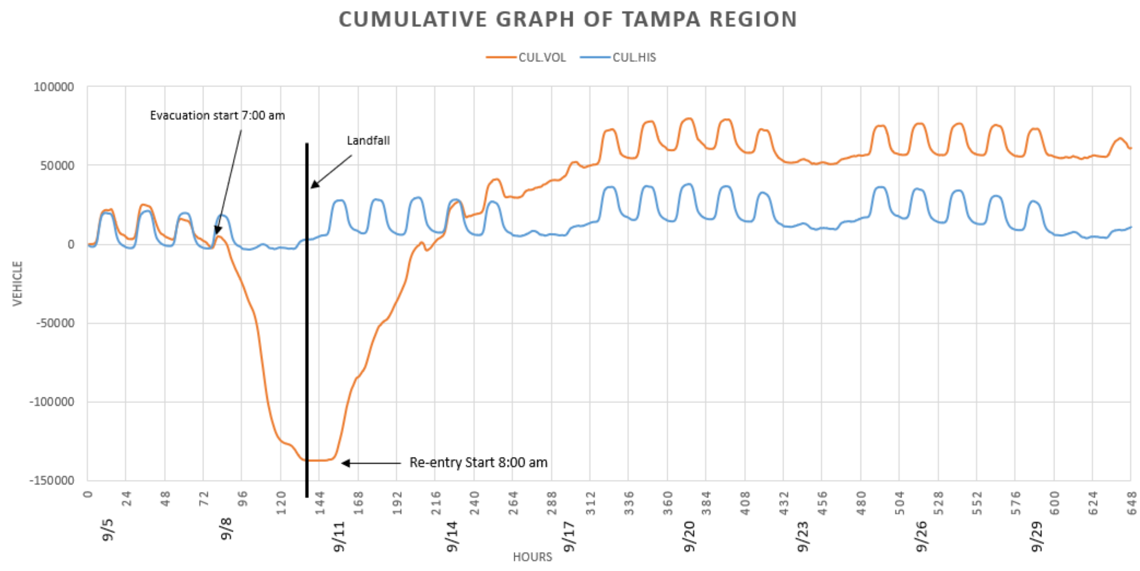

Figure 5-7: Cumulative Graph of Tampa Region

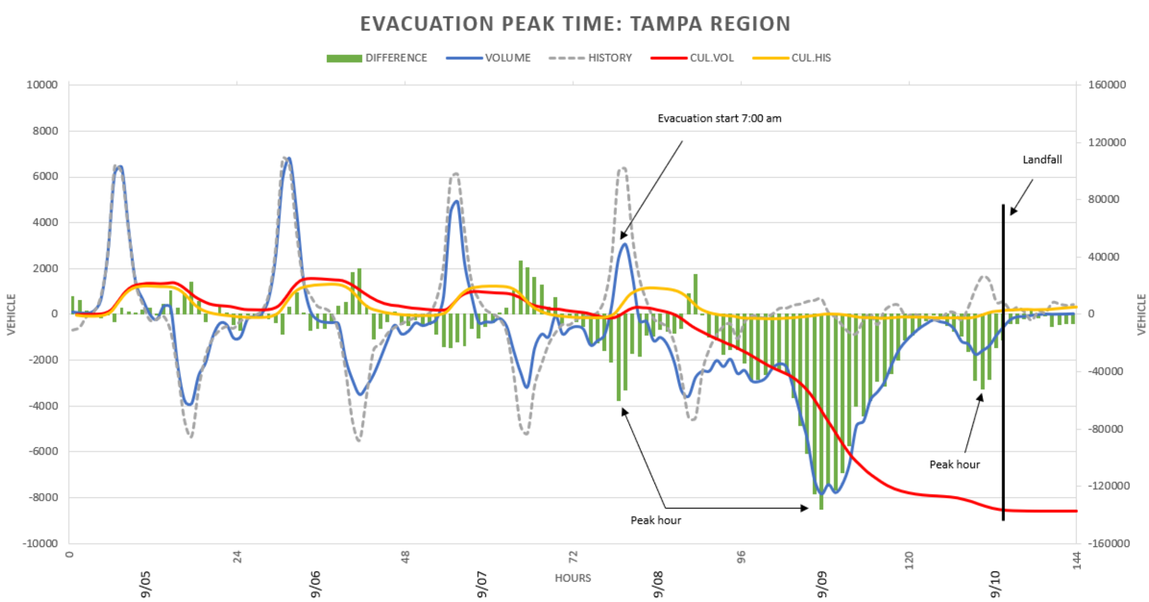

Figure 5-8: Evacuation Peak Time: Tampa Region

Table 5-4: Relationship of Tampa Region Timepoints

Tampa Region										
Information	**Information Time**	**Evacuation Start time**	**Difference 1 (Hours)**	**Evacuation Peak Time**	**Difference 2 (Hours)**	**Landfall**	**Difference 3 (Hours)**	**Reentry Time**	**Difference 4 (Hours)**
First NHC Report	9/4/17 11:00	9/8/17 7:00	92	9/8/17 7:00	92	9/10/17 15:30	57	9/11/17 8:00	17
State of Emergency	9/4/17 18:00	9/8/17 7:00	85	9/8/17 7:00	85	9/10/17 15:30	57	9/11/17 8:00	17
Order release 3	9/7/17 9:56	9/8/17 7:00	21	9/8/17 7:00	21	9/10/17 15:30	57	9/11/17 8:00	17
Order release 2	9/7/17 16:22	9/8/17 7:00	15	9/8/17 7:00	15	9/10/17 15:30	57	9/11/17 8:00	17
Order release 1	9/7/17 17:53	9/8/17 7:00	13	9/8/17 7:00	13	9/10/17 15:30	57	9/11/17 8:00	17
Mandatory start 2	9/8/17 6:00	9/8/17 7:00	1	9/8/17 7:00	1	9/10/17 15:30	57	9/11/17 8:00	17
Voluntary 2	9/8/17 7:00	9/8/17 7:00	0	9/8/17 7:00	0	9/10/17 15:30	57	9/11/17 8:00	17
Voluntary 1 & Order release 4	9/8/17 8:00	9/8/17 7:00	-1	9/9/17 12:00	28	9/10/17 15:30	57	9/11/17 8:00	17
Hurricane Watch	9/8/17 11:00	9/8/17 7:00	-4	9/9/17 12:00	25	9/10/17 15:30	57	9/11/17 8:00	17
Mandatory start 4 & Order release 5	9/8/17 12:00	9/8/17 7:00	-5	9/9/17 12:00	24	9/10/17 15:30	57	9/11/17 8:00	17
Mandatory start 5	9/8/17 14:00	9/8/17 7:00	-7	9/9/17 12:00	22	9/10/17 15:30	57	9/11/17 8:00	17
Hurricane Warning	9/8/17 23:00	9/8/17 7:00	-16	9/9/17 12:00	13	9/10/17 15:30	57	9/11/17 8:00	17
Mandatory start 1 & 3	9/9/17 8:00	9/8/17 7:00	-25	9/9/17 12:00	4	9/10/17 15:30	57	9/11/17 8:00	17

5.1.5 Hernando Region

The analysis period of the Hernando region is from Sep 5th, 2017 to Oct 1th, 2017. Through the analysis of Figure 5.9 and the Wilcoxon Signed-Rank test result (Table E.4), the evacuation started at 8:00 am on Sep 5th, 2017, which is 128 hours before Hurricane Irma made landfall. The first National Hurricane report and declaration of the state of emergency, were available to the public before the evacuation started. The evacuation of this region started before the evacuation order was issued. This region experienced five evacuation peaks before landfall (Figure 5.10). All of them happened in the afternoon. The biggest evacuation peak happened on Sep 9th, 2017, one day before landfall. Reentry started 23 hours after landfall (Table 5.5).

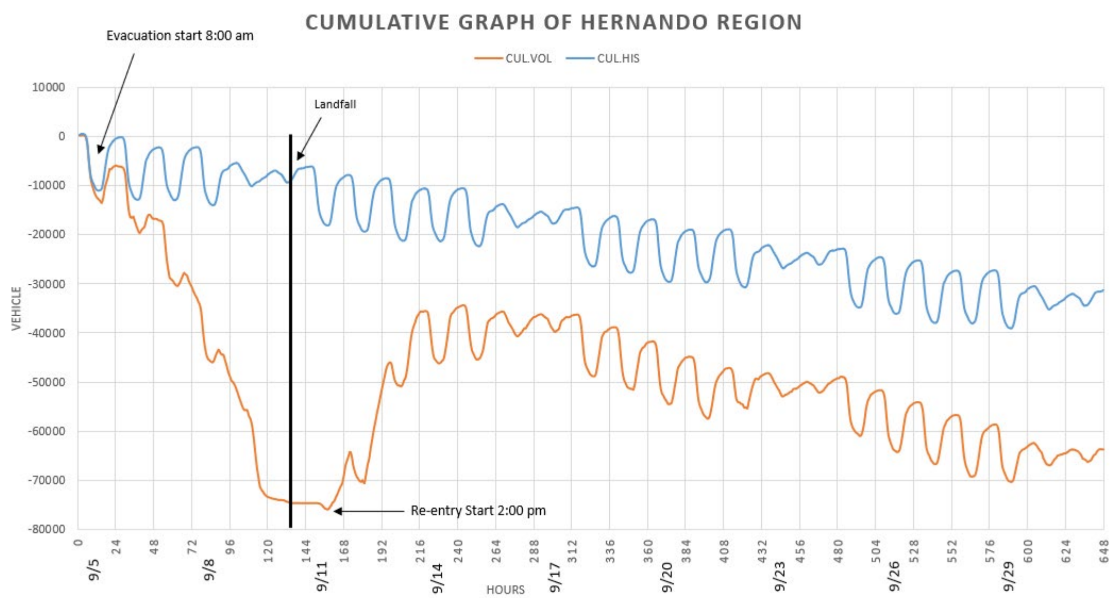

Figure 5-9: Cumulative Graph of Hernando Region

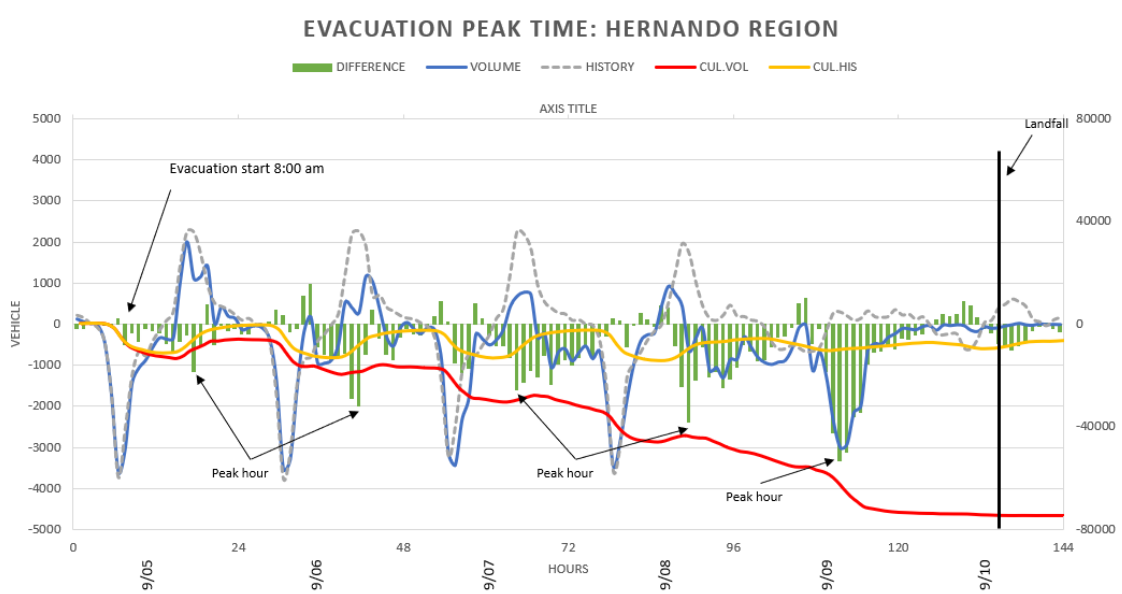

Figure 5-10: Evacuation Peak Time: Hernando Region

Table 5-5: Relationship of Hernando Region Timepoints

Hernando Region									
Information	**Information Time**	**Evacuation Start time**	**Difference 1 (Hours)**	**Evacuation Peak Time**	**Difference 2 (Hours)**	**Landfall**	**Difference 3 (Hours)**	**Reentry Time**	**Difference 4 (Hours)**
First NHC Report	9/4/17 11:00	9/5/17 8:00	21	9/5/17 18:00	31	9/10/17 15:30	128	9/11/17 14:00	23
State of Emergency	9/4/17 18:00	9/5/17 8:00	14	9/5/17 18:00	24	9/10/17 15:30	128	9/11/17 14:00	23
Order release 1	9/7/17 16:38	9/5/17 8:00	-57	9/7/17 17:00	0	9/10/17 15:30	128	9/11/17 14:00	23
Mandatory start 1&3	9/8/17 8:00	9/5/17 8:00	-72	9/8/17 18:00	10	9/10/17 15:30	128	9/11/17 14:00	23
Hurricane Watch	9/8/17 17:00	9/5/17 8:00	-81	9/8/17 18:00	1	9/10/17 15:30	128	9/11/17 14:00	23
Hurricane Warning	9/9/17 5:00	9/5/17 8:00	-93	9/9/17 16:00	11	9/10/17 15:30	128	9/11/17 14:00	23
Mandatory start 2	9/9/17 13:00	9/5/17 8:00	-101	9/9/17 16:00	3	9/10/17 15:30	128	9/11/17 14:00	23
Order release 2	9/9/17 14:26	9/5/17 8:00	-102	9/9/17 16:00	2	9/10/17 15:30	128	9/11/17 14:00	23

5.1.6 Polk Region

The analysis period of the Polk region is from Sep 5th, 2017 to Oct 1th, 2017. Figure 5.11 shows the cumulative graph for the Polk Region. Working with the Wilcoxon Signed-Rank test results (Table E.5), the evacuation started at 3:00 pm on Sep 5th, 2017, which is 121 hours before landfall. The first National Hurricane report and declaration of state of emergency appeared before the evacuation start time. The evacuation start time was before the time when the counties issued evacuation orders. This region experienced three evacuation peaks (Figure 5.12). The biggest evacuation peak happened on Sep 7th, 2017, three days before landfall. Reentry appeared to start 49 hours before landfall (Table 5.6). Rather than reentry, it was possible that other people chose this county as the evacuation shelter.

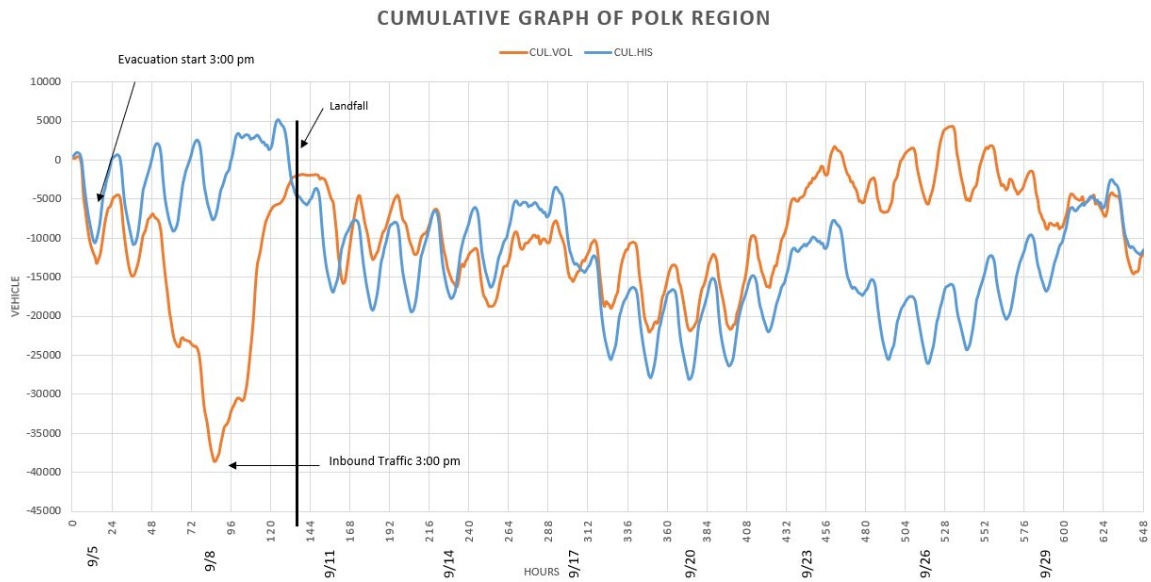

Figure 5-11: Cumulative Graph of Polk Region

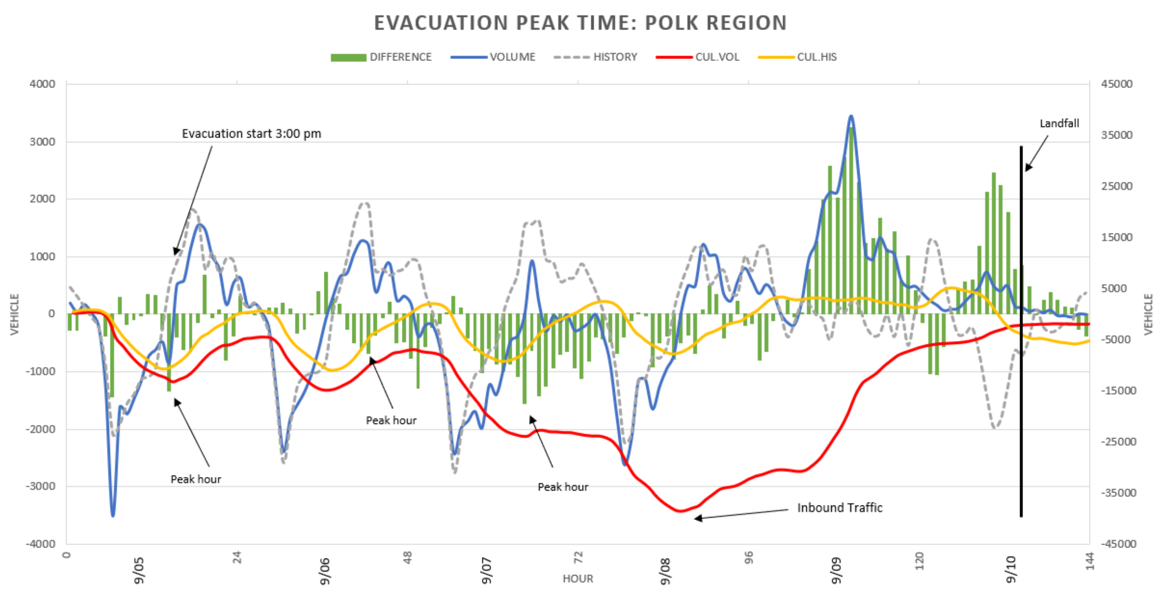

Figure 5-12: Evacuation Peak Time: Polk Region

Table 5-6: Relationship of Polk Region Timepoints

Polk Region										
Information	**Information Time**	**Evacuation Start time**	**Difference 1 (Hours)**	**Evacuation Peak Time**	**Difference 2 (Hours)**	**Landfall**	**Difference 3 (Hours)**	**Reentry Time**	**Difference 4 (Hours)**
First NHC Report	9/4/17 11:00	9/5/17 15:00	28	9/5/17 15:00	28	9/10/17 15:30	121	9/8/17 15:00	-49
State of Emergency	9/4/17 18:00	9/5/17 15:00	21	9/5/17 15:00	21	9/10/17 15:30	121	9/8/17 15:00	-49
Order release 1	9/8/17 8:58	9/5/17 15:00	-66	9/7/17 17:00	-16	9/10/17 15:30	121	9/8/17 15:00	-49
Hurricane Watch	9/8/17 11:00	9/5/17 15:00	-68	9/7/17 17:00	-18	9/10/17 15:30	121	9/8/17 15:00	-49
Order release 2	9/8/17 16:00	9/5/17 15:00	-73	9/7/17 17:00	-23	9/10/17 15:30	121	9/8/17 15:00	-49
Hurricane Warning	9/8/17 23:00	9/5/17 15:00	-80	9/7/17 17:00	-30	9/10/17 15:30	121	9/8/17 15:00	-49
Mandatory start 1	9/9/17 8:03	9/5/17 15:00	-89	9/7/17 17:00	-39	9/10/17 15:30	121	9/8/17 15:00	-49

5.1.7 Orlando Region

The analysis period of the Orlando region is from Sep 5th, 2017 to Oct 1th, 2017. Based on the cumulative graph (Figure 5.13) and Wilcoxon Signed-Rank test results (Table E.6), the evacuation started at 9:00 am on Sep 7th, which was 79 hours before landfall. The first National Hurricane report and declaration of state of emergency were given before the evacuation start time. For this region, the evacuation started before the evacuation order was issued. The Orlando region experienced four evacuation peaks and all happened in the morning (Figure 5.14). The biggest evacuation peak happened on Sep 7th, 2017, three days before landfall. Table 5.7 shows that reentry traffic started 24 hours after landfall.

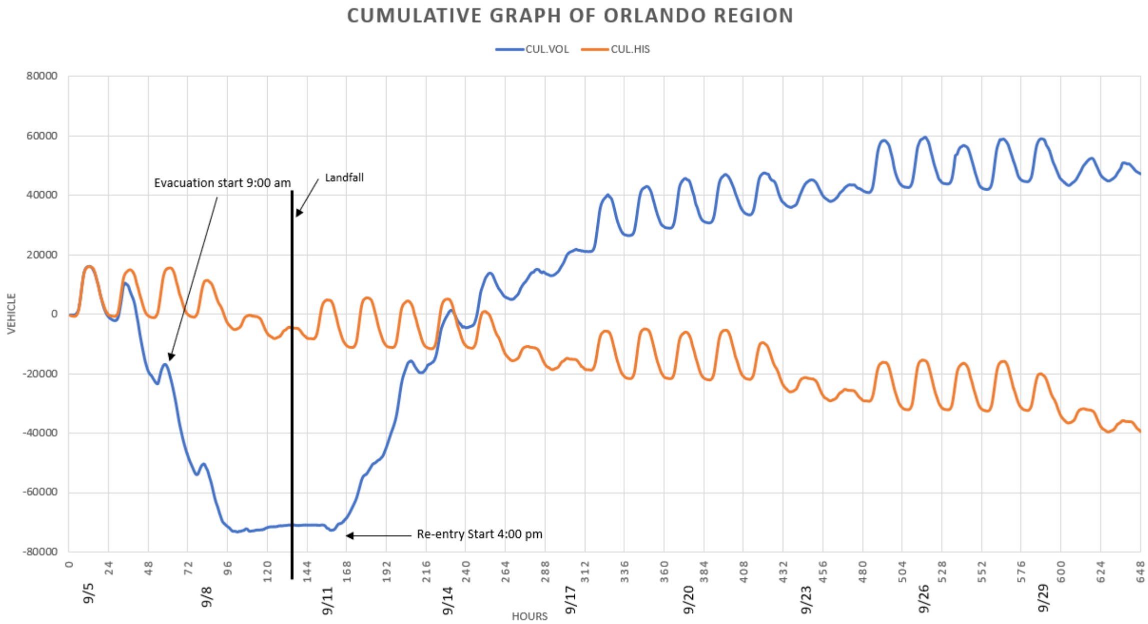

Figure 5-13: Cumulative Graph of Orlando Region

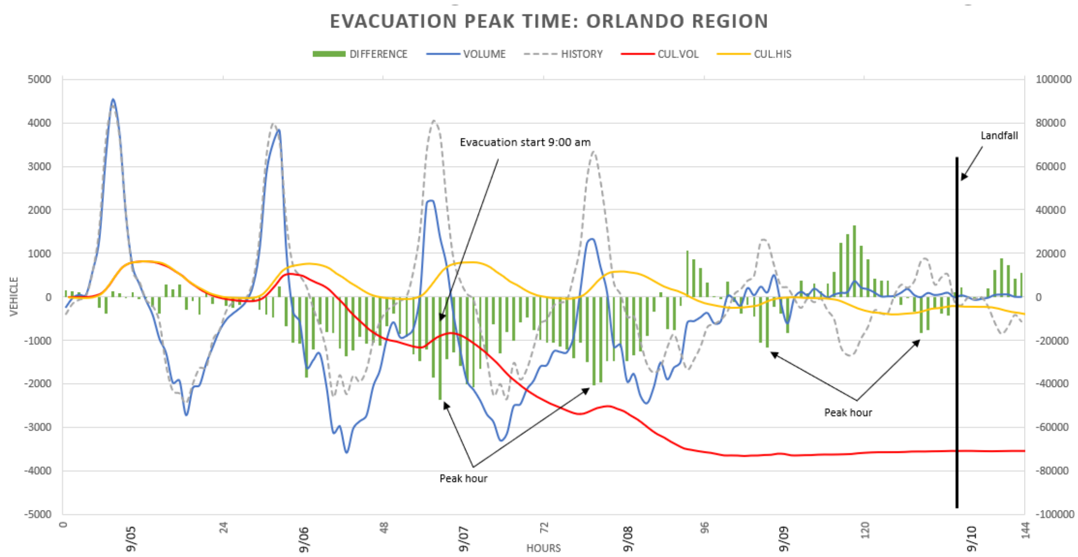

Figure 5-14: Evacuation Peak Time: Orlando Region

Table 5-7: Relationship of Orlando Region Timepoints

Orlando Region										
Information	**Information Time**	**Evacuation Start time**	**Difference 1 (Hours)**	**Evacuation Peak Time**	**Difference 2 (Hours)**	**Landfall**	**Difference 3 (Hours)**	**Reentry Time**	**Difference 4 (Hours)**
First NHC Report	9/4/17 11:00	9/7/17 9:00	70	9/7/17 9:00	70	9/10/17 15:30	79	9/11/17 16:00	24
State of Emergency	9/4/17 18:00	9/7/17 9:00	63	9/7/17 9:00	63	9/10/17 15:30	79	9/11/17 16:00	24
Hurricane Watch	9/8/17 11:00	9/7/17 9:00	-26	9/9/17 10:00	23	9/10/17 15:30	79	9/11/17 16:00	24
Order release 1	9/8/17 17:35	9/7/17 9:00	-33	9/9/17 10:00	16	9/10/17 15:30	79	9/11/17 16:00	24
Hurricane Warning	9/8/17 23:00	9/7/17 9:00	-38	9/9/17 10:00	11	9/10/17 15:30	79	9/11/17 16:00	24
Order release 2	9/9/17 12:00	9/7/17 9:00	-51	9/10/17 9:00	21	9/10/17 15:30	79	9/11/17 16:00	24

5.2 Road Utilization Results

This study focused on the traffic count stations located around the seven analysis regions. Seventy-five traffic count stations were examined and the volume to capacity ratios were obtained. Among these 75 traffic count stations, 28 had speed data during Hurricane Irma. The density was calculated for these 28 traffic count stations and Level of Service (LOS) was obtained. Based on these two analyses (v/c ratio and LOS), two Geographic Information System (GIS) maps are provided in this section to show the road utilization. In this section, the analysis periods are from September 5th, 2017 to September 10th, 2017. Several sample volume to capacity ratio results and density results of traffic count stations are shown in this chapter below. In prior studies, Wolshon (2008) found the volume did not exceed the road's theoretical capacity during evacuation. This section gives several reasons why the volume to capacity is less than 1.0 when the traffic reaches level of service F based on HCM (2016). The x-axis is the hours after the analysis periods start. This section below shows five representative situations. The analysis results of other traffic count stations can be found in Appendix F.

Site 357 (Figure 5.15) is located on Interstate-75 in the Southeast region with hourly traffic volume and average speed data recorded. The volume to capacity ratio result and density result of Westbound traffic are shown in Figure 5.15. The maximum volume to capacity ratio is below the threshold 0.80, suggesting it is below capacity. According to the Highway Capacity Manual (2016) Level of Service category, the maximum level of service of this traffic count station is LOS B. This is one representative situation with a volume to capacity ratio below capacity, potentially because less people used this road segment for the evacuation.

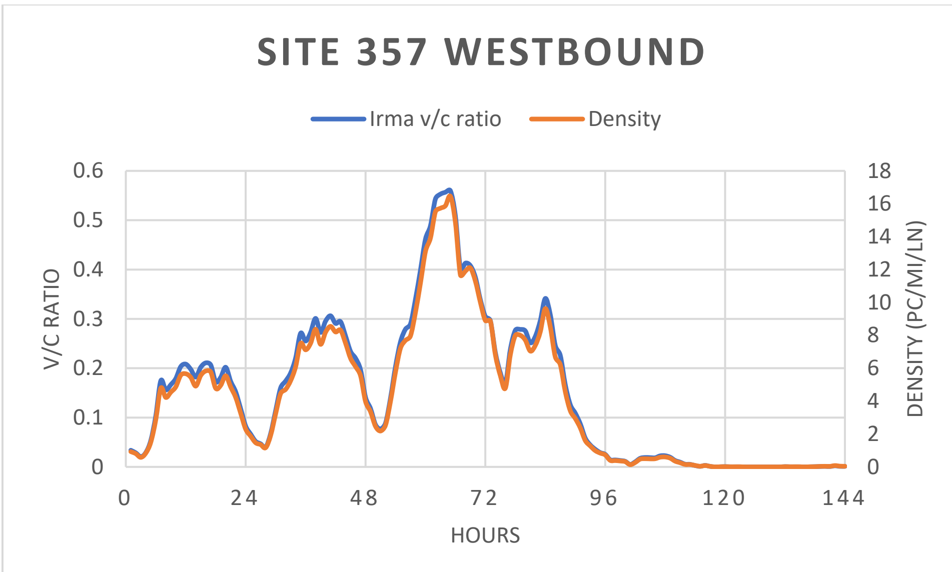

Figure 5-15: v/c ratio and Density result of Site 357

Site 106 is located at Interstate-4 in the Tampa Region and with hourly traffic volume and average speed data recorded. The volume to capacity ratio result and density result of eastbound traffic are shown in Figure 5.16. The results show that there are several times when the volume to capacity ratio is above 0.80 and less than 1.0. According to the Highway Capacity Manual (2016) Level of Service category, the maximum level of service of this traffic count station is LOS D. This is one situation where the road traffic is near its capacity. It indicates that there are many vehicles using this road but the traffic volume is under the road's capacity.

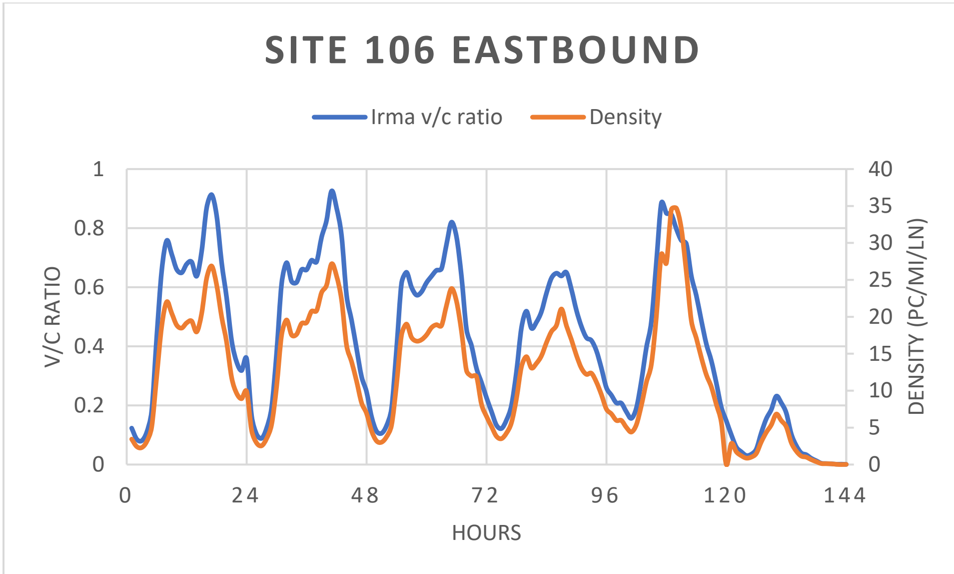

Figure 5-16: v/c ratio and Density result of Site 106

In the following three examples, the volume to capacity ratios are all below 1.0, but the density analysis results show LOS F. This study explores several reasons that may cause this situation.

Figure 5.17 shows the analysis result of Site 217 located on Interstate-1 in the Southeast region. The maximum volume to capacity ratio result is 0.64, which should be viewed as below its capacity. But based on the density analysis result, there are several hours when the level of service reaches LOS F. By checking Google Maps, the current segment has 5 lanes but in a later segment, the number of lanes is reduced to three. This lane reduction situation may cause traffic congestion in the upstream segment and influence the traffic passing the analysis traffic count station. It is one reason that the volume to capacity ratio is lower than 1.0.

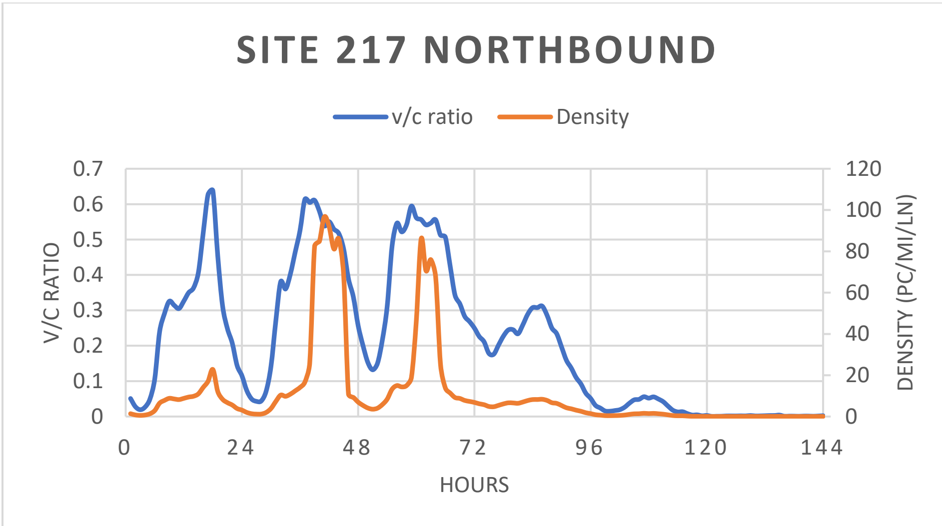

Figure 5-17: v/c ratio and Density result of Site 217

Figure 5.18 shows the analysis result of Site 44 which is located on US Highway 98 in the Hernando region. The volume to capacity result shows that the road is below its capacity while the density analysis result shows that the level of service of this road reaches LOS F in several hours. Checking on the real street situation in Google map, two roads merge into one road just before Site 44. Also, the speed limit is 60 miles/hour before Site 44 while in a later segment, the speed limit is 55 miles/hour. These two reasons, merged roads and speed limit change, may cause congestion in the current segment and the volume to capacity ratio is lower than 1.0.

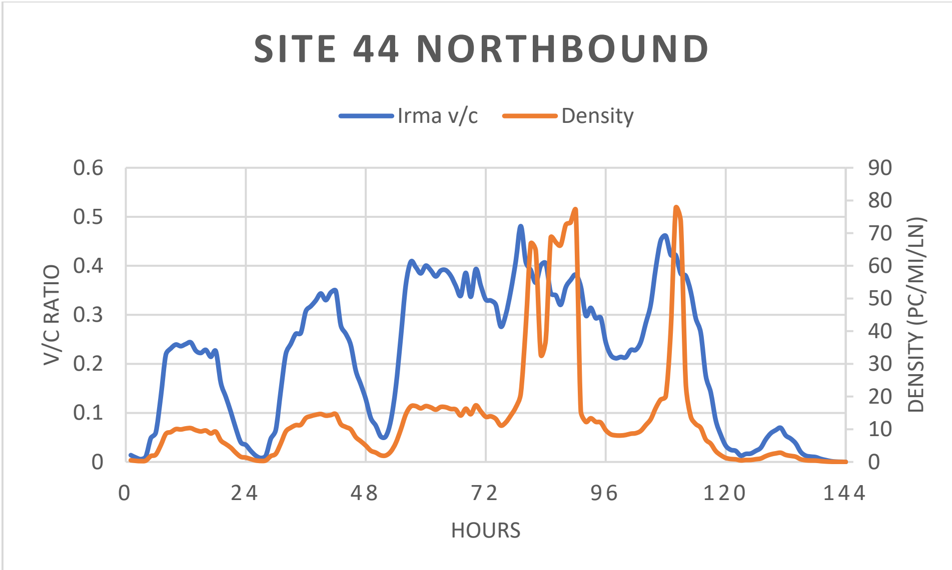

Figure 5-18: v/c ratio and Density result of Site 44

Figure 5.19 shows the analysis result of Site 417 located on SR-91 in the Southeast region. The volume to capacity ratio is less than 1.0 while the density results shows that there are times that level of service research LOS F. Checking on Google Maps, there are no road merges, lane reductions nor speed limit changes in this segment. The volume to capacity ratio lower than 1.0 may simply be due to a lot of traffic using this road and traffic congestion.

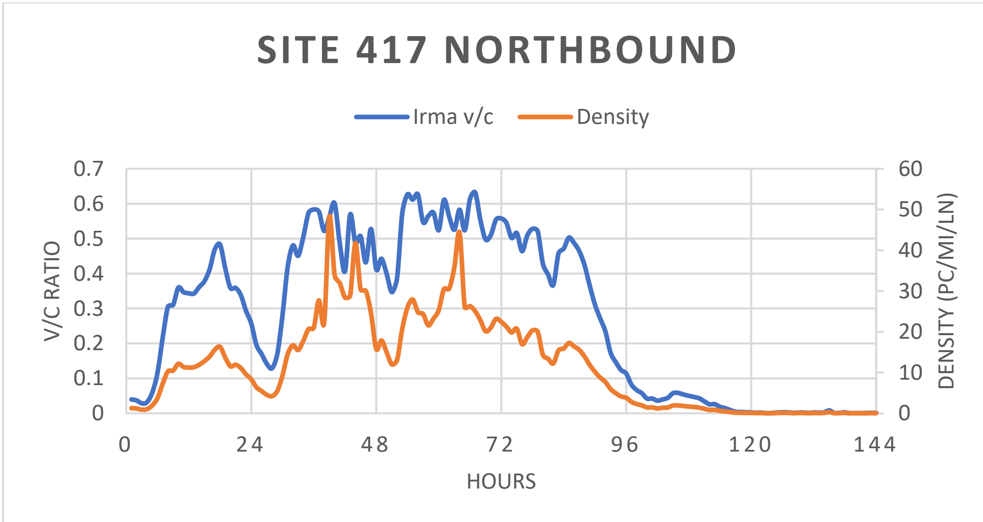

Figure 5-19: v/c ratio and Density result of Site 417

Based on the volume to capacity ratios of all 75 traffic count stations, Figure 5.20 shows the road utilization. It takes the maximum volume to capacity ratio before Sep 10th, 2017 to present in the map. This map shows where the traffic is within the road's capacity, where the traffic is near the road's capacity and where the traffic reaches the road's capacity. Table 5.8 shows the volume to capacity ratio results by road types. There are 75 traffic count stations in the analysis. There are 29 traffic count stations located on the Freeways. 48.28% of them are near capacity. There are 39 traffic count stations located on the Multilane Highways and just 2.56% of them are near capacity. And for the 7 traffic count stations located on the Two-Lane Highways, the traffic on the them are all within capacity.

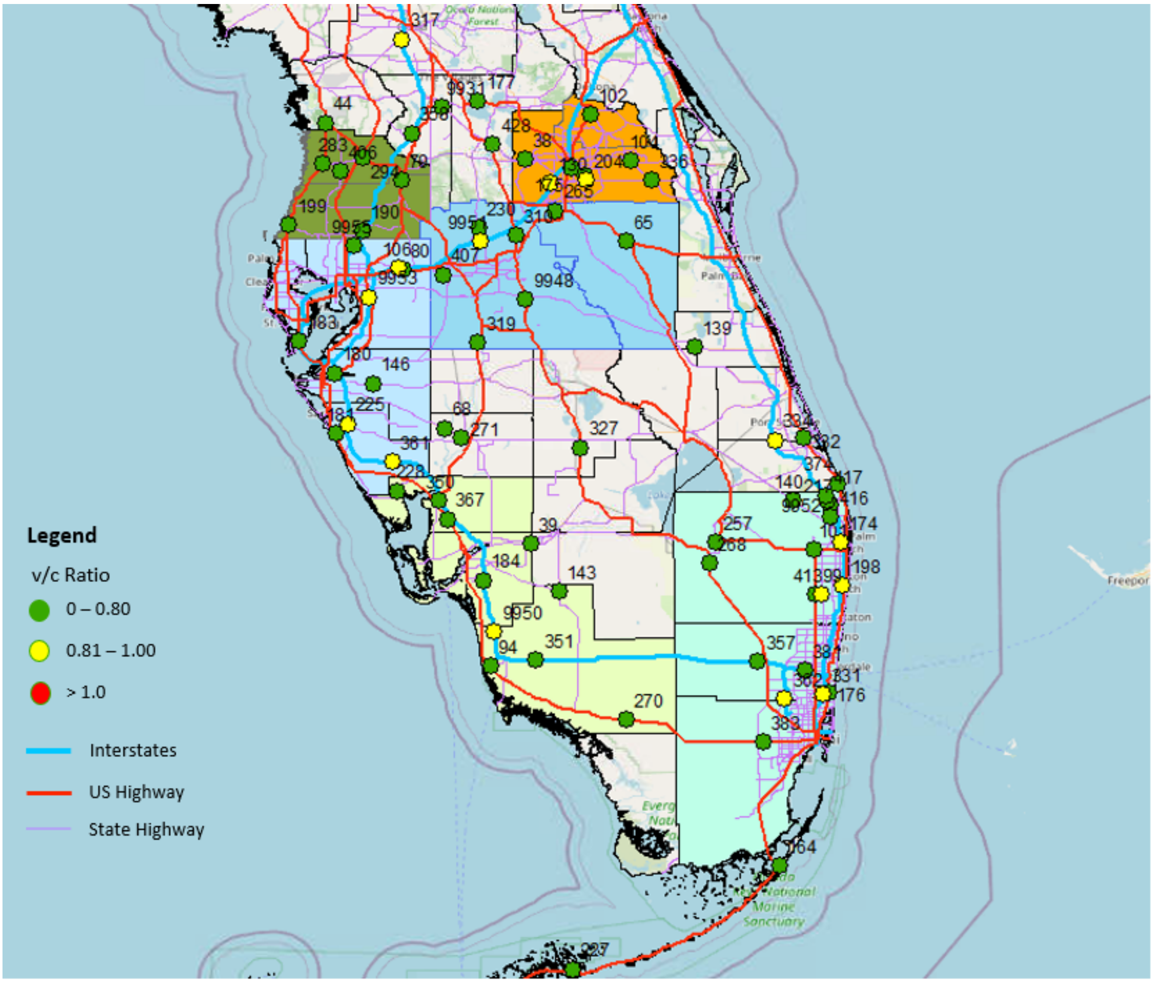

Figure 5-20: Volume to Capacity Geographic Information System (GIS) Map

Table 5-8: Volume to Capacity Analysis Result

v/c Category	v/c Range	Freeways	Percentage	Mutilane Highways	Percentage	Two-lane Highways	Percentage
Within capacity	0 – 0.80	15	51.72%	38	97.44%	7	100%
Near Capacity	0.81 – 1.00	14	48.28%	1	2.56%	0	0
Exceed Capacity	>1.00	0	0.00%	0	0.00%	0	0
Total		29	100%	39	100%	7	100%

Figure 5.21 shows the Level of Service (LOS) Geographic Information System (GIS) Map based on the density analysis results. It takes the maximum density before landfall. Table 5.9 shows the level of service results by road types. There are 28 traffic

count stations in the analysis. For the 16 traffic count stations located on the Freeways, 43.75% of them are LOS F. Among the 11 traffic count stations located on the Multilane Highways, just 18.18% of them are LOS F. Just one traffic count station is located on a Two-Lane highway and it is at a better LOS than F.

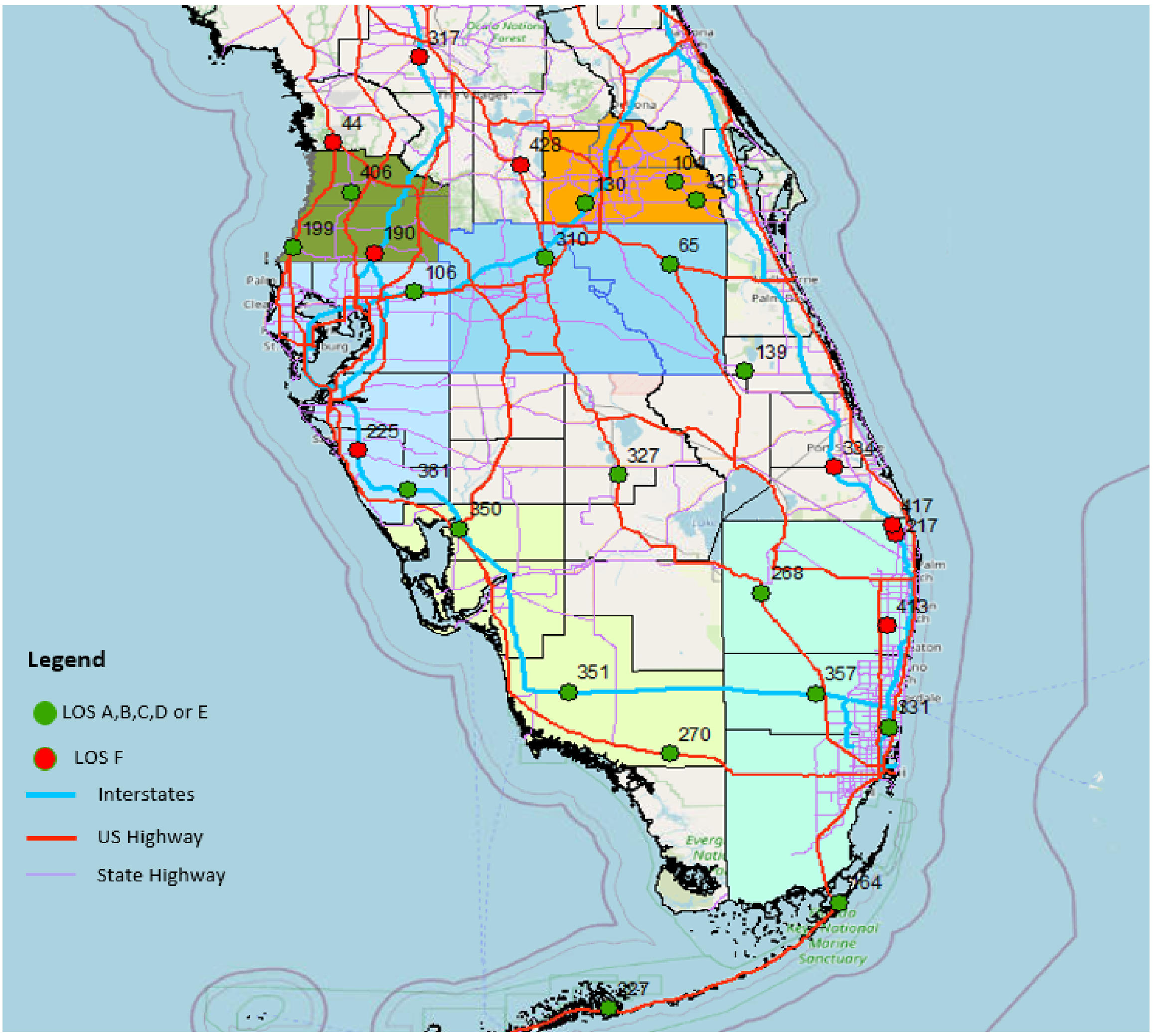

Figure 5-21: Level of Service (LOS) Geographic Information System (GIS) Map

Table 5-9: Level of Service Analysis Result

Utilization Situation	Level of Service	Freeways	Percentage	Mutilane Highways	Percentage	Two-lane Highways	Percentage
Under Capacity	LOS A,B,C,D or E	9	56.25%	9	81.82%	1	100%
Over Capacity	LOS F	7	43.75%	2	18.18%	0	0
Total		16	100%	11	100%	1	100%

Figure 5-22 shows the locations with LOS F during the evacuation for Hurricane Irma and the possible reasons that may cause that. The possible reasons include lane reduction, road merge, and speed limit change. If there are no lane reduction, road merge and speed limit identified, it may be due to the high demand. Based on these results, FDOT could develop strategies to improve the road condition or improve the evacuation plan.

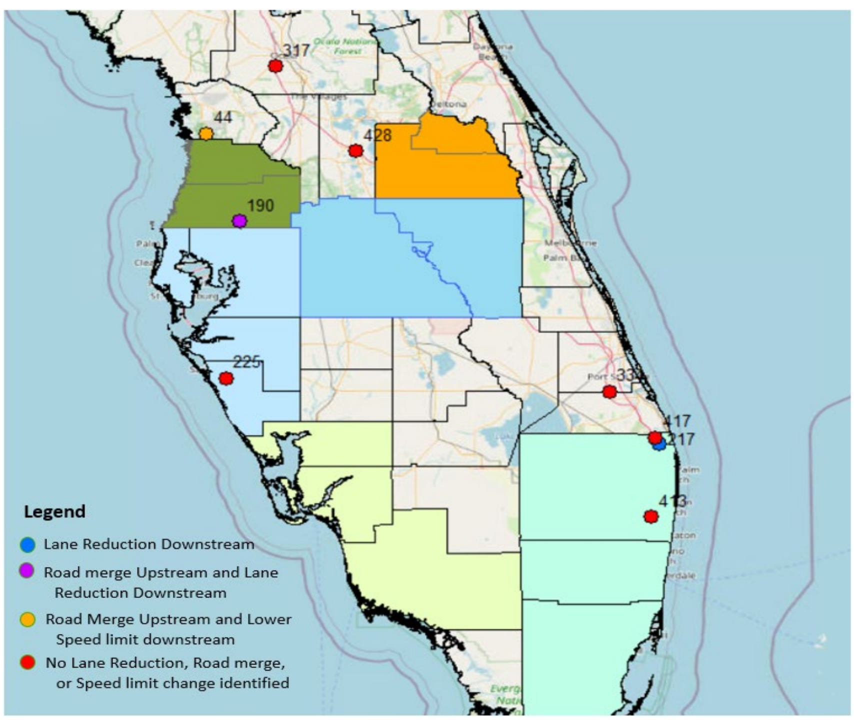

Figure 5-22: Site Location that Traffic Reached Road Capacity and Reasons

Based on the analysis results using two methods, both measures indicate the Freeways are more frequently congested than Multilane highways and Two-lane highways during evacuation. In this study, nearly half of the traffic count stations located on the Freeways were near capacity or over capacity using the two methods' standards. Just a small portion of Multilane highways are near capacity or over capacity. And all the observed Two-lane highways are below capacity or under capacity. Analyzing the volume to capacity ratio and density of different segments across State of Florida together would help FDOT to examine the current traffic systems during evacuation. The GIS maps show the location of roads that could be improved to better serve the evacuation traffic. Also, analyzing the road network utilization situation when evacuation happens would help the government to make improvements on the existing evacuation plan.

Figure 5-23 shows potential alternative/parallel routes near the traffic count stations that reached LOS F. These routes could also be used for evacuation but there is no speed data provided to determine which route is faster or the LOS on these alternate routes. By considering two parallel evacuation roads, if the analysis results shows that one evacuation road is overutilized while another parallel evacuation road is underutilized, the local government could suggest people to use the road that is underutilized. For example, US Highway 41 and Interstate 75 are two parallel evacuation roads for the Marco Island region. US Highway 1 and Interstate 95 are two parallel evacuation roads for the Southeast region. Due to the reason that this study just has speed data for the Interstates 75 and Interstates 95, it is not able to provide conclusive suggestions. To make a better evacuation plan, this research suggests that FDOT should also implement devices to collect the speed data of these routes during evacuation and conduct additional works to compare the performance and travel times on these routes

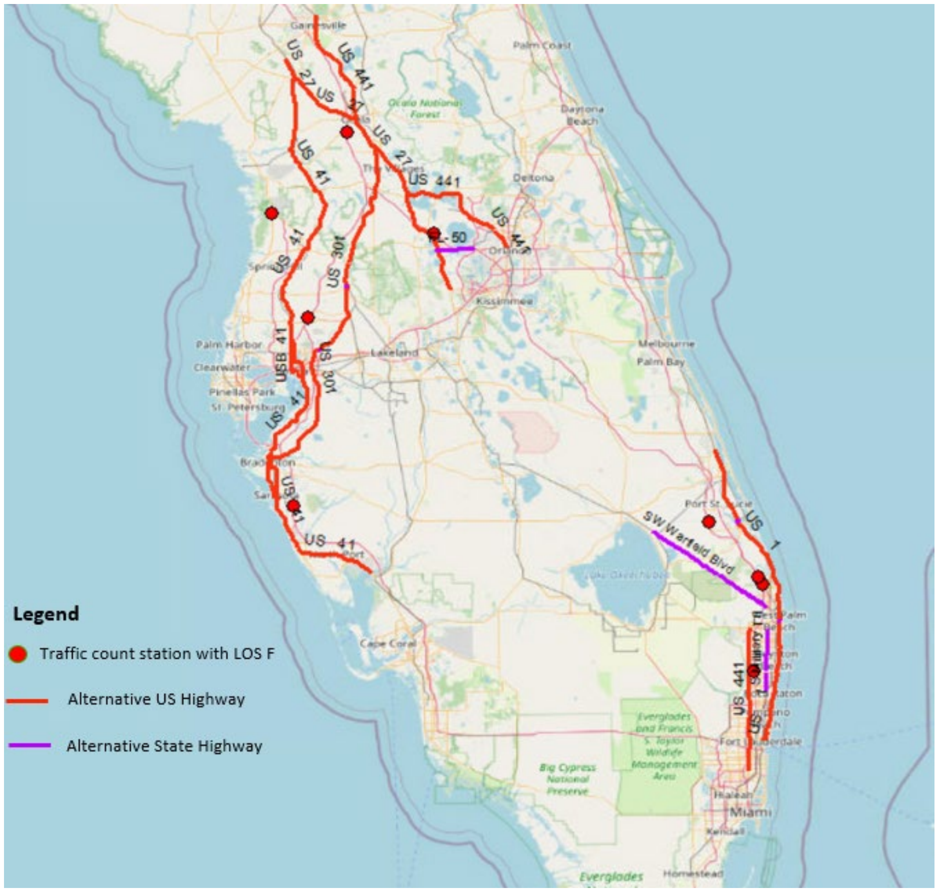

Figure 5-23: Potential Alternative Routes

CHAPTER 6:

CONCLUSION

6.1 Summary

This research used the traffic data, including hourly traffic volume data and speed data, collected across the State of Florida to conduct the roadway traffic analysis during Hurricane Irma in 2017. Seven regions were analyzed, including the Florida Key, Southeast, Marco Island, Tampa, Hernando, Polk and Orlando Regions.

First, this study presented two methods, comparison of cumulative graphs and the Wilcoxon Signed-Rank test, which work together to identify the evacuation start time of each analysis region. The evacuation peak time in each day, the time of the greatest evacuation peak and traffic reentry time of each region were also identified. The relationship of information release time and the evacuation behavior were examined. For the Florida Key and Southeast Regions, the results show that the evacuation started after the evacuation orders were released and the evacuation start time was before the evacuation orders took effect. For the Marco Island, Polk, Hernando and Orlando Regions, the evacuation started even before these regions issued evacuation orders. The analysis results indicated that people based their decisions on information that precedes evacuation orders.

For the seven regions, each of them experienced several evacuation peak hours before Hurricane Irma made landfall. For the Florida Key and Southeast regions, the evacuation peak happened in the evening and afternoon in the early days. Closer to landfall, the evacuation peaks happened in the morning. For the Marco Island region, the evacuation peak happened in the evening in the early days before landfall. One day before landfall, the evacuation peak happened around noon. This region experienced a nighttime evacuation peak on Sep 8th, 2017 after several evacuation orders and notices were issued on Sep 7th, 2017. The evacuation peak time of the Tampa region happened in the morning and noon time before landfall. For the Hernando region, the evacuation peak time happened in the afternoon and evening. The evacuation peak time for the Polk region happened in the afternoon. The evacuation peak time of the Orlando region happened in the morning. For the Florida Keys region, the greatest evacuation peak happened four days before landfall. The highest evacuation peak of the Southeast, Polk and Orlando regions happened 3 days before landfall. Marco Island region's highest evacuation peak happened 2 days before landfall. The greatest evacuation peak of the Tampa and Hernando regions happened 1 day before landfall.

Traffic reentry results showed that people started returning to their homes within 24 hours after Hurricane Irma made landfall. People in the Florida Key region started returning to their homes after 2 days. This delay is due to the damage caused by Hurricane Irma in this area and the local government prohibiting people from returning to this region early.

Second, this research utilized the Highway Capacity Manual 6th edition to examine the volume to capacity ratio of 75 traffic count stations near the seven analysis regions. Among them there were 28 traffic count stations had the speed data, and the densities (Level of Service) were analyzed. The analysis results suggest that Freeways were more frequently congested than Multilane highways and Two-lane highways. Nearly half of the

Freeways were near capacity or over capacity based on the volume to capacity category and reached LOS F. There was just a small fraction of Multilane highway that were near capacity or over capacity. And Two-lane highways were all below capacity or under capacity.

In a prior study, Wolshon (2008) found that the traffic volume did not exceed the road's theoretical capacity during evacuation. This study explored the reasons that may cause the volume to capacity ratio to be less than 1.0 when LOS F was reached. The possible reasons are shown below:

- There was simply a large demand and congestion limited the traffic volume that could pass the traffic count stations.
- Lane reduction in the downstream segment and the congestion in the downstream segment limited the traffic volume that could pass the traffic count stations.
- When several roads merged and there was a speed limit reduction downstream, congestion could happen and limit the traffic volume that passes the traffic count stations.

6.2 Contributions

This research was practice oriented and consistency with prior findings indicates that some of the phenomena previously observed for a single hurricane are transferable to other hurricanes. The transferability of volumes not reaching theoretical capacity, consistent with Wolshon (2008) is an important finding. This suggests that when evacuation time estimates are calculated, the theoretical capacity should only be used with caution as they could be overly optimistic for evacuation conditions. Road utilization results find that the evacuation traffic reached LOS F in several locations during Hurricane Irma even though the volume did not reach the capacity. The locations where evacuation traffic reached LOS F and the possible reasons are provided in Figure 5-22. The reasons, including lane reduction, road merge or speed limit change, may cause traffic congestion. Also, if the public prefers a certain road to evacuate, the traffic congestion could happen.

6.3 Future Directions

This research identified that speed data are important for analyzing road utilization during evacuations. State DOTs could consider collecting speed data through appropriate detectors and/or mobile sensors (or companies providing this data) to determine roadway performance through LOS analysis and travel times. These future analyses could allow emergency managers to make suggestions to the public about alternative/parallel evacuation routes.

APPENDICES

Appendix A

Sample of Hourly Volume from Traffic Count Station 228 during Hurricane Irma

COUNTY	SITE	BEGDATE	DIR	HR1	HR2	HR3	HR4	HR5	HR6
01	0228	08/27/2017 00:00:00	E	40	120	38	23	29	67
01	0228	08/27/2017 00:00:00	W	65	164	54	23	21	63
01	0228	08/28/2017 00:00:00	E	36	22	20	37	80	212
01	0228	08/28/2017 00:00:00	W	37	24	28	23	50	205
01	0228	08/29/2017 00:00:00	E	27	22	23	36	61	220
01	0228	08/29/2017 00:00:00	W	40	24	20	29	66	224
01	0228	08/30/2017 00:00:00	E	31	28	28	36	85	235
01	0228	08/30/2017 00:00:00	W	65	31	22	26	60	203
01	0228	08/31/2017 00:00:00	E	35	20	17	39	68	233
01	0228	08/31/2017 00:00:00	W	48	23	17	32	84	208
01	0228	09/01/2017 00:00:00	E	35	28	27	44	76	209
01	0228	09/01/2017 00:00:00	W	64	35	34	29	71	211
01	0228	09/02/2017 00:00:00	E	76	62	30	21	54	98
01	0228	09/02/2017 00:00:00	W	97	61	38	36	49	105
01	0228	09/03/2017 00:00:00	E	57	51	22	29	28	75
01	0228	09/03/2017 00:00:00	W	96	39	31	31	39	68
01	0228	09/04/2017 00:00:00	E	64	43	30	37	70	97
01	0228	09/04/2017 00:00:00	W	66	41	24	33	56	125
01	0228	09/05/2017 00:00:00	E	43	26	23	44	71	235
01	0228	09/05/2017 00:00:00	W	48	17	28	21	72	234
01	0228	09/06/2017 00:00:00	E	39	25	27	36	87	245
01	0228	09/06/2017 00:00:00	W	42	25	24	29	63	180
01	0228	09/07/2017 00:00:00	E	33	32	33	50	64	192
01	0228	09/07/2017 00:00:00	W	58	33	26	36	67	166
01	0228	09/08/2017 00:00:00	E	44	36	26	25	60	126
01	0228	09/08/2017 00:00:00	W	83	33	28	30	63	154
01	0228	09/09/2017 00:00:00	E	43	26	15	25	23	58
01	0228	09/09/2017 00:00:00	W	35	21	18	16	10	36
01	0228	09/10/2017 00:00:00	E	9	5	1	3	6	14
01	0228	09/10/2017 00:00:00	W	5	1	3	6	4	4

Appendix B

Information of each Region

Table B-1: Information of Florida Key Region

Florida Key		
Information	**Information Time**	**Content**
First National Hurricane(NHC) Report	9/4/17 11:00	Increasing chance Hurricane Irma make landfall on Florida (National Hurricane Center, 2017)
State of Emergency Issued	9/4/17 18:00	Florida Governor declared State of Emergency (CBS NEWS, 2017)
Order Release	9/5/17 11:55	Mandatory evacuation order 1 start at 7:00 am on 9/6/17 for visitors and non-residents Mandatory evacuation order 2 start at 7:00 pm on 9/6/17 for residents (Krietz, 2017)
Hurricane Watch	9/7/17 11:00	Hurricane Watch Issued (National Hurricane Center, 2017)
Hurricane Warning	9/7/17 23:00	Hurricane Warning Issued (National Hurricane Center, 2017)

Table B-2: Information of Southeast Region

Southeast Region		
Information	**Information Time**	**Content**
First National Hurricane(NHC) Report	9/4/17 11:00	Increasing chance Hurricane Irma make landfall on Florida (National Hurricane Center, 2017)
State of Emergency Issued	9/4/17 18:00	Florida Governor declared State of Emergency (CBS NEWS, 2017)
Order release 1	9/6/17 7:15	Miami Dade mandatory evacuations order 1 start at 7:00 am on 09/07/17 (Josephsen,2017 and Miami-Dade County, 2017)
Order release 2	9/6/17 15:00	Broward voluntary start now and mandatory evacuation order 2 start at 12:00 pm on 09/07/17 (Man, 2017)
Hurricane Watch	9/7/17 11:00	Hurricane Watch Issued (National Hurricane Center, 2017)
Order release 3	9/7/17 19:00	Palm beach county mandatory evacuation order 3 start at 10:00 am pm 9/8/17 (Freeman, 2017)
Hurricane Warning	9/7/17 23:00	Hurricane Warning Issued (National Hurricane Center, 2017)

Table B-3: Information of Marco Island Region

Marco Island Region		
Information	**Information Time**	**Content**
First NHC Report	9/4/17 11:00	Increasing chance Hurricane Irma make landfall on Florida (National Hurricane Center, 2017)
State of Emergency	9/4/17 18:00	Florida Governor declared State of Emergency (CBS NEWS, 2017)
Order release 1	9/5/17 17:00	Marco Island voluntary order start immediately (NBC2, 2017)
Hurricane Watch	9/7/17 11:00	Hurricane Watch Issued (National Hurricane Center, 2017)
Order release 2	9/7/17 16:00	Lee county mandatory evacuation order 1 start at 9:30 am on 9/08/17 (Smith, 2017)
Order release 3	9/7/17 17:00	Collier mandatary evacuation order 2 start at 1:00 pm on 9/8/17 (Collier county, 2017)
Hurricane Warning	9/7/17 23:00	Hurricane Warning Issued (National Hurricane Center, 2017)
Order release 4	9/8/17 15:09	Charlotte issued voluntary evacuation order (Winsor, 2017)
Order release 5	9/9/17 8:23	Charlotte issued mandatory evacuation order (The News-Press, 2017)

Table B-4: Information of Tampa Region

Tampa Region		
Information	**Information Time**	**Content**
First NHC Report	9/4/17 11:00	Increasing chance Hurricane Irma make landfall on Florida (National Hurricane Center, 2017)
State of Emergency	9/4/17 18:00	Florida Governor declared State of Emergency (CBS NEWS, 2017)
Order release 3	9/7/17 9:56	Manatee voluntary evacuation order 2 start at 7:00 am on 9/8/17 (Lonon, 2017a)
Order release 2	9/7/17 16:22	Pinellas mandatory evacuation order 2 start at 6:00 am on 9/8/17 (Pinellas county, 2017)
Order release 1	9/7/17 17:53	Hillsborough voluntary evacuation order 1 start at 8:00 am on 9/8/17 (Lonon, 2017b)
Voluntary 1 & Order release 4	9/8/17 8:00	Hillsborough voluntary evacuation order 1 start, Sarasota voluntary evacuation order start immediately (Sarasota county, 2017)
Hurricane Watch	9/8/17 11:00	Hurricane Watch Issued (National Hurricane Center, 2017)
Mandatory start 4 & Order release 5	9/8/17 12:00	Manatee mandatory evacuation order 4 start & Sarasota mandatory evacuation order 5 start at 2:00 pm on 9/8/17 (Lane, 2017& Sarasota county, 2017& Conway, 2017)
Hurricane Warning	9/8/17 23:00	Hurricane Warning Issued (National Hurricane Center, 2017)
Mandatory start 1	9/9/17 8:00	Hillsborough mandatory evacuation order 1 start & Pinellas mandatory evacuation order 3 start (Tampa Bay Times, 2017)

Table B-5: Information of Hernando Region

Hernando Region		
Information	**Information Time**	**Content**
First NHC Report	9/4/17 11:00	Increasing chance Hurricane Irma make landfall on Florida (National Hurricane Center, 2017)
State of Emergency	9/4/17 18:00	Florida Governor declared State of Emergency (CBS NEWS, 2017)
Order release 1	9/7/17 16:38	Pasco voluntary evacuation start (Pasco county, 2017a)
Mandatory start 1&3	9/8/17 8:00	Pasco and Hernando mandatory evacuation order 1&3 start (Pasco county,2017b and Waters, 2017)
Hurricane Watch	9/8/17 17:00	Hurricane Watch Issued (National Hurricane Center, 2017)
Hurricane Warning	9/9/17 5:00	Hurricane Warning Issued (National Hurricane Center, 2017)
Order release 2	9/9/17 14:26	Pasco mandatory evacuation order 2 expand start at 1:00 pm on 9/9/17 (Pasco county, 2017c)

Table B-6: Information of Polk Region

Polk Region		
Information	**Information Time**	**Content**
First NHC Report	9/4/17 11:00	Increasing chance Hurricane Irma make landfall on Florida
State of Emergency	9/4/17 18:00	Florida Governor declared State of Emergency
Order release 1	9/8/17 8:58	Polk voluntary evacuation (Lonon, 2017d)
Hurricane Watch	9/8/17 11:00	Hurricane Watch Issued (National Hurricane Center, 2017)
Order release 2	9/8/17 16:00	Osceola voluntary start (Osceola County, 2017)
Hurricane Warning	9/8/17 23:00	Hurricane Warning Issued (National Hurricane Center, 2017)
Mandatory start 1	9/9/17 8:03	Polk mandatory evacuation start (Lonon, 2017c)

Table B-7: Information of Orlando Region

Orlando Region		
Information	**Information Time**	**Content**
First NHC Report	9/4/17 11:00	Increasing chance Hurricane Irma make landfall on Florida (National Hurricane Center, 2017)
State of Emergency	9/4/17 18:00	Florida Governor declared State of Emergency (CBS NEWS, 2017)
Hurricane Watch	9/8/17 11:00	Hurricane Watch Issued (National Hurricane Center, 2017)
Order release 1	9/8/17 17:35	Orange mandatory evacuation start (Lemongello, 2017)
Hurricane Warning	9/8/17 23:00	Hurricane Warning Issued (National Hurricane Center, 2017)
Order release 2	9/9/17 12:00	Seminole mandatory start immediately (Waters, 2017)

Appendix C

Sample of Combined Hourly Volume Data of Traffic Count Station 217

ID	FID	COUNTY	SITE	BEGDATE	MONTH	DAY	YEAR	Weekday	DIR	Hour	CURVOL	HAVGVOL	CURAVSPD	LATITUDE	LNGITUDE	ROUTE
16723	16723	93	217	42983	9	5	2017	Tue	N	1	460	434.3333	76	26.89359	-80.1343	I 95
34763	34763	93	217	42983	9	5	2017	Tue	N	2	252	252	74	26.89359	-80.1343	I 95
52803	52803	93	217	42983	9	5	2017	Tue	N	3	175	209	73	26.89359	-80.1343	I 95
70843	70843	93	217	42983	9	5	2017	Tue	N	4	242	242.3333	75	26.89359	-80.1343	I 95
88883	88883	93	217	42983	9	5	2017	Tue	N	5	445	413.6667	75	26.89359	-80.1343	I 95
106923	106923	93	217	42983	9	5	2017	Tue	N	6	962	854	76	26.89359	-80.1343	I 95
124963	124963	93	217	42983	9	5	2017	Tue	N	7	2162	2178.667	76	26.89359	-80.1343	I 95
143003	143003	93	217	42983	9	5	2017	Tue	N	8	2625	3080	76	26.89359	-80.1343	I 95
161043	161043	93	217	42983	9	5	2017	Tue	N	9	2943	2846.333	76	26.89359	-80.1343	I 95
179083	179083	93	217	42983	9	5	2017	Tue	N	10	2841	2627	76	26.89359	-80.1343	I 95
197123	197123	93	217	42983	9	5	2017	Tue	N	11	2756	2707.667	76	26.89359	-80.1343	I 95
215163	215163	93	217	42983	9	5	2017	Tue	N	12	2947	2721	76	26.89359	-80.1343	I 95
233203	233203	93	217	42983	9	5	2017	Tue	N	13	3162	2991.667	76	26.89359	-80.1343	I 95
251243	251243	93	217	42983	9	5	2017	Tue	N	14	3281	3144.667	76	26.89359	-80.1343	I 95
269283	269283	93	217	42983	9	5	2017	Tue	N	15	3669	3678	76	26.89359	-80.1343	I 95
287323	287323	93	217	42983	9	5	2017	Tue	N	16	4680	4676.333	76	26.89359	-80.1343	I 95
305363	305363	93	217	42983	9	5	2017	Tue	N	17	5665	5983	76	26.89359	-80.1343	I 95
323403	323403	93	217	42983	9	5	2017	Tue	N	18	5764	6353.667	58	26.89359	-80.1343	I 95
341443	341443	93	217	42983	9	5	2017	Tue	N	19	4112	4015.333	77	26.89359	-80.1343	I 95
359483	359483	93	217	42983	9	5	2017	Tue	N	20	2828	2593.333	77	26.89359	-80.1343	I 95
377523	377523	93	217	42983	9	5	2017	Tue	N	21	2246	2064	76	26.89359	-80.1343	I 95
395563	395563	93	217	42983	9	5	2017	Tue	N	22	1876	1607	76	26.89359	-80.1343	I 95
413603	413603	93	217	42983	9	5	2017	Tue	N	23	1304	1046.333	76	26.89359	-80.1343	I 95
431643	431643	93	217	42983	9	5	2017	Tue	N	24	1042	702	76	26.89359	-80.1343	I 95
16725	16725	93	217	42984	9	6	2017	Wed	N	1	664	497.5	76	26.89359	-80.1343	I 95
34765	34765	93	217	42984	9	6	2017	Wed	N	2	449	280.75	75	26.89359	-80.1343	I 95
52805	52805	93	217	42984	9	6	2017	Wed	N	3	388	207	75	26.89359	-80.1343	I 95
70845	70845	93	217	42984	9	6	2017	Wed	N	4	398	240.75	75	26.89359	-80.1343	I 95
88885	88885	93	217	42984	9	6	2017	Wed	N	5	647	413.25	74	26.89359	-80.1343	I 95
106925	106925	93	217	42984	9	6	2017	Wed	N	6	1282	839	75	26.89359	-80.1343	I 95
124965	124965	93	217	42984	9	6	2017	Wed	N	7	2442	2139.75	76	26.89359	-80.1343	I 95
143005	143005	93	217	42984	9	6	2017	Wed	N	8	3440	3161.75	75	26.89359	-80.1343	I 95
161045	161045	93	217	42984	9	6	2017	Wed	N	9	3255	2967.75	76	26.89359	-80.1343	I 95
179085	179085	93	217	42984	9	6	2017	Wed	N	10	3636	2641.75	76	26.89359	-80.1343	I 95
197125	197125	93	217	42984	9	6	2017	Wed	N	11	4197	2751.5	77	26.89359	-80.1343	I 95
215165	215165	93	217	42984	9	6	2017	Wed	N	12	4751	2843.75	77	26.89359	-80.1343	I 95
233205	233205	93	217	42984	9	6	2017	Wed	N	13	5544	2967.75	76	26.89359	-80.1343	I 95
251245	251245	93	217	42984	9	6	2017	Wed	N	14	5463	3210	48	26.89359	-80.1343	I 95
269285	269285	93	217	42984	9	6	2017	Wed	N	15	5520	3671.25	15	26.89359	-80.1343	I 95
287325	287325	93	217	42984	9	6	2017	Wed	N	16	5242	4685.5	14	26.89359	-80.1343	I 95
305365	305365	93	217	42984	9	6	2017	Wed	N	17	4868	5993.25	11	26.89359	-80.1343	I 95
323405	323405	93	217	42984	9	6	2017	Wed	N	18	4975	6102.5	12	26.89359	-80.1343	I 95
341445	341445	93	217	42984	9	6	2017	Wed	N	19	4783	4026	13	26.89359	-80.1343	I 95
359485	359485	93	217	42984	9	6	2017	Wed	N	20	4672	2692	12	26.89359	-80.1343	I 95
377525	377525	93	217	42984	9	6	2017	Wed	N	21	4278	2161.75	14	26.89359	-80.1343	I 95
395565	395565	93	217	42984	9	6	2017	Wed	N	22	3514	1701.5	73	26.89359	-80.1343	I 95
413605	413605	93	217	42984	9	6	2017	Wed	N	23	3057	1106.5	75	26.89359	-80.1343	I 95
431645	431645	93	217	42984	9	6	2017	Wed	N	24	2320	706.75	76	26.89359	-80.1343	I 95

* CURVOL: Traffic data during Hurricane Irma
* HAVGVOL: Traffic data in 2018
* CURAVSPD: Average traffic speed data during Hurricane Irma

Appendix D

Traffic Count Stations Selected for Each Analysis Region

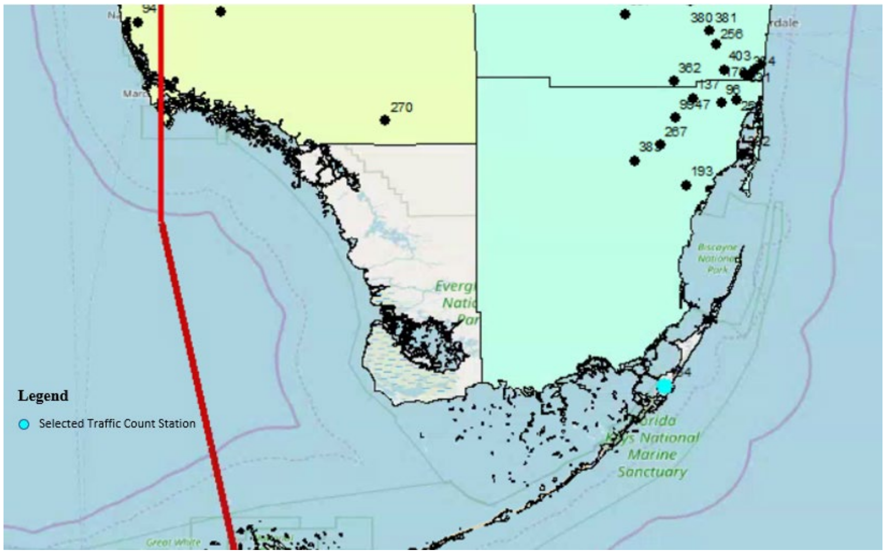

Figure D-1: Traffic Count Station for Florida Key Region

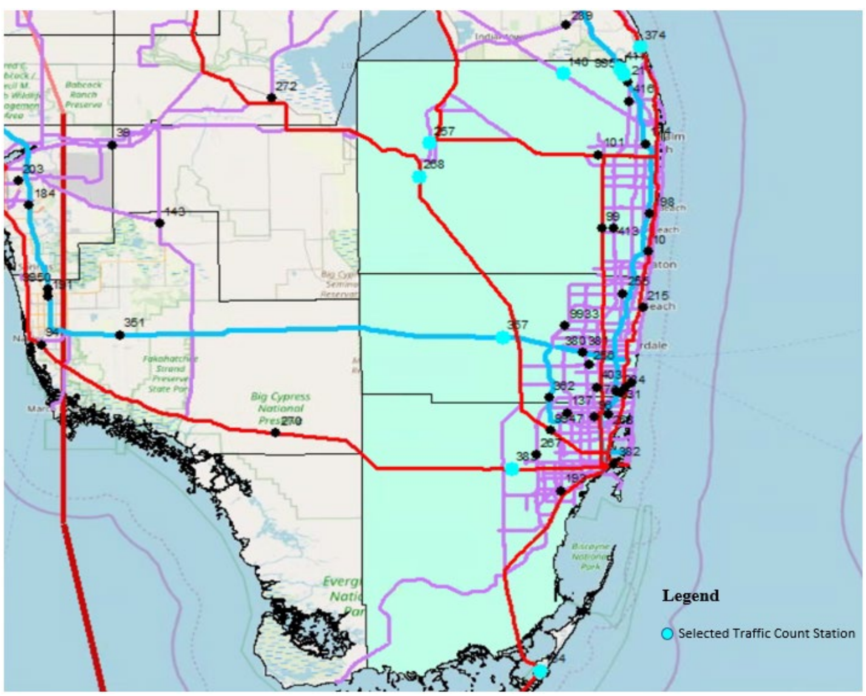

Figure D-2: Traffic Count Stations for Southeast Region

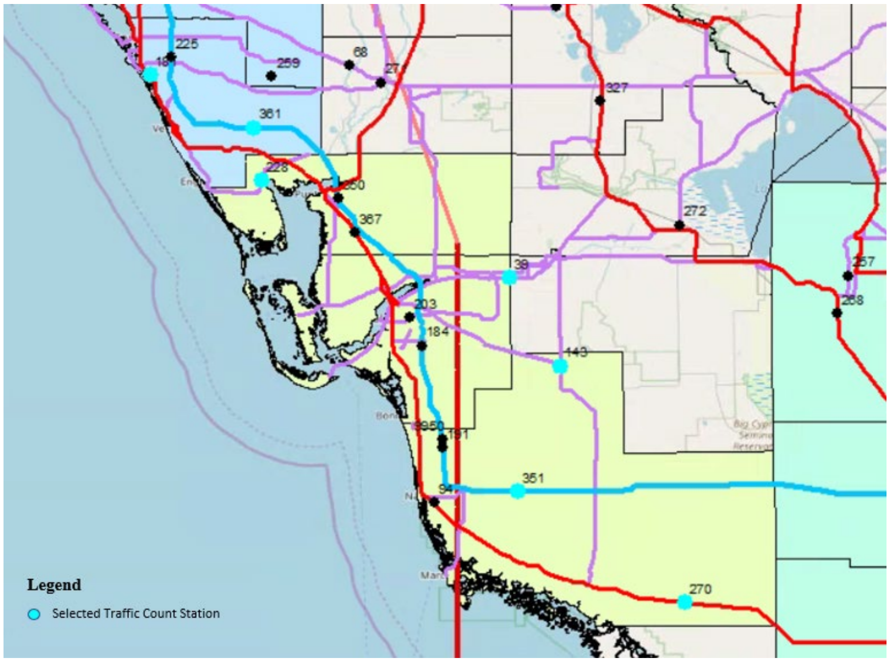

Figure D-3: Traffic Count Stations for Marco Island Region

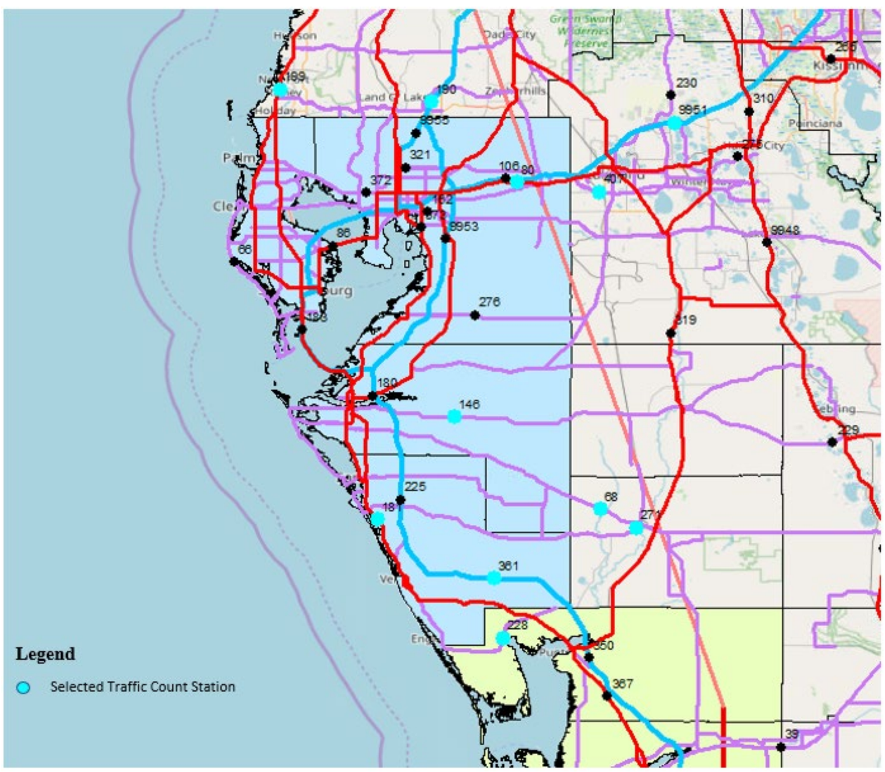

Figure D-4: Traffic Count Stations for Tampa Region

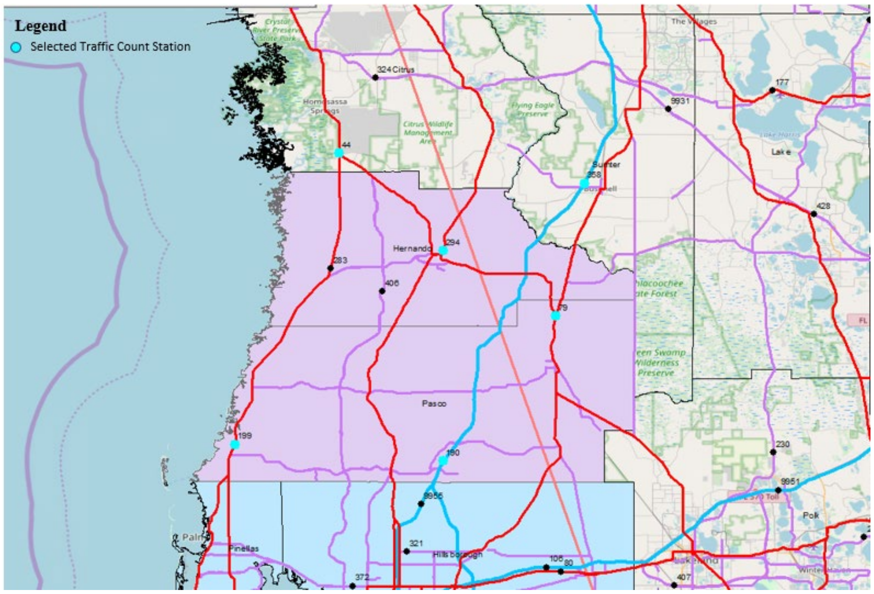

Figure D-5: Traffic Count Stations for Hernando Region

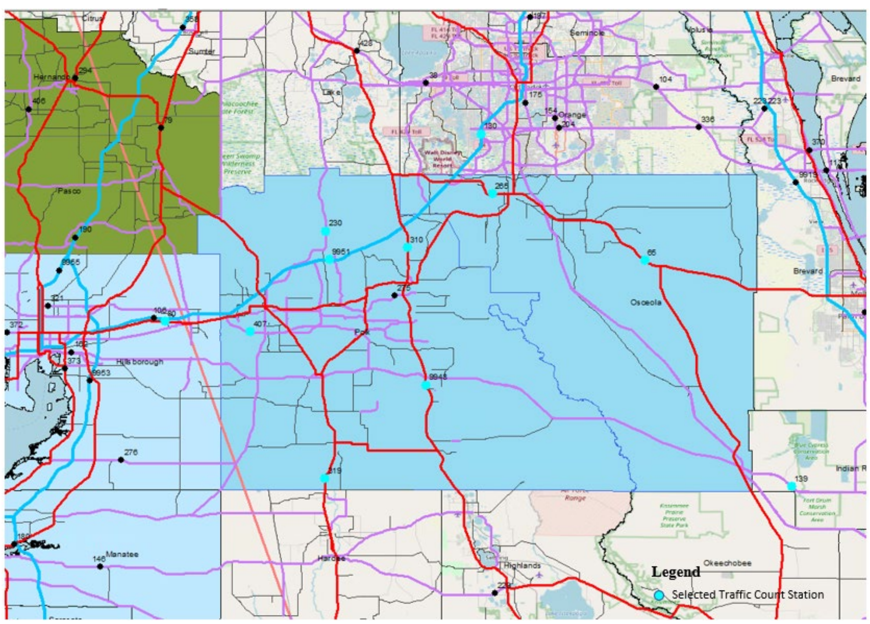

Figure D-6: Traffic Count Stations for Polk Region

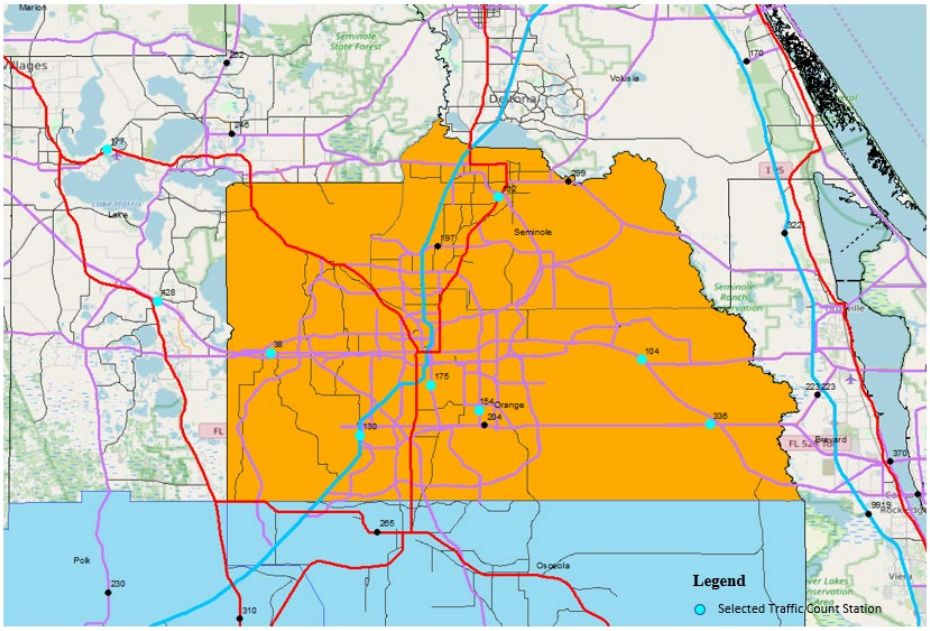

Figure D-7: Traffic Count Stations for Orlando Region

Appendix E

Wilcoxon Signed-Rank Test Result of Each Region

Table E-1: Wilcoxon Signed-Rank Test Result of Southeast Region

9/5/2017	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	p-value	0.012	0.008	0.139	0.051	0.953	0.110	0.214	0.260	0.594	0.859	0.594	0.767	0.441	0.953	0.953	0.953	0.767	0.173	0.515	0.678	0.139	0.441	0.735	0.515
9/6/2017	Hour	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	p-value	0.594	0.594	0.214	0.678	0.214	0.139	0.139	0.110	0.374	0.374	0.066	0.214	0.139	0.066	0.110	0.139	0.314	0.314	0.066	0.110	0.086	0.038	0.086	0.051
9/7/2017	Hour	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
	p-value	0.260	0.066	0.086	0.123	0.086	0.066	0.086	0.066	0.086	0.086	0.066	0.051	0.038	0.066	0.051	0.021	0.038	0.051	0.028	0.028	0.028	0.028	0.028	0.086
9/8/2017	Hour	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
	p-value	0.051	0.051	0.086	0.038	0.066	0.038	0.086	0.066	0.051	0.066	0.066	0.066	0.066	0.066	0.374	0.767	0.110	0.173	0.066	0.015	0.066	0.110	0.066	0.214
9/9/2017	Hour	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	p-value	0.138	0.173	0.953	0.678	0.953	0.441	0.260	0.086	0.110	0.214	0.086	0.051	0.021	0.008	0.015	0.066	0.441	0.594	0.374	0.086	0.173	0.594	0.086	0.314
9/10/2017	Hour	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
	p-value	0.314	0.575	0.594	0.515	0.678	0.038	0.515	0.051	0.066	0.110	0.260	0.859	0.314	0.214	0.139	0.139	0.110	0.110	0.110	0.066	0.086	0.038	0.028	0.139

Table E-2: Wilcoxon Signed-Rank Test Result of Marco Island Region

9/5/2017	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	p-value	0.400	0.128	0.672	0.866	0.173	0.176	0.866	1.000	0.310	0.310	0.310	0.043	0.446	0.043	0.735	0.398	1.000	0.237	0.866	0.499	0.612	0.735	0.400	0.917
9/6/2017	Hour	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	p-value	0.735	0.398	0.612	0.553	0.237	0.866	0.499	0.735	0.128	0.310	0.237	0.398	0.310	0.310	0.237	0.176	0.735	0.310	0.735	0.499	0.866	0.866	0.735	0.735
9/7/2017	Hour	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
	p-value	0.735	0.612	0.866	0.866	0.735	0.866	0.237	0.735	0.499	0.499	0.499	0.499	0.735	0.398	0.866	0.866	0.735	0.735	0.735	0.735	1.000	0.866	0.866	0.612
9/8/2017	Hour	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
	p-value	0.735	0.735	0.735	0.735	1.000	0.866	0.866	0.866	0.866	0.866	1.000	0.866	0.735	0.866	0.735	0.612	1.000	1.000	0.176	0.091	0.091	0.091	0.237	0.128
9/9/2017	Hour	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	p-value	0.063	0.063	0.310	0.116	0.499	0.237	0.398	0.866	0.866	0.176	0.310	0.176	0.116	0.063	0.063	0.043	0.043	0.128	0.237	0.237	0.310	0.237	0.173	0.176
9/10/2017	Hour	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
	p-value	0.310	0.398	0.500	0.866	0.553	0.091	0.173	0.310	0.398	0.237	0.398	1.000	0.398	0.204	1.000	0.237	0.397	0.398	0.398	0.128	0.128	0.237	0.128	0.398

Table E-3: Wilcoxon Signed-Rank Test Result of Tampa Region

9/5/2017	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	p-value	0.041	0.333	0.262	0.333	0.241	0.799	0.241	0.475	0.878	0.959	0.241	0.445	0.959	0.059	0.203	0.646	0.059	0.037	0.139	0.386	0.594	0.575	0.646	0.575
9/6/2017	Hour	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	p-value	0.386	0.575	0.959	0.799	0.445	0.241	0.203	0.646	0.241	0.508	0.721	0.445	0.333	0.575	0.721	0.799	0.575	0.575	0.721	0.721	0.646	0.878	0.959	0.959
9/7/2017	Hour	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
	p-value	0.646	0.878	0.333	0.721	0.799	0.114	0.333	0.139	0.799	0.646	0.445	0.508	0.721	0.959	0.959	0.285	0.262	0.760	0.508	0.386	0.445	0.575	0.959	0.959
9/8/2017	Hour	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
	p-value	0.878	0.878	0.799	0.878	0.799	0.262	0.047	0.114	0.114	0.059	0.959	0.721	0.721	0.959	0.799	0.799	0.878	0.575	0.959	0.386	0.575	0.575	0.799	0.959
9/9/2017	Hour	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	p-value	0.575	0.445	0.445	0.285	0.139	0.047	0.037	0.005	0.005	0.028	0.037	0.047	0.059	0.093	0.093	0.139	0.169	0.093	0.059	0.203	0.114	0.203	0.333	0.959
9/10/2017	Hour	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
	p-value	0.646	0.646	0.721	0.285	0.646	0.028	0.007	0.007	0.022	0.017	0.028	0.037	0.093	0.153	0.333	0.445	0.386	0.241	0.646	0.575	0.445	0.575	0.878	0.799

Table E-4: Wilcoxon Signed-Rank Test Result of Hernando Region

9/5/2017	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	p-value	0.917	0.600	0.345	0.753	0.753	0.917	0.753	0.075	0.463	0.116	0.600	0.463	0.345	0.345	0.249	0.345	0.345	0.028	0.028	0.753	0.249	0.600	0.917	0.345
9/6/2017	Hour	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	p-value	0.674	0.345	0.463	0.463	0.753	0.917	0.753	0.600	0.600	0.753	0.917	0.345	0.463	0.463	0.463	0.463	0.173	0.116	0.463	0.463	0.463	0.463	0.345	0.463
9/7/2017	Hour	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
	p-value	0.463	0.463	0.463	0.753	0.753	0.753	0.753	0.463	0.600	0.463	0.600	0.600	0.600	0.463	0.463	0.463	0.249	0.249	0.600	0.463	0.753	0.600	0.753	0.753
9/8/2017	Hour	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
	p-value	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.753	0.917	0.917	0.463	0.463	0.345	0.345	0.463	0.345	0.463	0.600	0.345
9/9/2017	Hour	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	p-value	0.600	0.753	0.600	0.600	0.600	0.600	0.753	0.600	0.753	0.753	0.753	0.600	0.600	0.600	0.345	0.345	0.345	0.463	0.600	0.600	0.600	0.753	0.917	0.345
9/10/2017	Hour	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
	p-value	0.600	0.463	0.249	0.116	0.917	0.600	0.600	0.463	0.753	0.600	0.600	0.917	0.917	0.600	0.753	0.753	0.600	0.463	0.917	0.917	0.528	0.345	0.600	0.600

Table E-5: Wilcoxon Signed-Rank Test Result of Polk Region

9/5/2017	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	p-value	0.929	0.424	0.534	0.534	0.374	0.213	0.182	1.000	0.374	0.859	0.722	0.328	0.424	0.374	0.062	0.424	0.033	0.657	0.859	0.248	0.722	0.722	0.859	0.722
9/6/2017	Hour	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	p-value	0.424	0.657	0.248	0.306	0.929	0.424	0.859	0.575	0.534	0.594	0.594	0.328	0.722	0.929	0.929	0.534	0.722	0.594	0.594	0.722	0.929	1.000	0.657	0.790
9/7/2017	Hour	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
	p-value	0.722	0.534	0.534	0.657	0.859	0.328	0.534	1.000	0.477	0.790	0.594	0.790	0.594	0.790	0.477	0.286	0.248	0.477	0.424	0.328	0.424	0.534	0.790	0.722
9/8/2017	Hour	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
	p-value	0.722	0.657	0.790	0.722	0.657	0.722	0.722	0.859	0.657	1.000	0.424	0.477	0.534	0.374	0.594	0.722	0.477	1.000	0.722	0.722	0.859	0.859	0.790	0.790
9/9/2017	Hour	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	p-value	0.594	0.859	0.790	0.790	0.374	0.182	0.213	0.286	0.328	0.424	0.477	1.000	0.534	0.424	0.477	0.790	0.929	0.859	0.929	0.594	0.594	0.424	0.929	0.534
9/10/2017	Hour	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
	p-value	0.594	0.594	0.657	0.657	0.248	0.477	0.424	0.374	0.424	0.075	0.075	0.026	0.010	0.075	0.008	0.286	0.790	0.790	0.722	0.477	1.000	0.328	0.929	0.722

Table E-6: Wilcoxon Signed-Rank Test Result of Orlando Region

9/5/2017	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	p-value	0.208	0.025	0.735	1.000	0.401	0.327	0.093	0.779	1.000	0.889	0.327	0.674	0.779	0.400	0.069	0.401	0.674	0.050	0.327	1.000	0.036	0.674	0.674	0.575
9/6/2017	Hour	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
	p-value	0.674	0.889	1.000	0.484	0.208	0.327	0.674	0.327	0.208	0.484	0.779	0.889	0.161	0.441	0.327	0.575	0.484	0.484	0.575	0.889	0.484	0.575	0.484	0.401
9/7/2017	Hour	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
	p-value	0.575	0.327	0.484	0.889	0.575	0.889	1.000	0.161	0.050	0.263	0.779	0.779	0.779	0.484	0.674	0.674	0.674	0.889	0.674	0.779	0.575	0.779	0.779	0.889
9/8/2017	Hour	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
	p-value	0.575	1.000	0.575	0.779	1.000	0.674	0.779	0.263	0.401	0.889	0.575	0.889	0.779	0.674	0.889	1.000	0.889	1.000	0.575	1.000	0.889	0.093	0.123	0.263
9/9/2017	Hour	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
	p-value	0.575	0.161	0.674	0.050	0.484	1.000	0.779	0.401	0.161	0.123	0.779	0.674	0.327	0.674	0.263	1.000	0.674	0.779	0.575	0.327	0.069	0.093	0.093	0.093
9/10/2017	Hour	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
	p-value	0.263	0.327	0.161	0.036	1.000	0.735	0.484	0.484	0.327	0.263	0.779	0.779	0.779	0.889	0.674	0.575	0.674	1.000	0.889	0.484	0.484	0.401	0.327	0.161

* p-value less than 0.1 are marked in red color

Appendix F

Road Network Utilization Analysis Results

Traffic Count Stations with Speed data

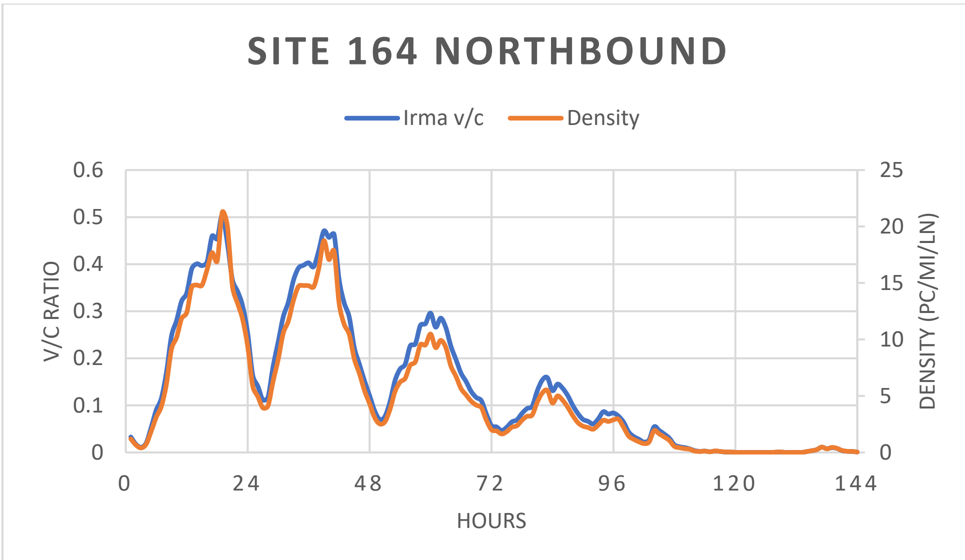

Figure F-1: v/c ratio and Density result of Site 164

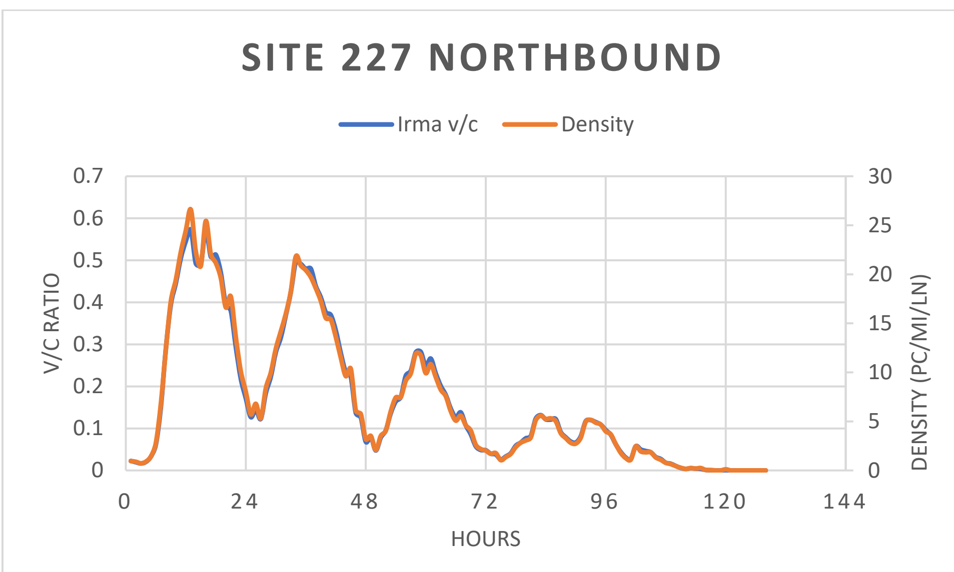

Figure F-2: v/c ratio and Density result of Site 227

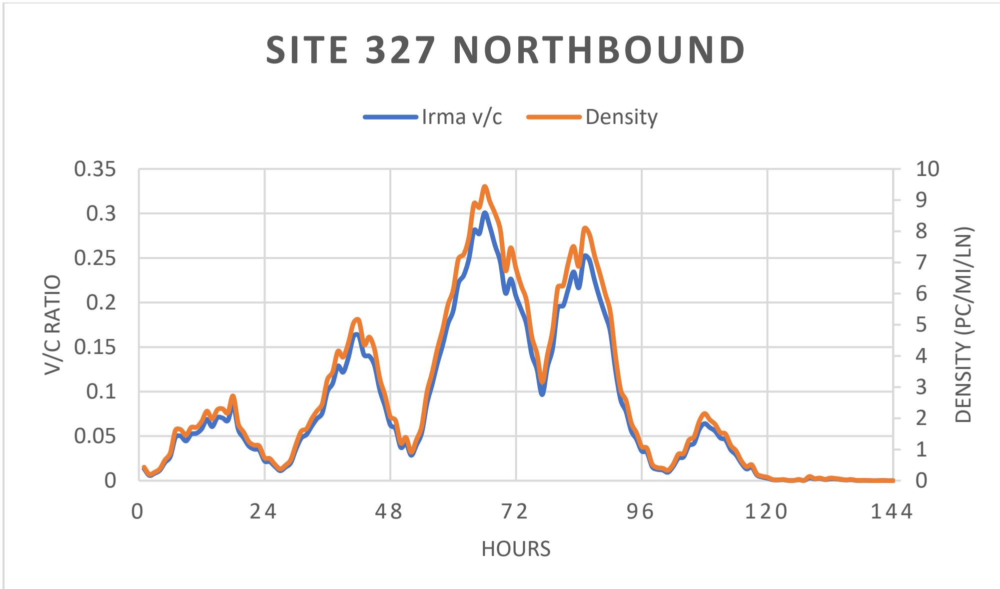

Figure F-3: v/c ratio and Density result of Site 327

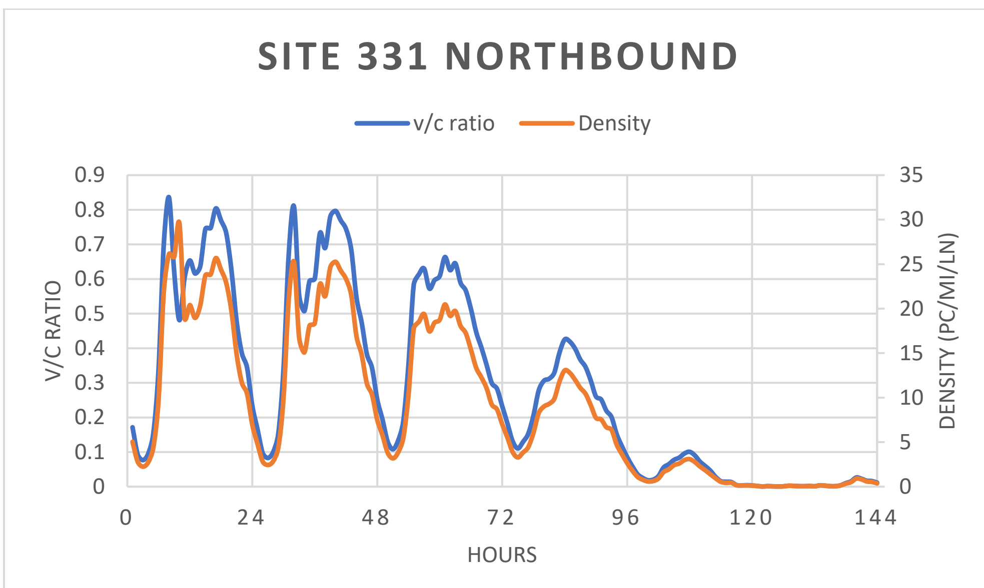

Figure F-4: v/c ratio and Density result of Site 331

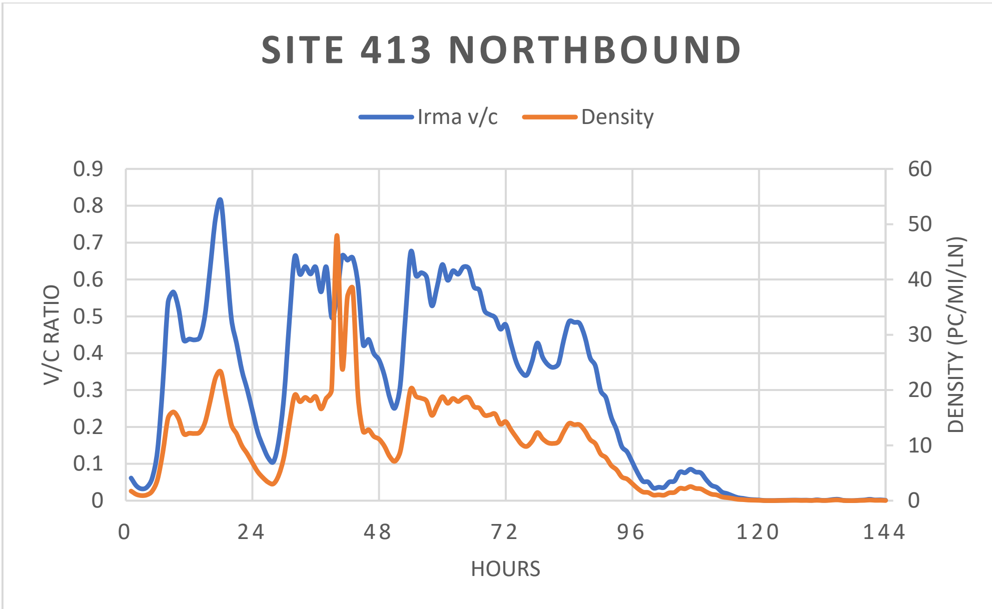

Figure F-5: v/c ratio and Density result of Site 413

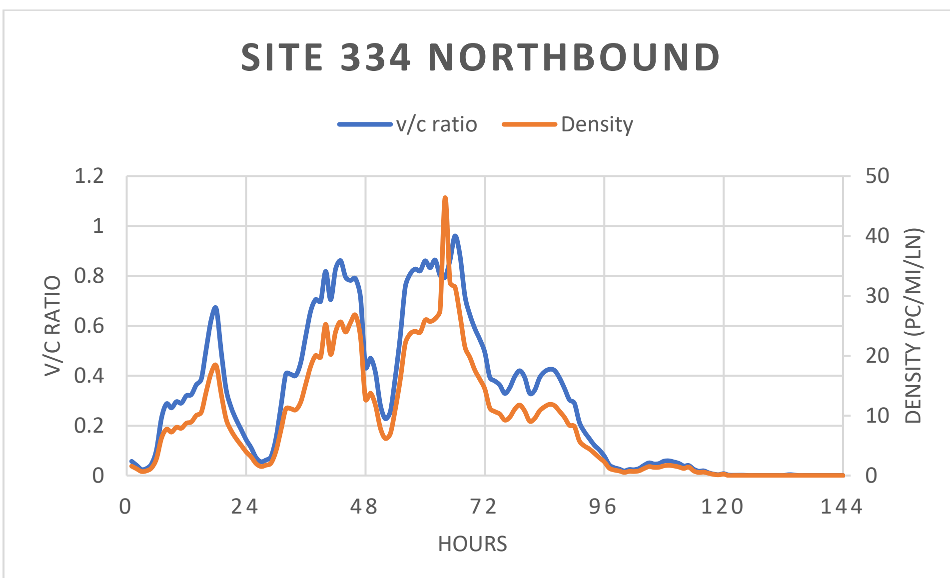

Figure F-6: v/c ratio and Density result of Site 334

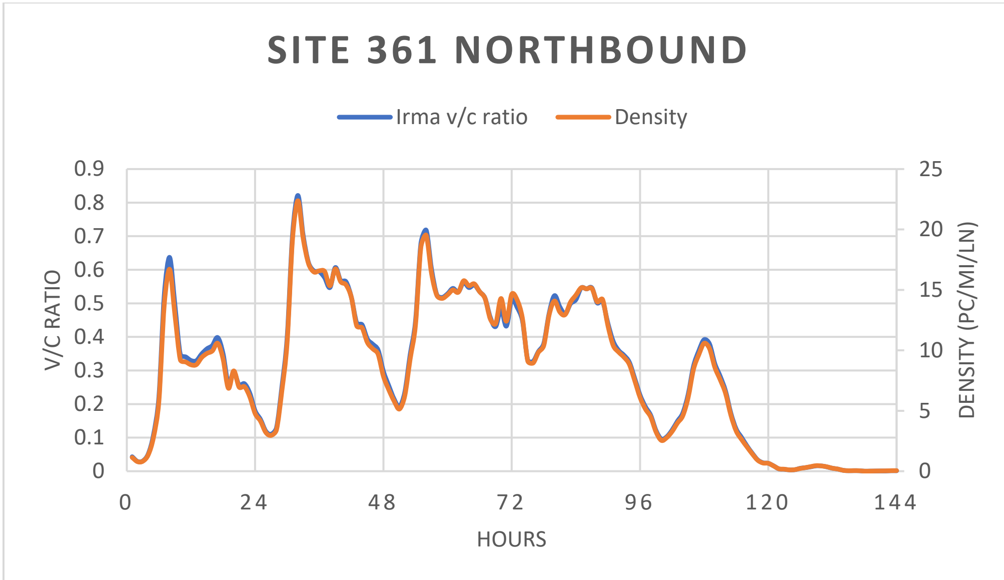

Figure F-7: v/c ratio and Density result of Site 361

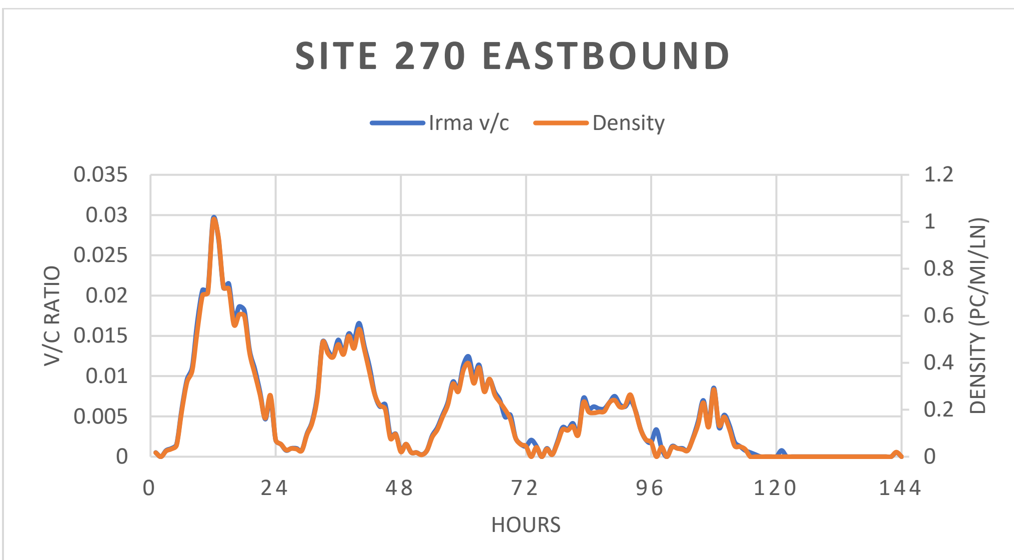

Figure F-8: v/c ratio and Density result of Site 270

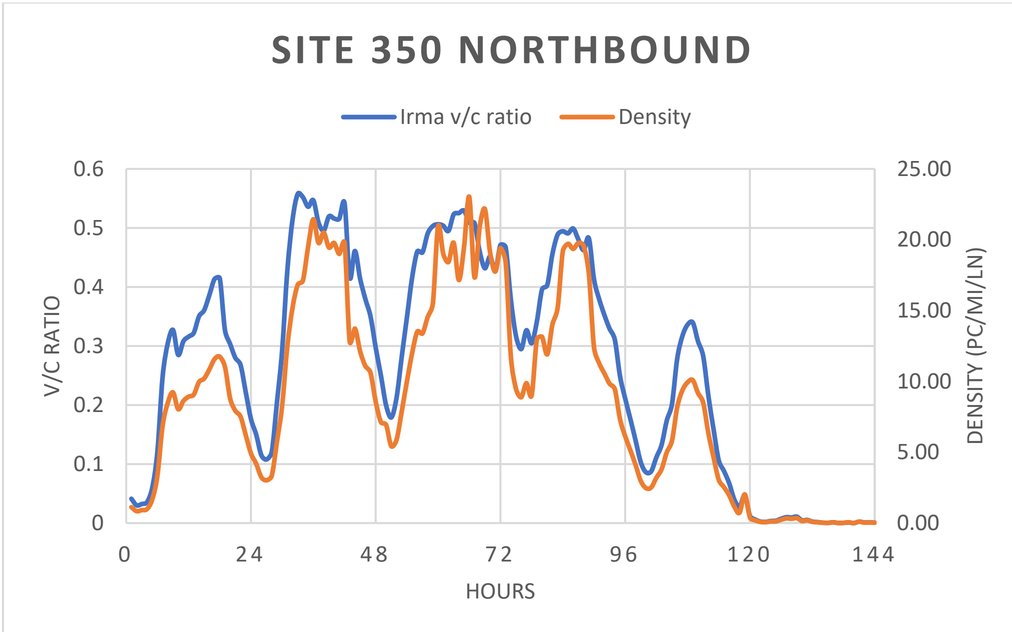

Figure F-9: v/c ratio and Density result of Site 350

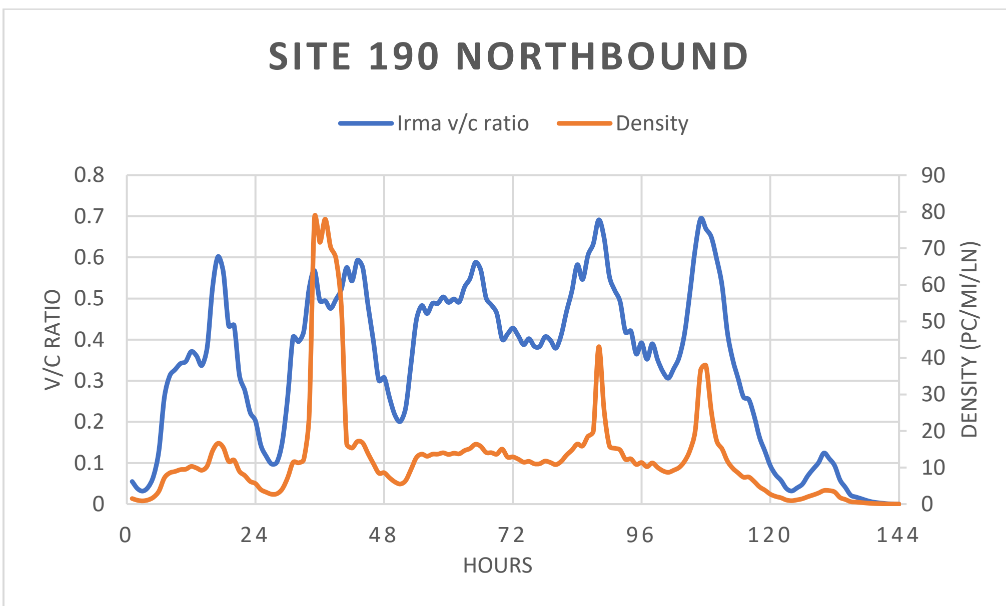

Figure F-10: v/c ratio and Density result of Site 190

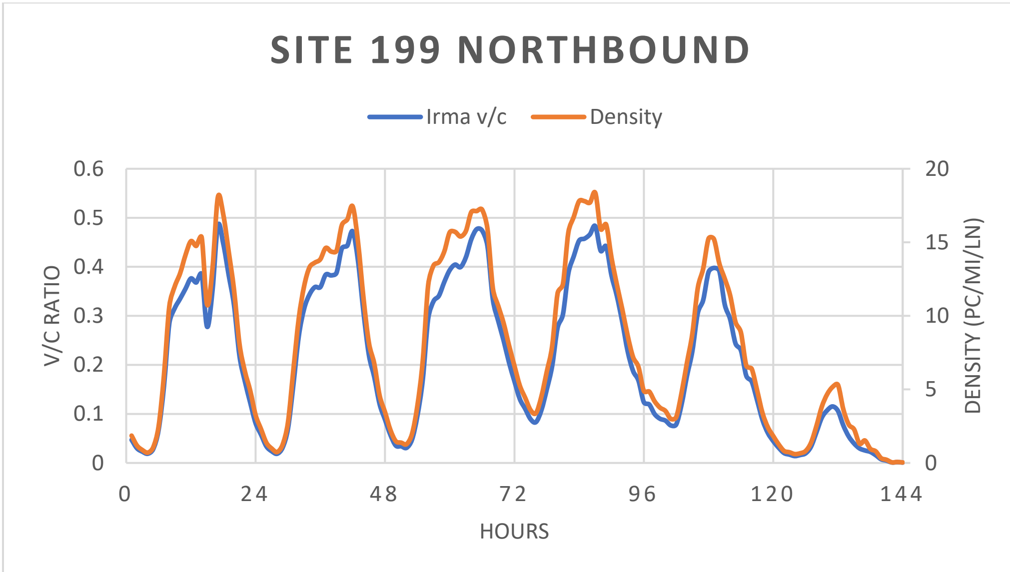

Figure F-11: v/c ratio and Density result of Site 199

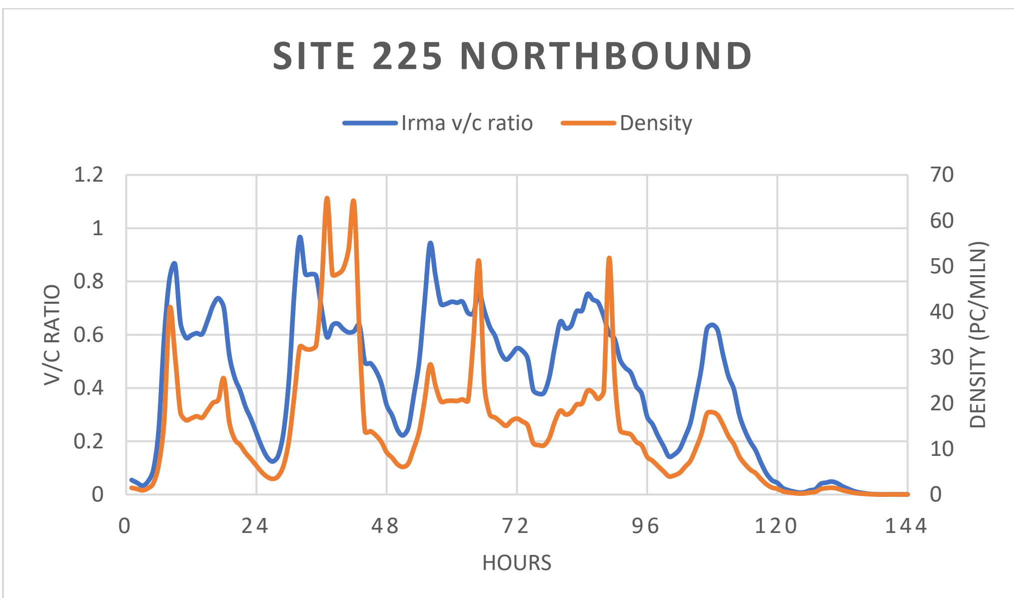

Figure F-12: v/c ratio and Density result of Site 225

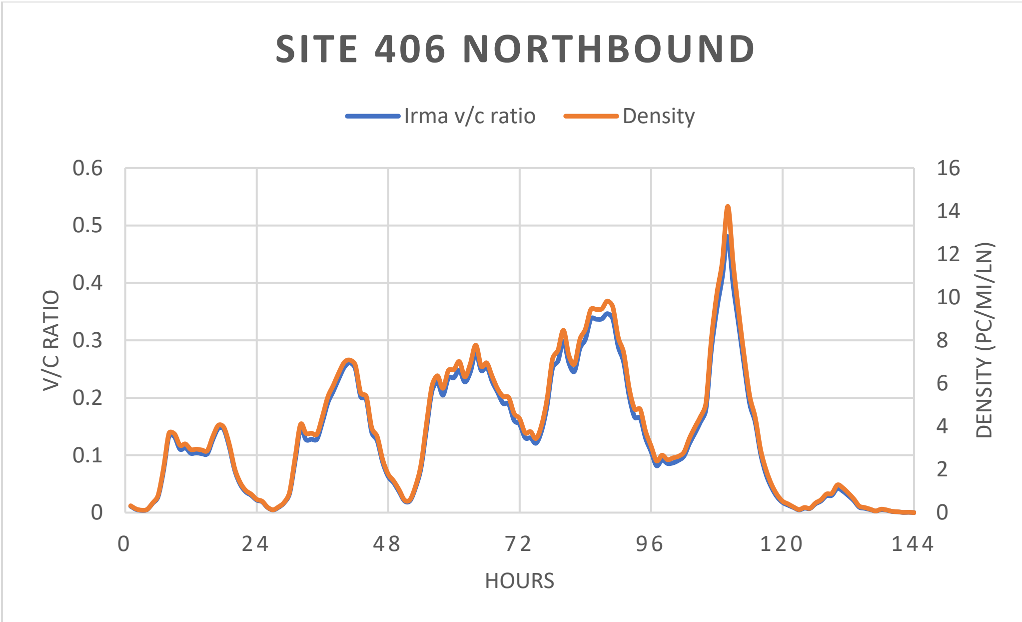

Figure F-13: v/c ratio and Density result of Site 406

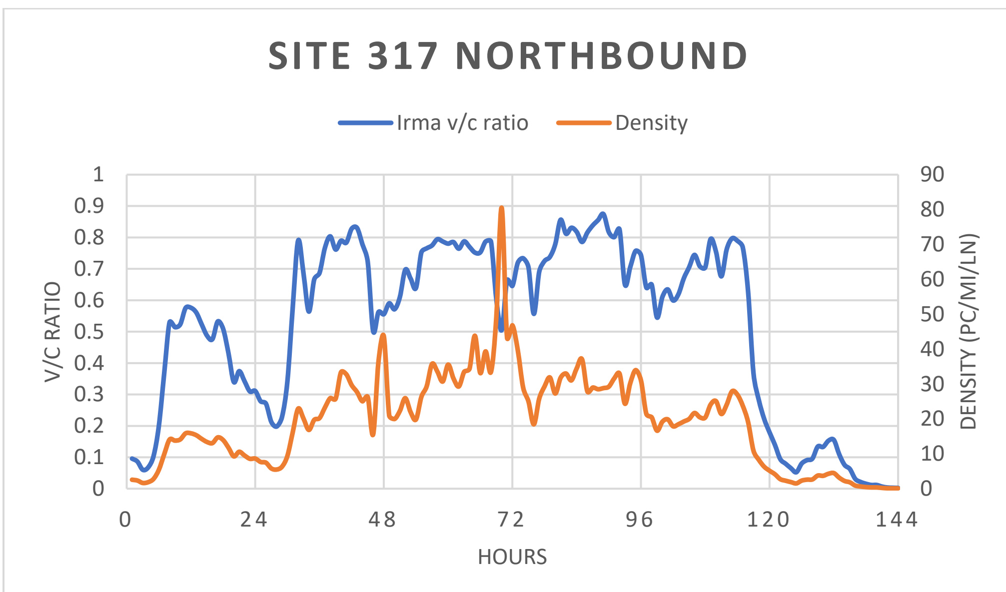

Figure F-14: v/c ratio and Density result of Site 317

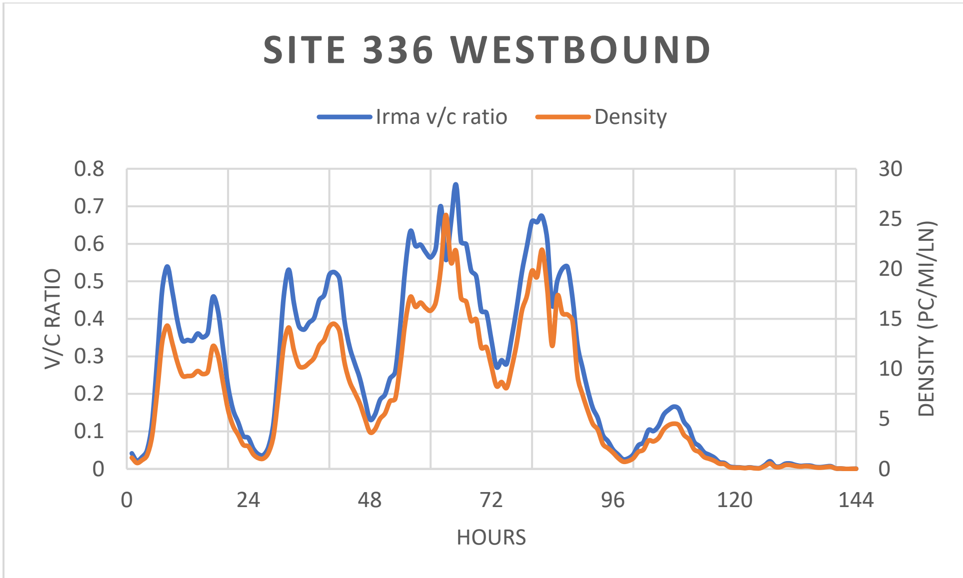

Figure F-15: v/c ratio and Density result of Site 336

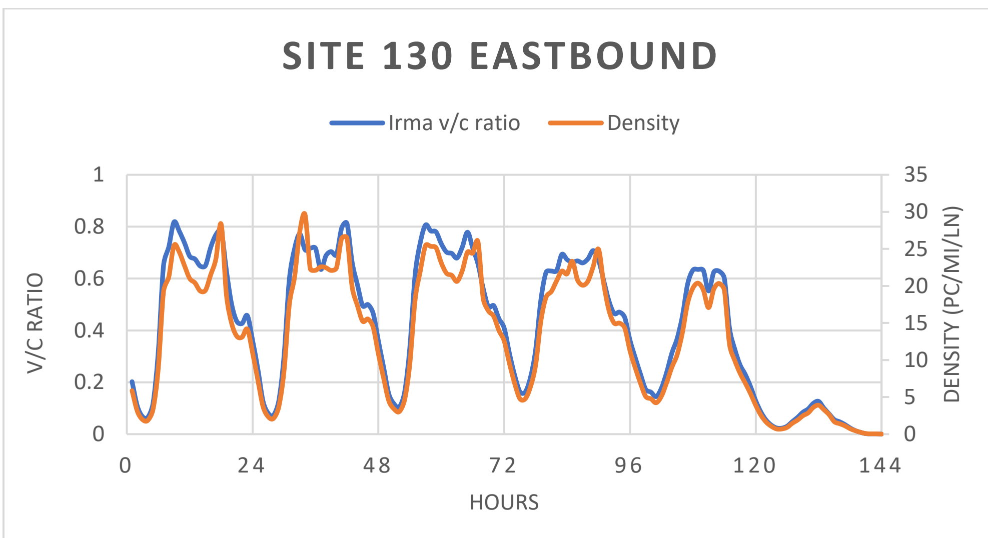

Figure F-16: v/c ratio and Density result of Site 130

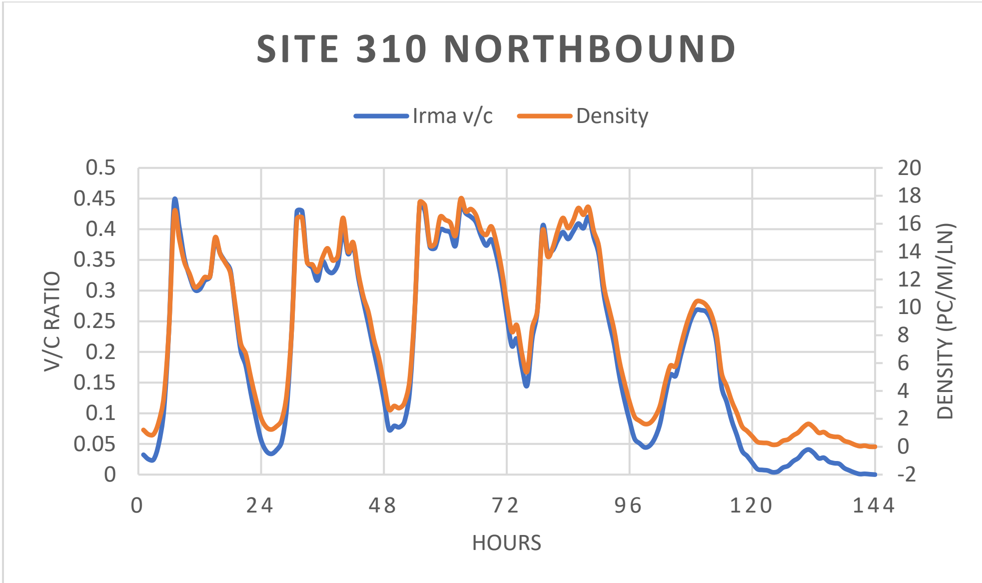

Figure F-17: v/c ratio and Density result of Site 130

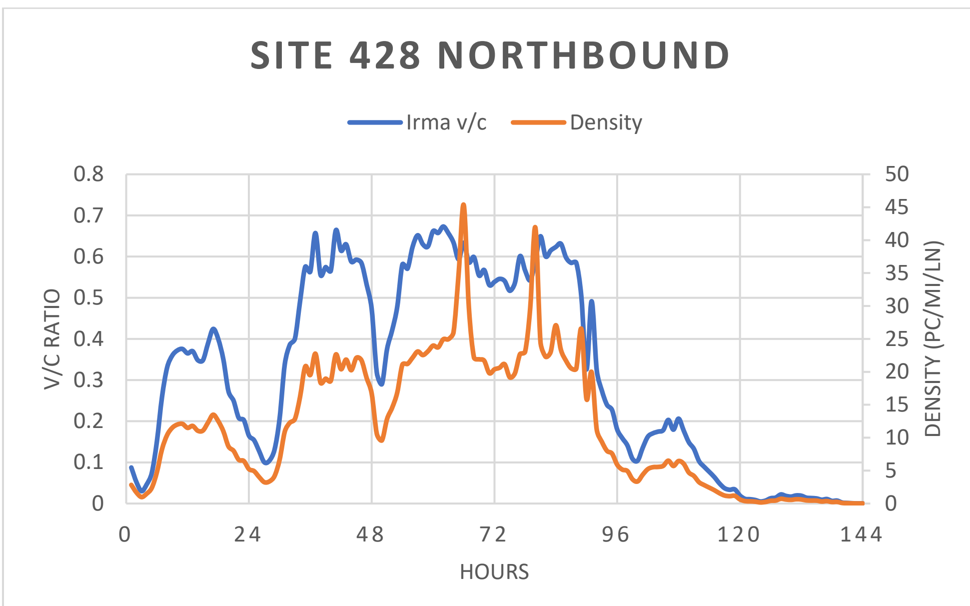

Figure F-18: v/c ratio and Density result of Site 428

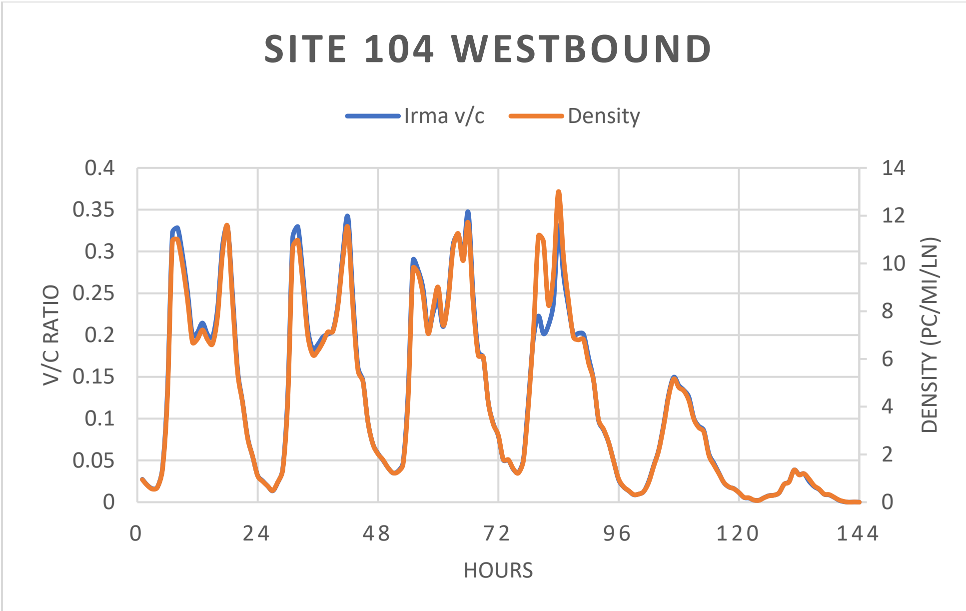

Figure F-19: v/c ratio and Density result of Site 104

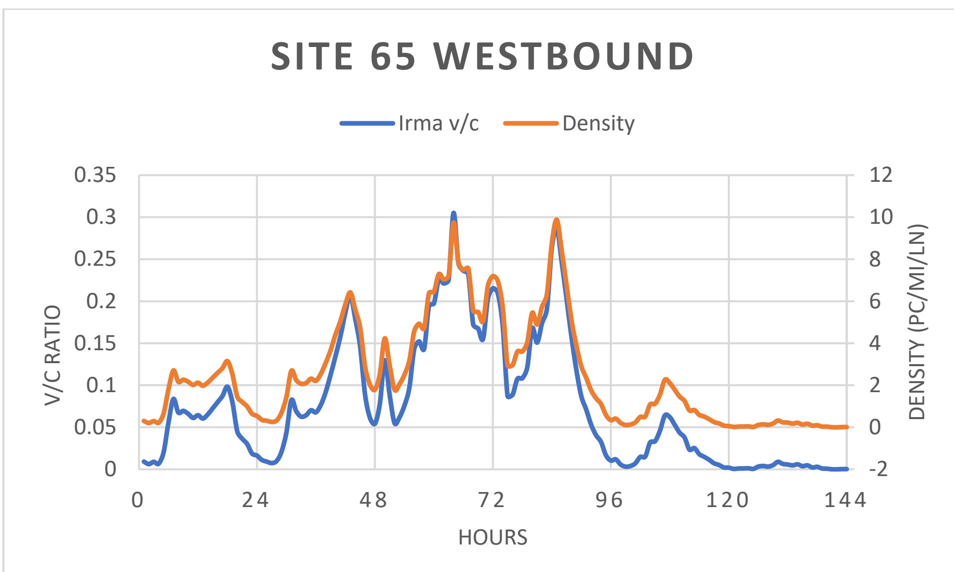

Figure F-20: v/c ratio and Density result of Site 65

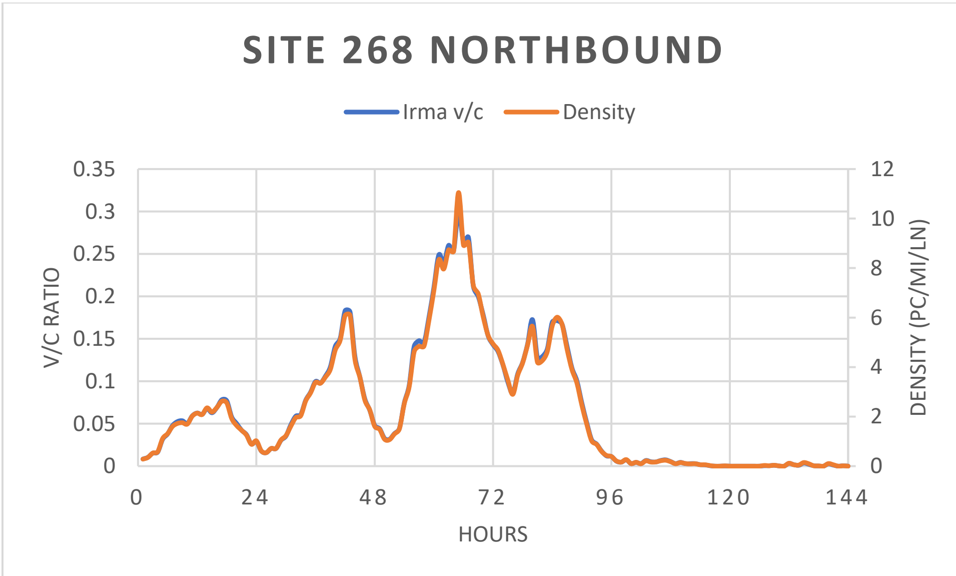

Figure F-21: v/c ratio and Density result of Site 268

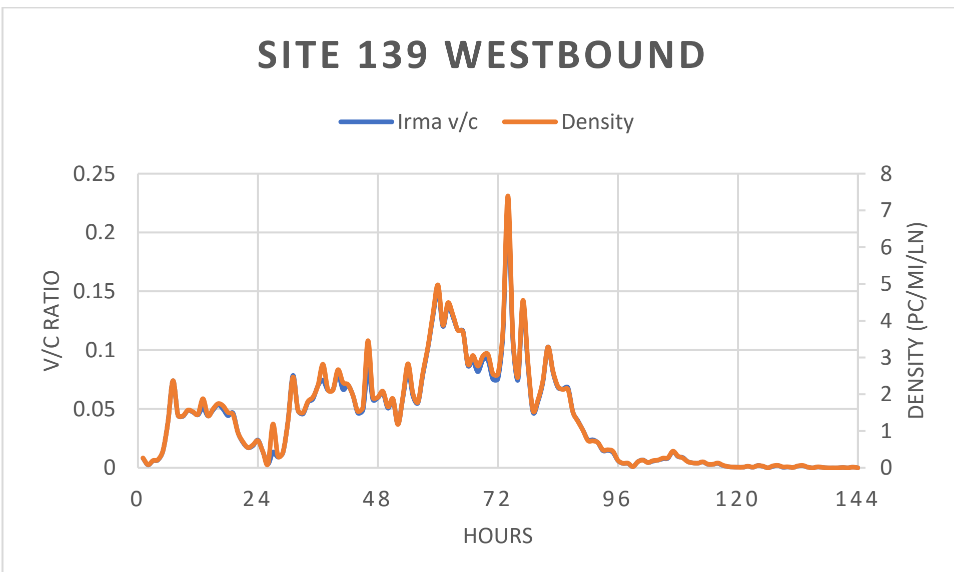

Figure F-22: v/c ratio and Density result of Site 139

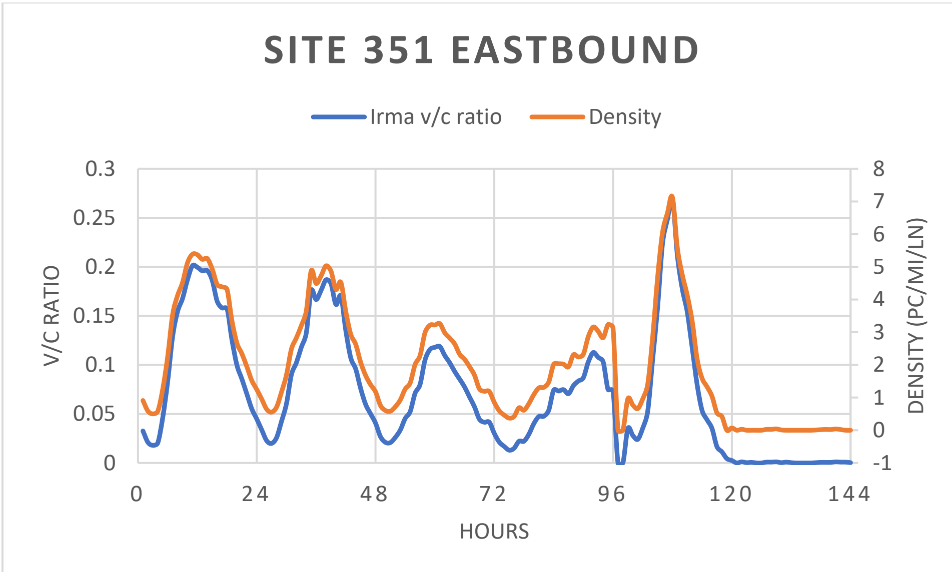

Figure F-23: v/c ratio and Density result of Site 331

Traffic Count Stations Without Speed data

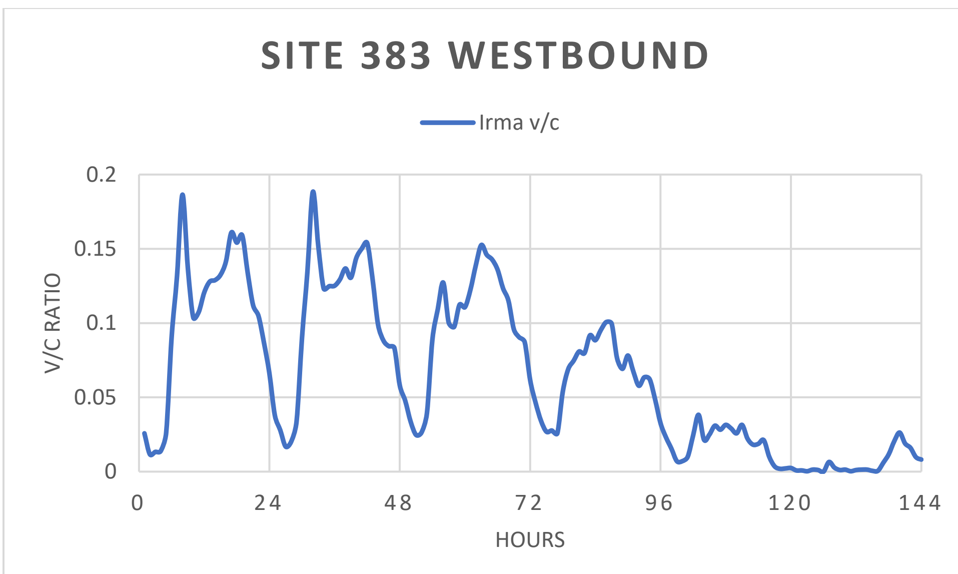

Figure F-24: v/c ratio result of Site 383

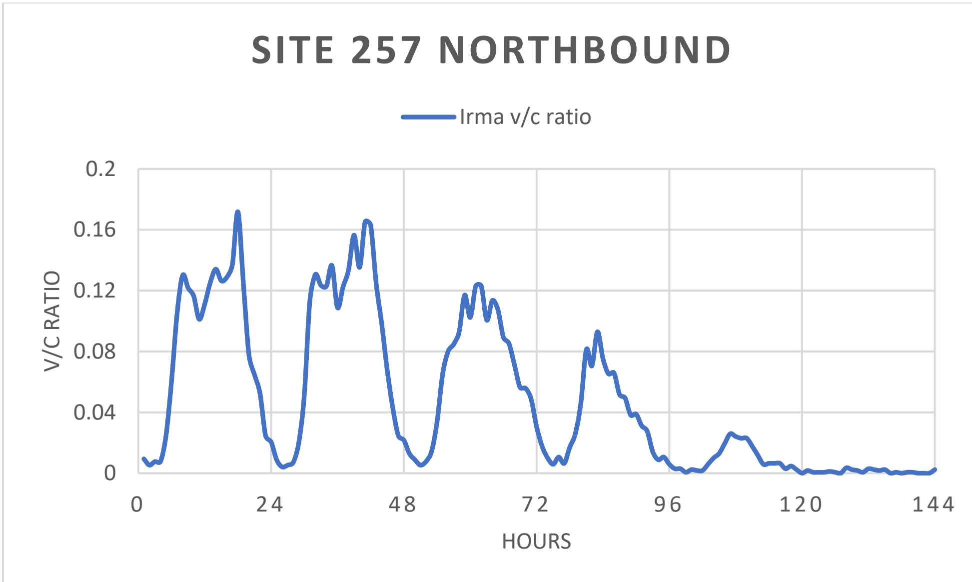

Figure F-25: v/c ratio result of Site 257

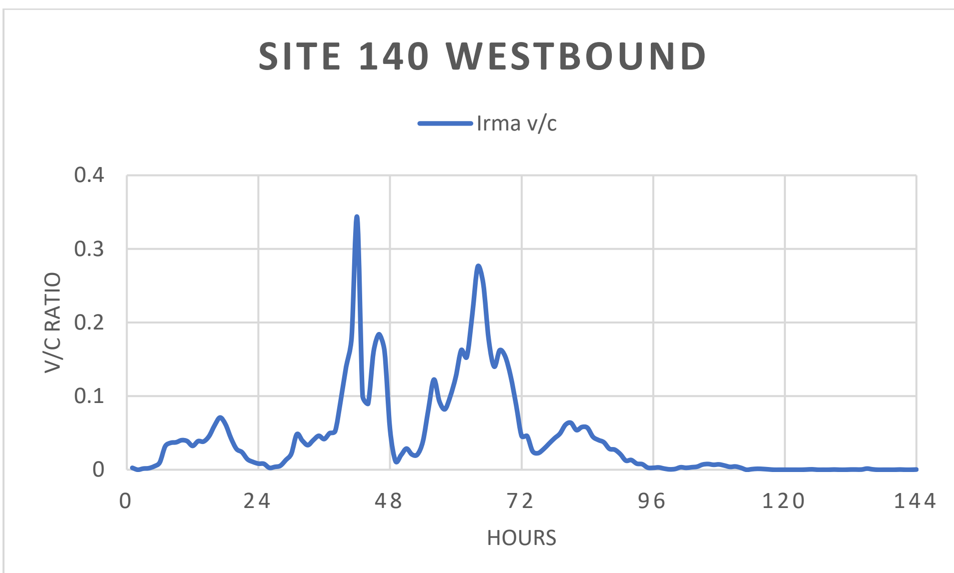

Figure F-26: v/c ratio result of Site 140

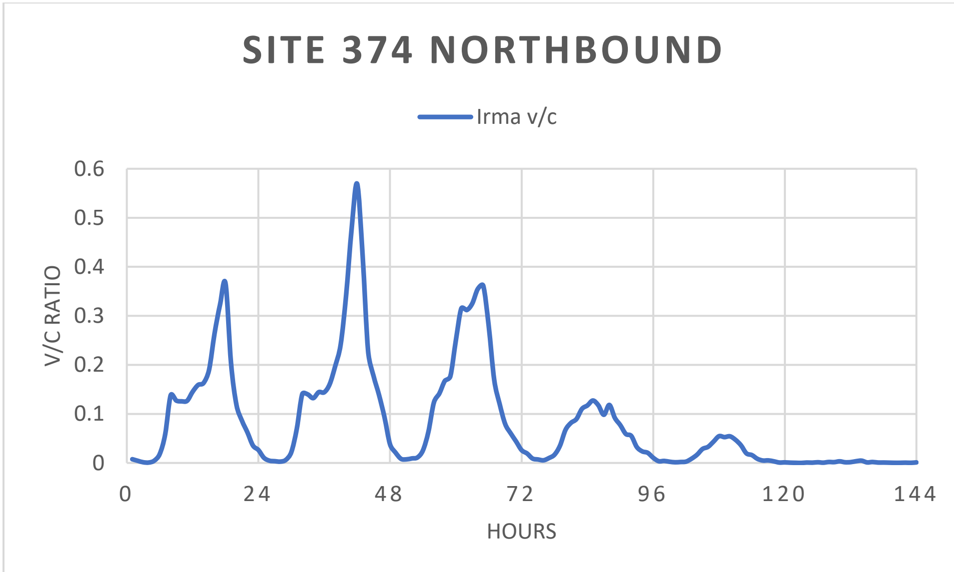

Figure F-27: v/c ratio result of Site 374

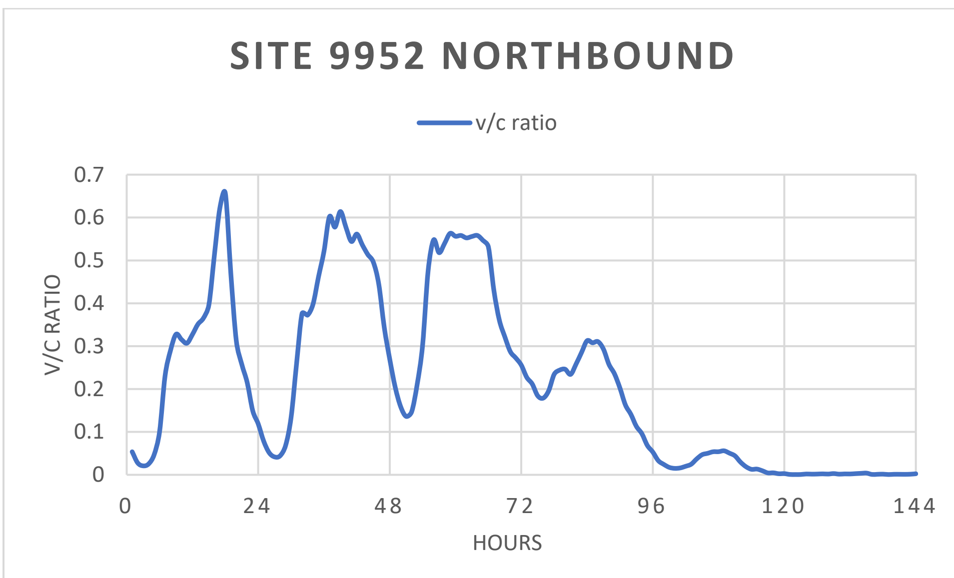

Figure F-28: v/c ratio result of Site 9952

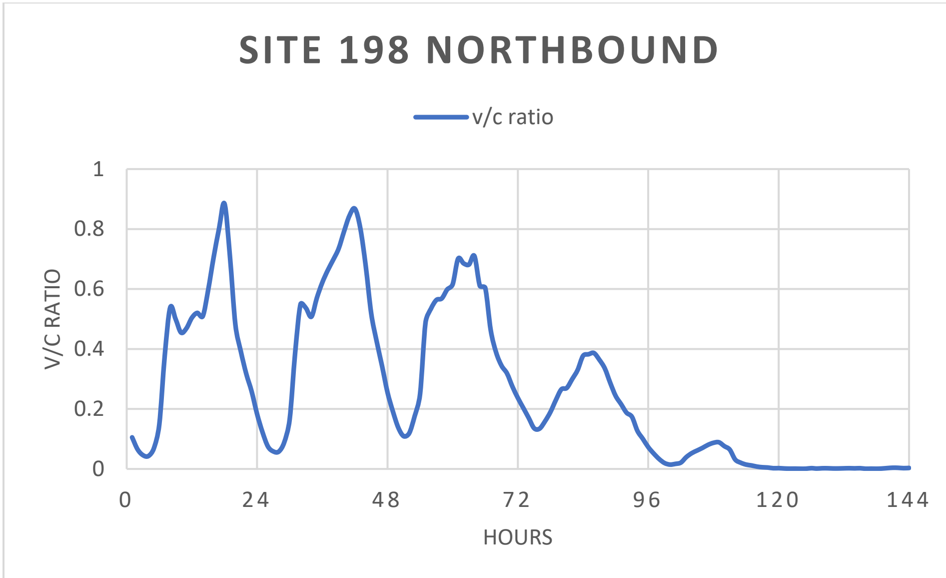

Figure F-29: v/c ratio result of Site 198

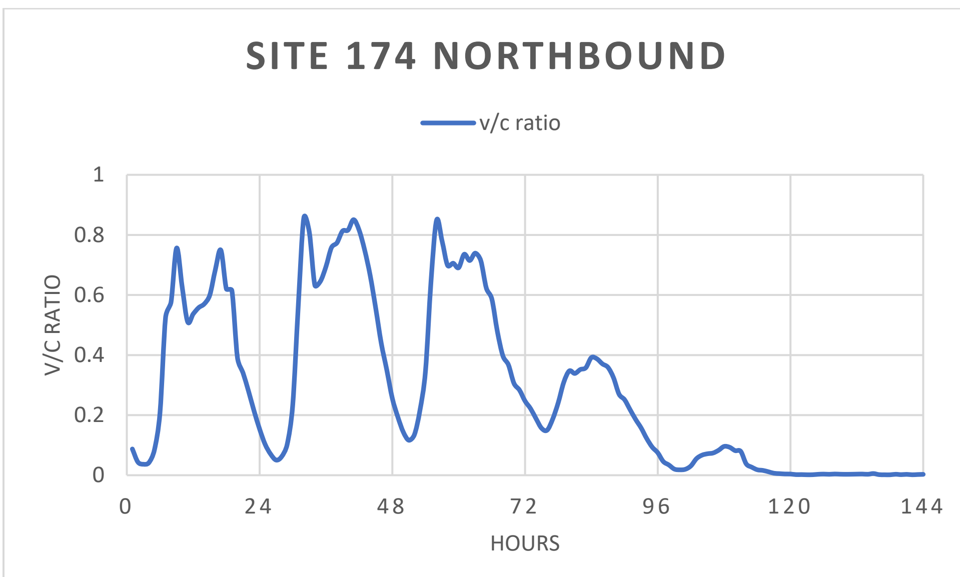

Figure F-30: v/c ratio result of Site 174

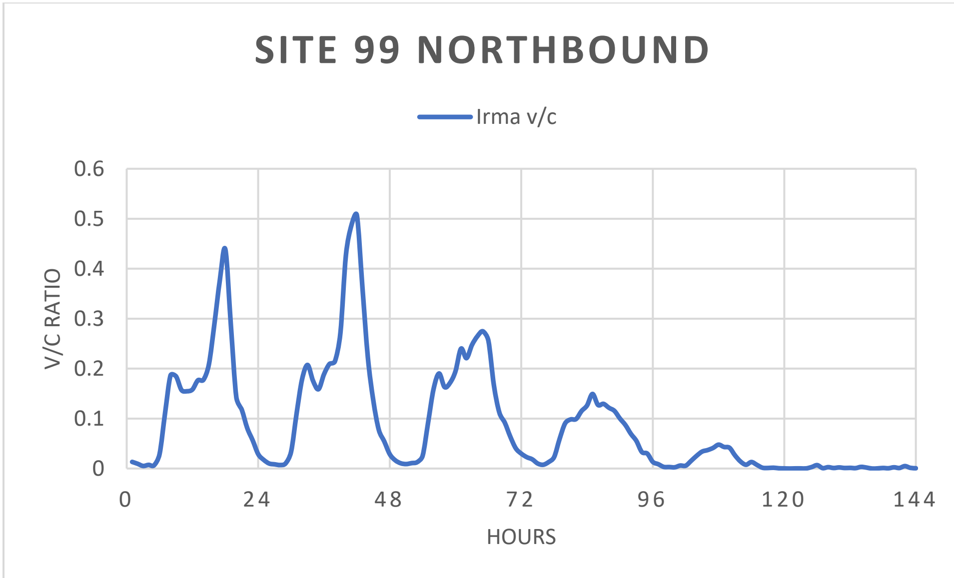

Figure F-31: v/c ratio result of Site 99

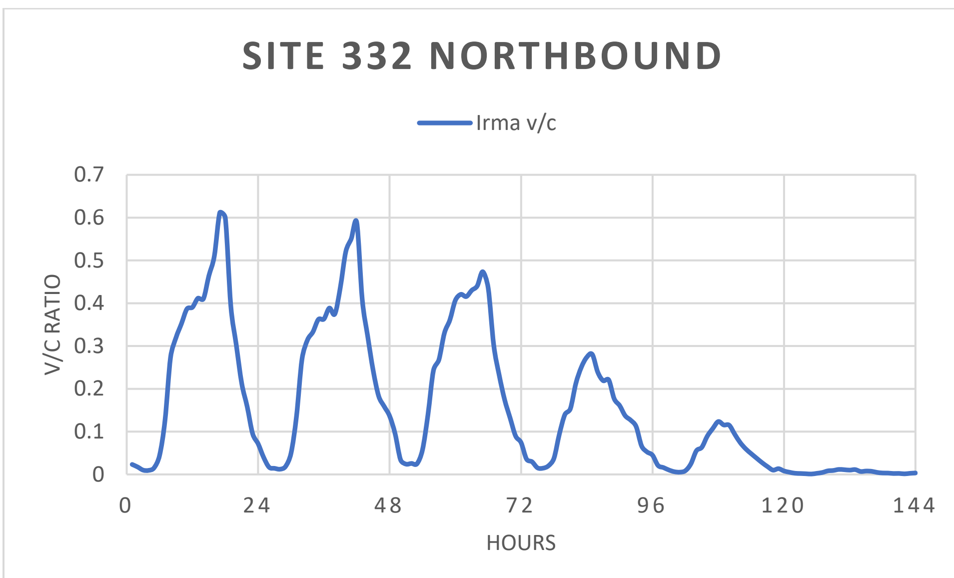

Figure F-32: v/c ratio result of Site 332

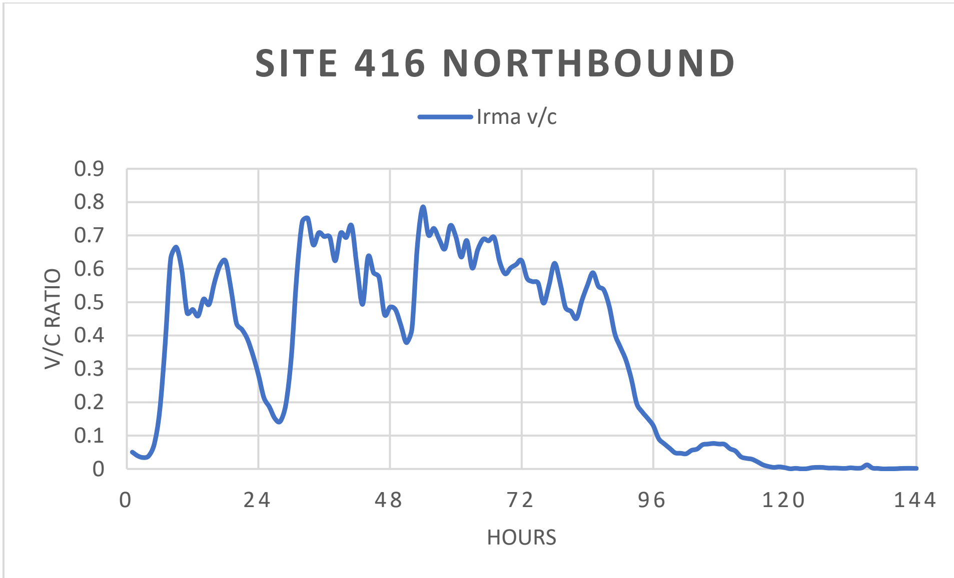

Figure F-33: v/c ratio result of Site 416

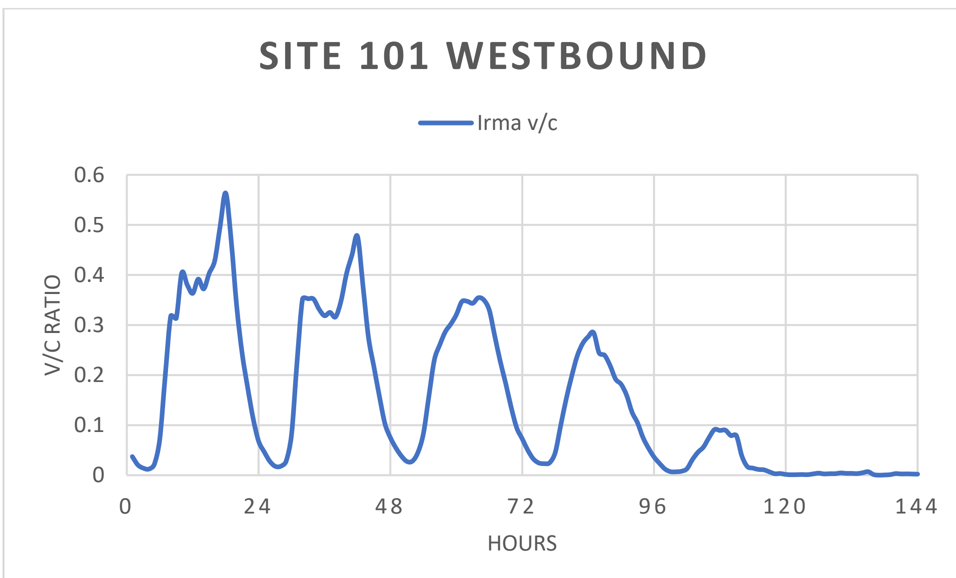

Figure F-34: v/c ratio result of Site 101

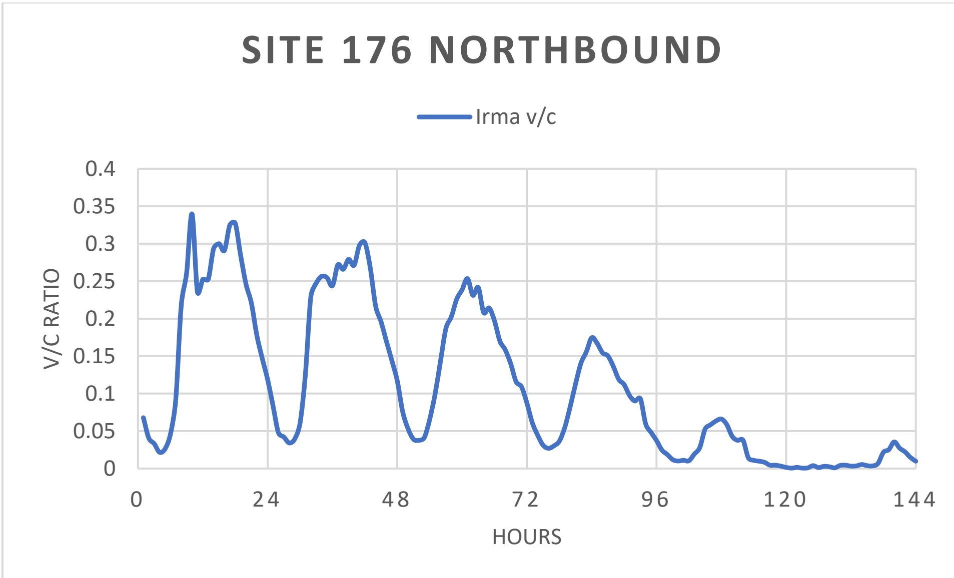

Figure F-35: v/c ratio result of Site 176

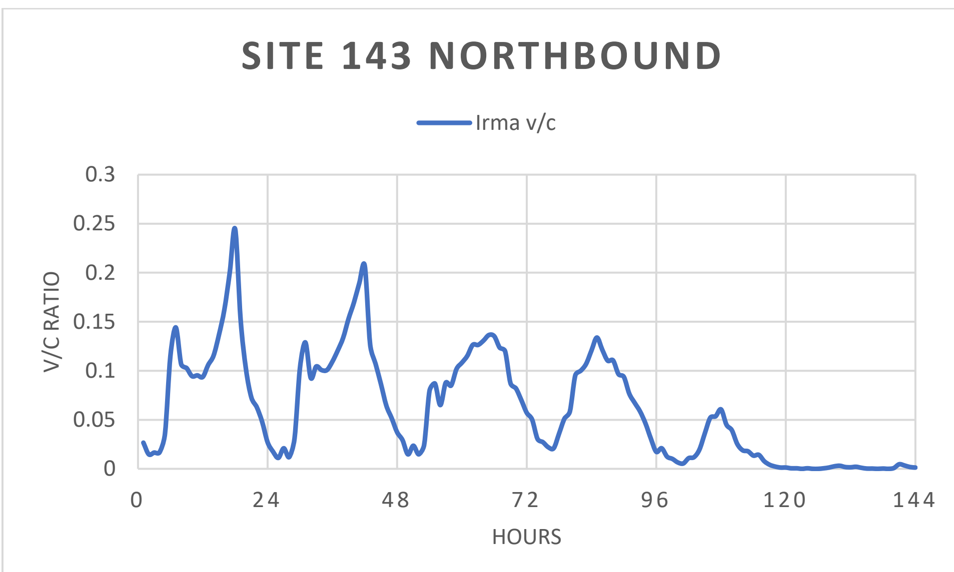

Figure F-36: v/c ratio result of Site 143

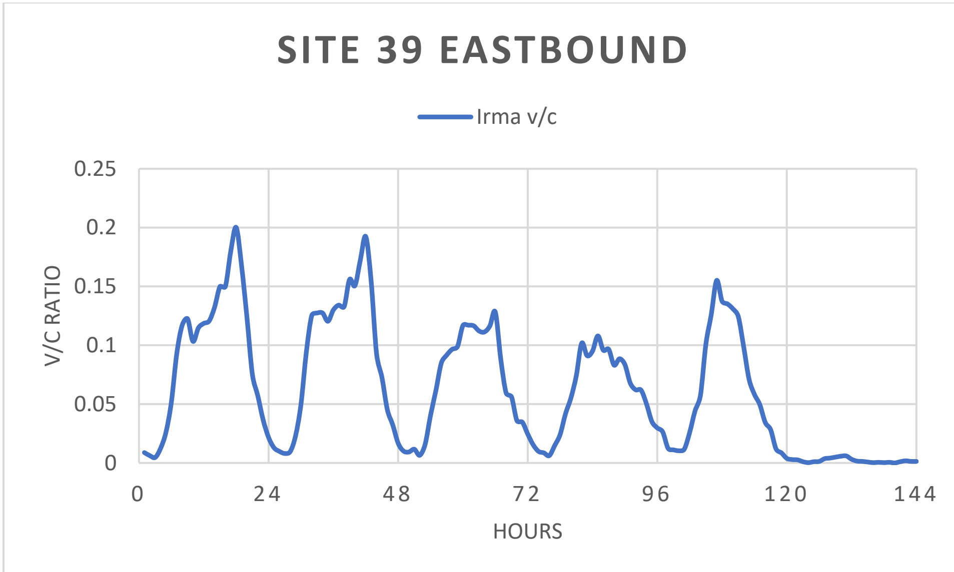

Figure F-37: v/c ratio result of Site 39

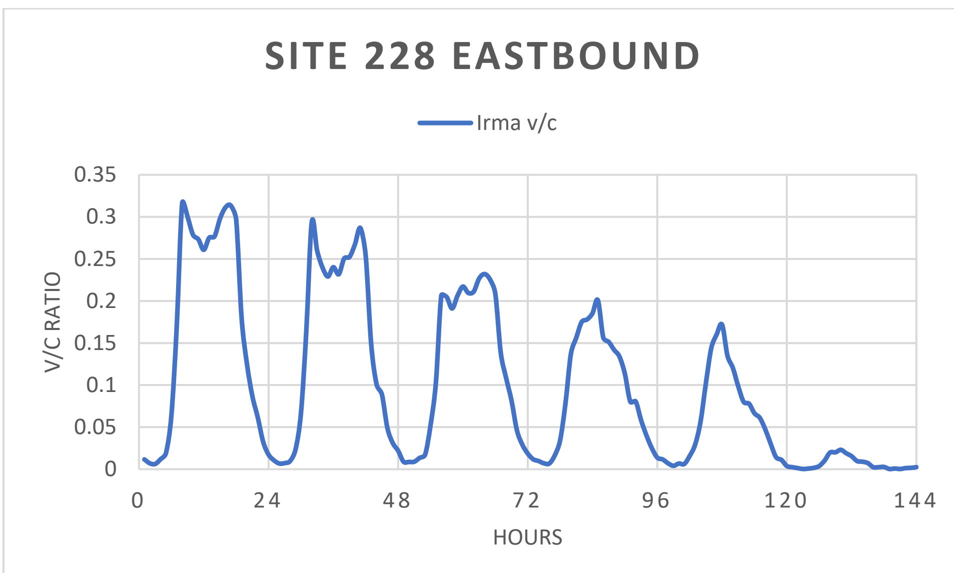

Figure F-38: v/c ratio result of Site 228

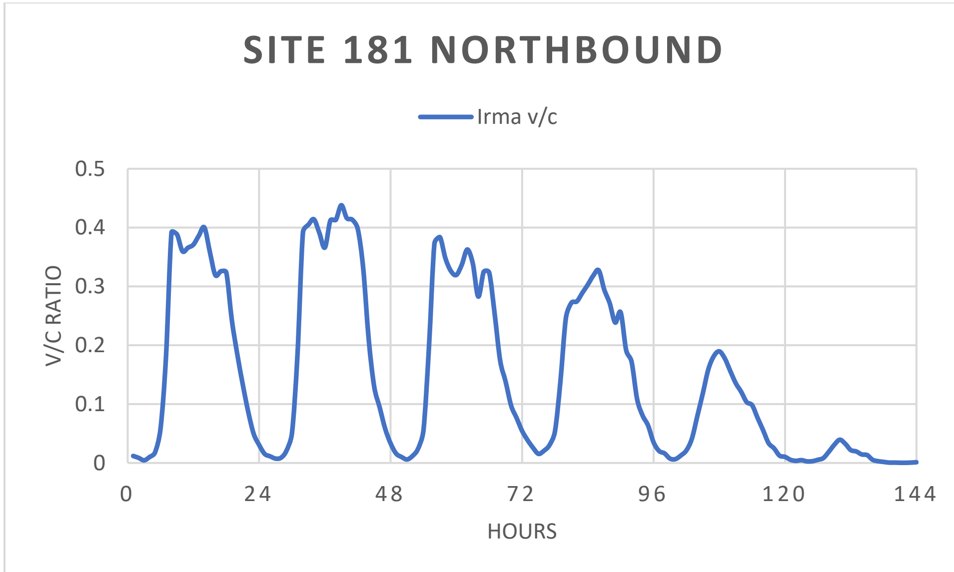

Figure F-39: v/c ratio result of Site 181

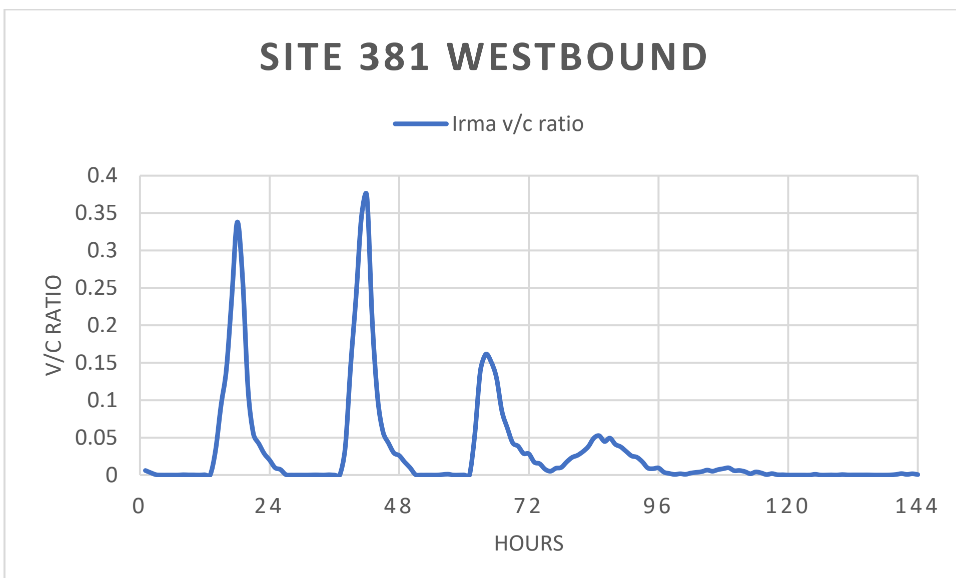

Figure F-40: v/c ratio result of Site 381

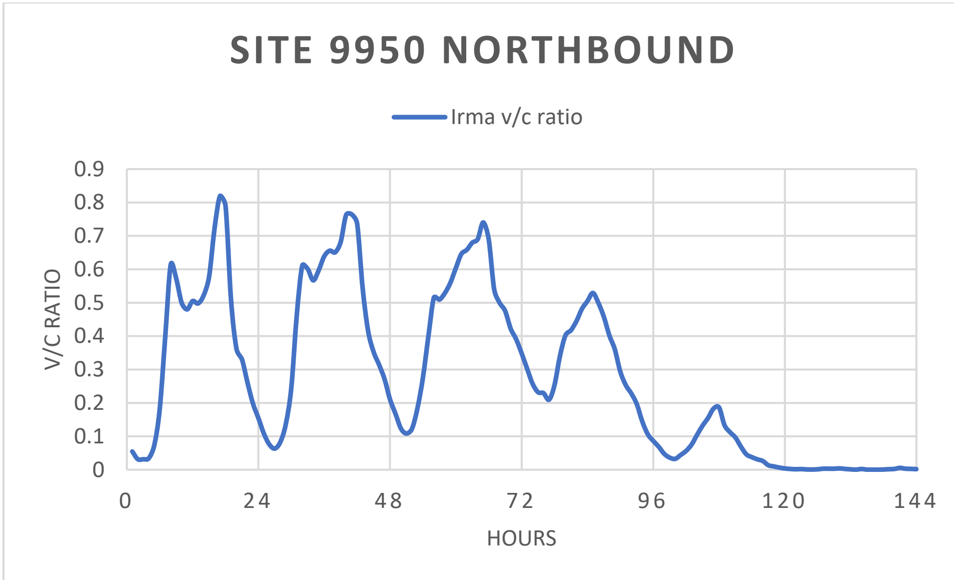

Figure F-41: v/c ratio result of Site 9950

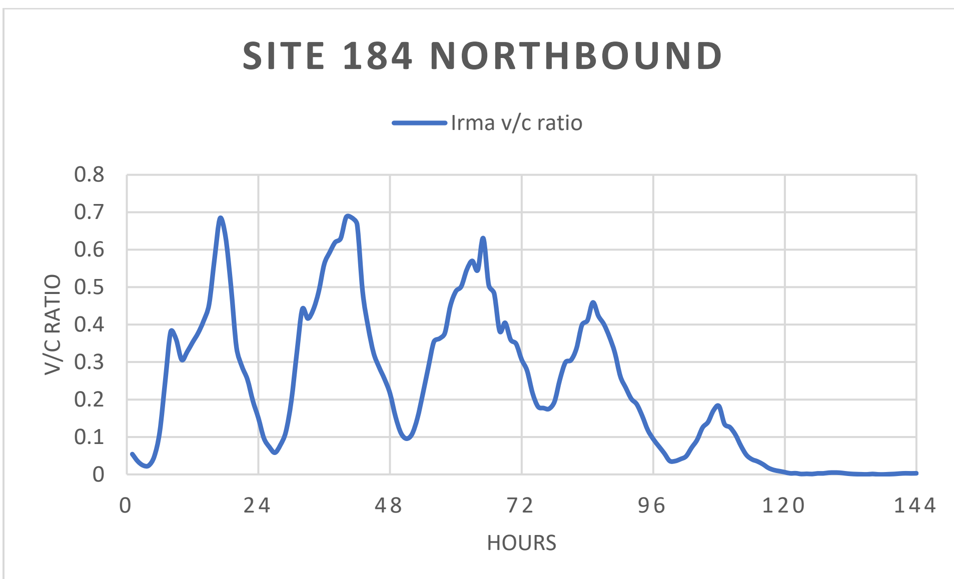

Figure F-42: v/c ratio result of Site 184

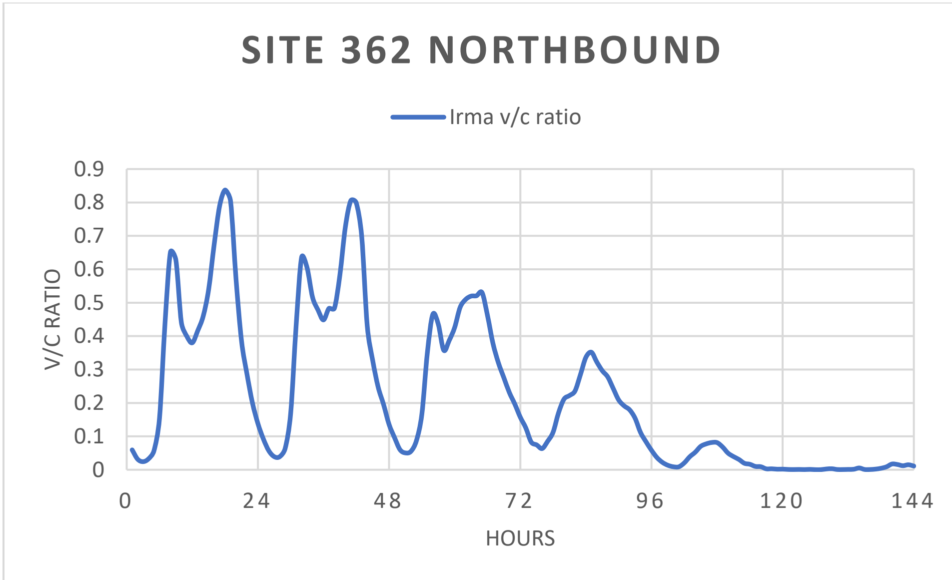

Figure F-43: v/c ratio result of Site 362

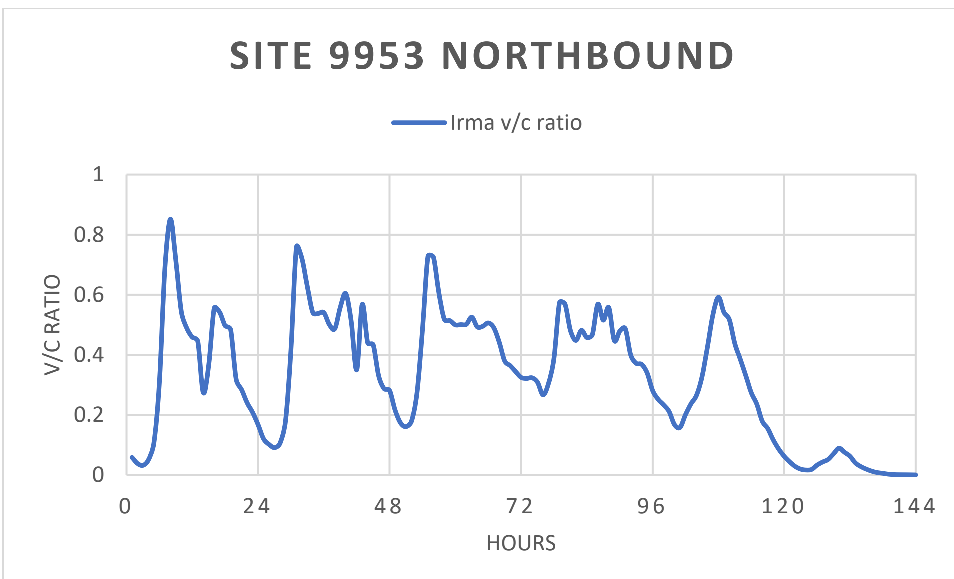

Figure F-44: v/c ratio result of Site 9953

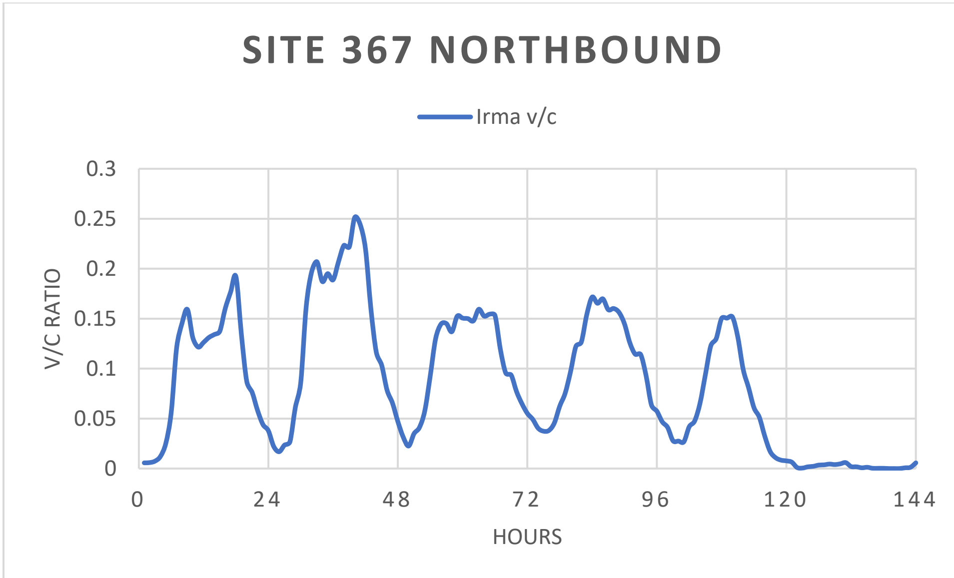

Figure F-45: v/c ratio result of Site 367

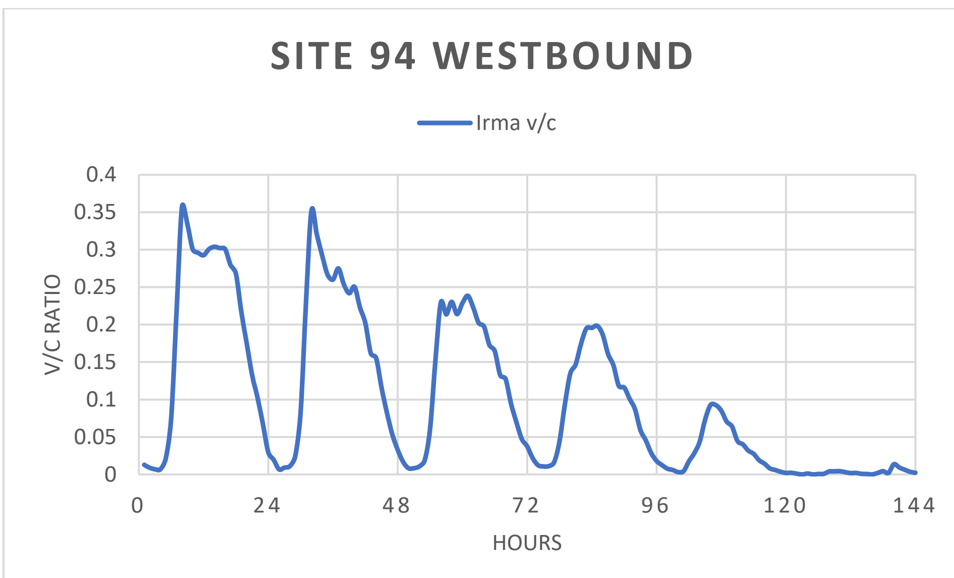

Figure F-46: v/c ratio result of Site 94

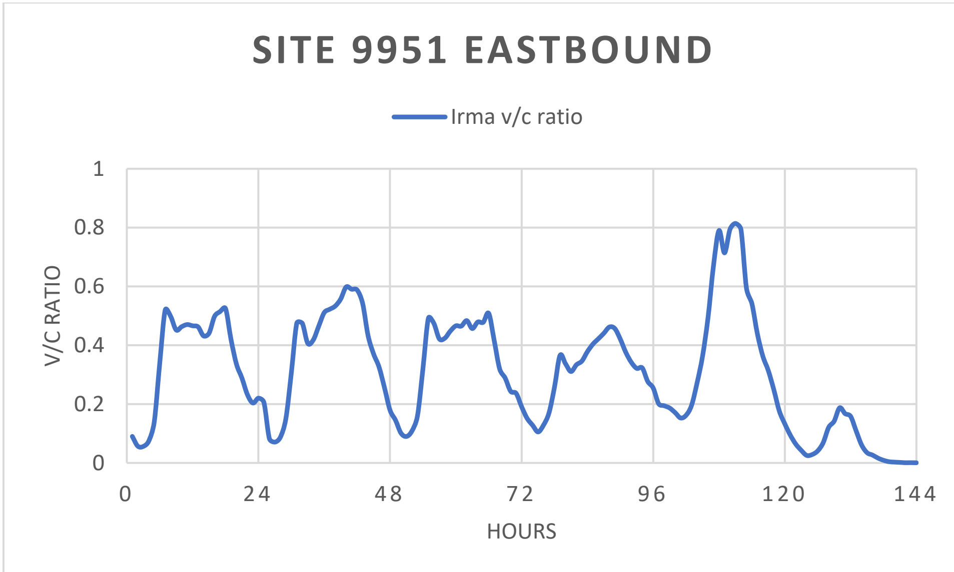

Figure F-47: v/c ratio result of Site 9951

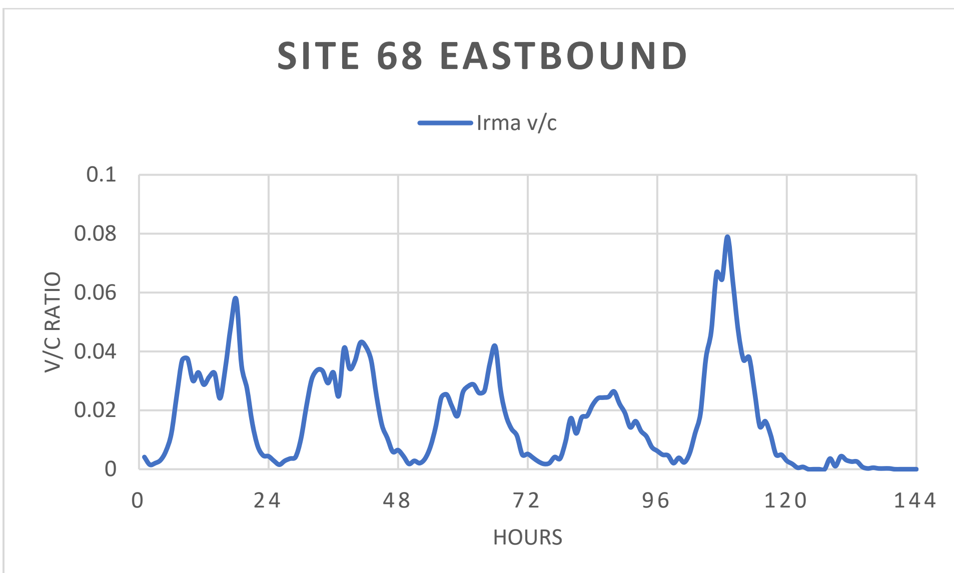

Figure F-48: v/c ratio result of Site 68

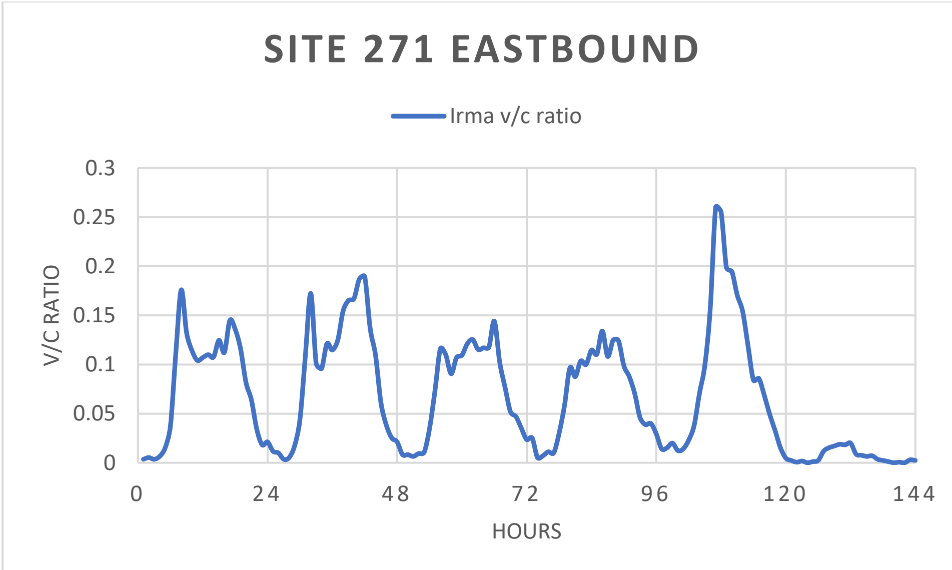

Figure F-49: v/c ratio result of Site 271

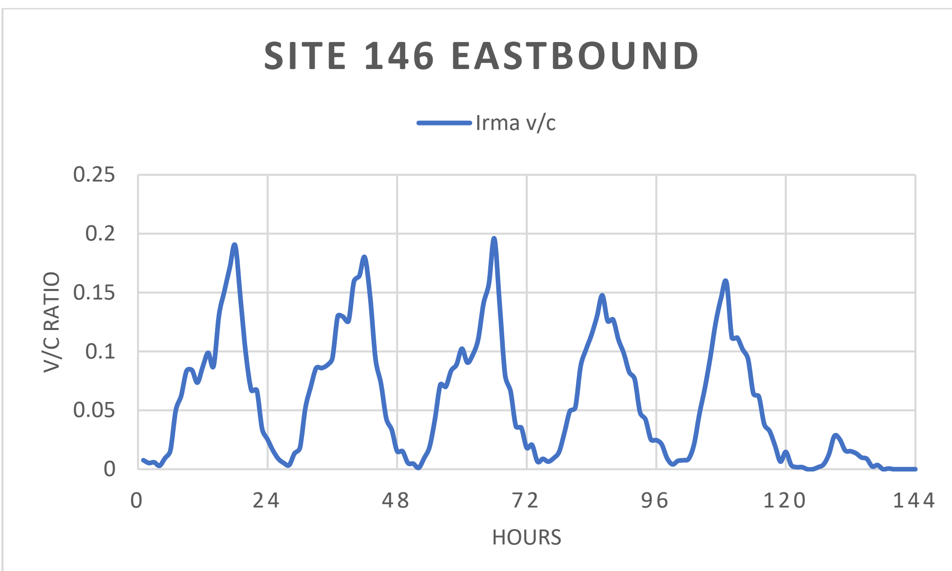

Figure F-50: v/c ratio result of Site 146

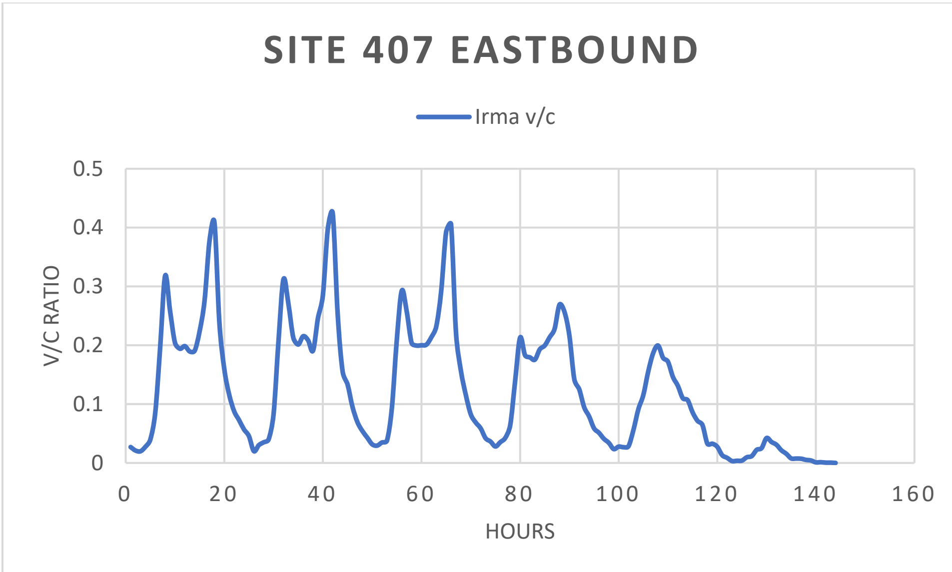

Figure F-51: v/c ratio result of Site 407

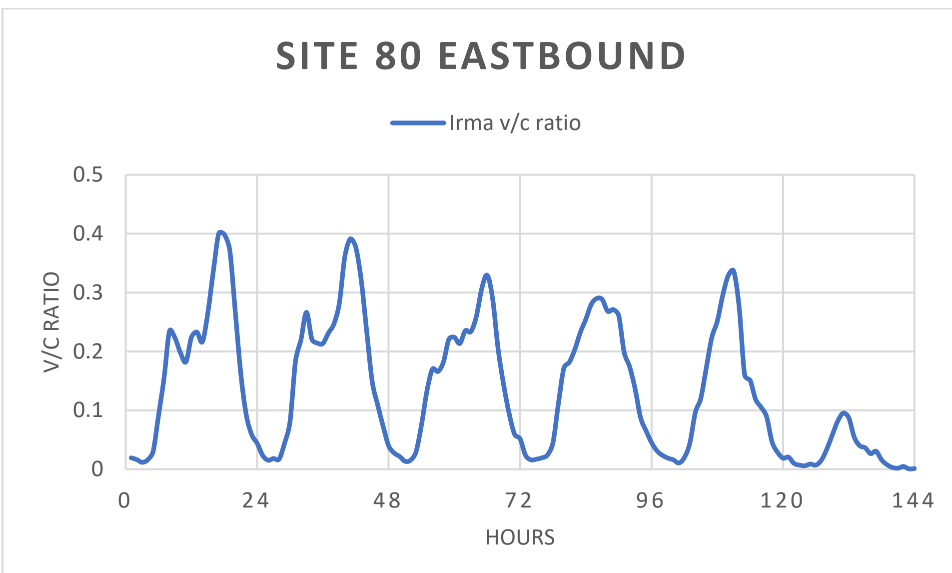

Figure F-52: v/c ratio result of Site 80

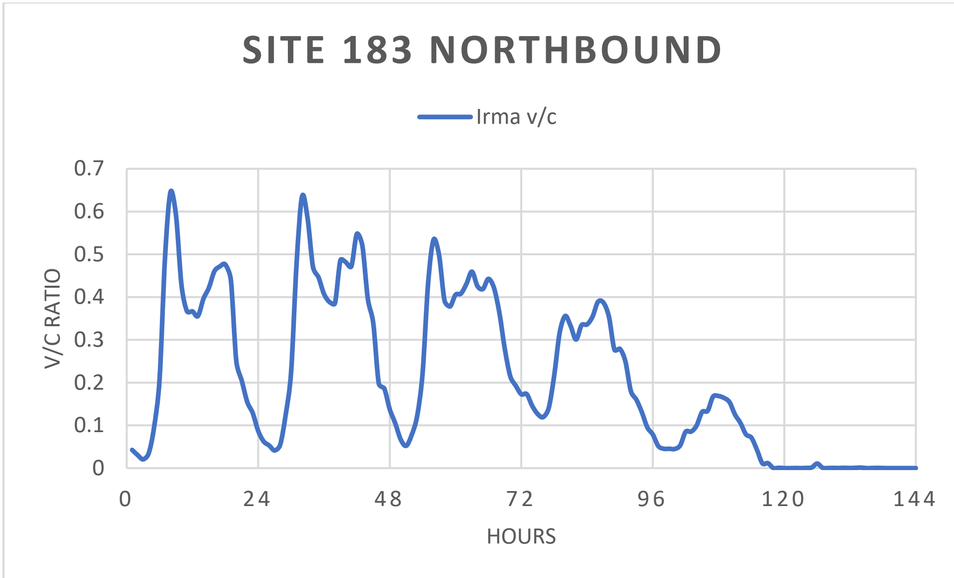

Figure F-53: v/c ratio result of Site 183

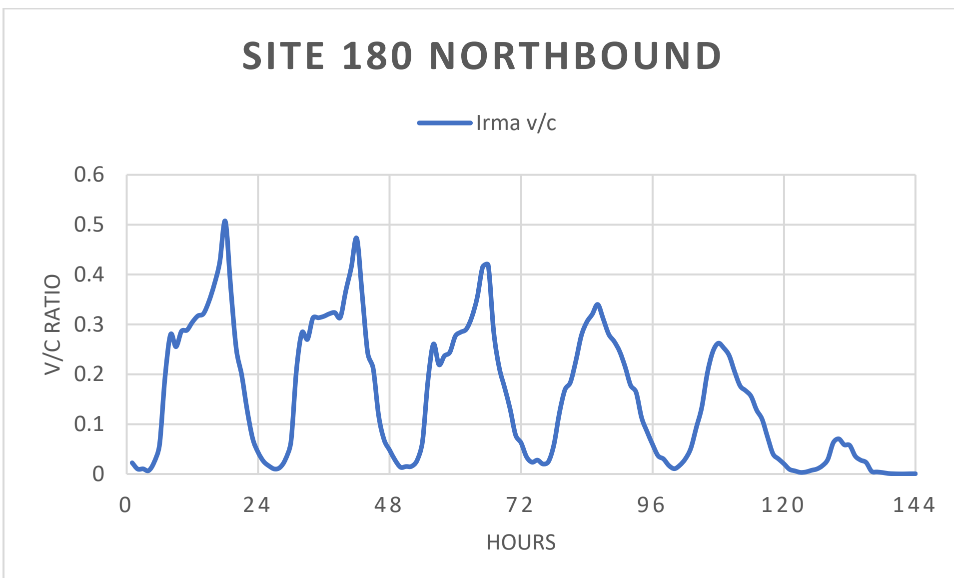

Figure F-54: v/c ratio result of Site 180

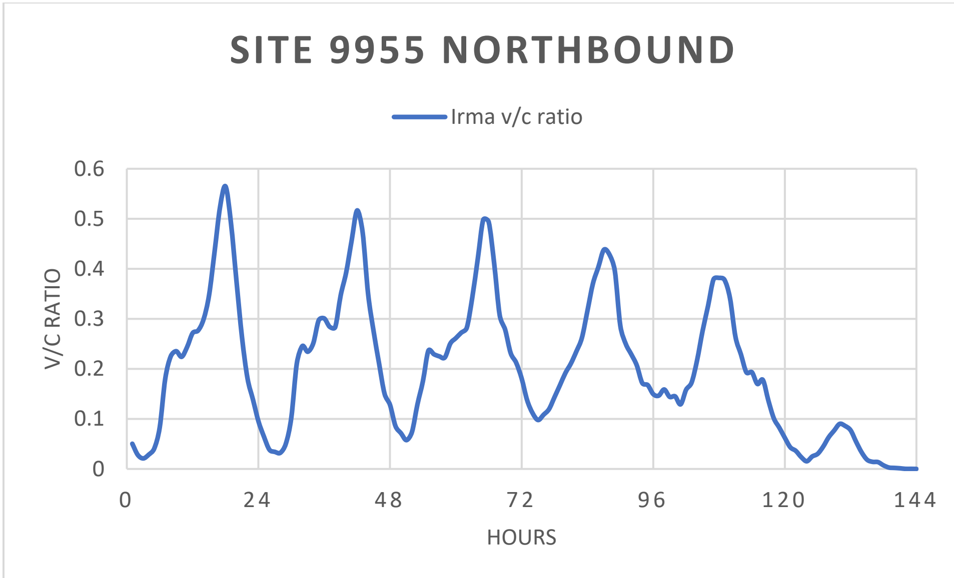

Figure F-55: v/c ratio result of Site 9955

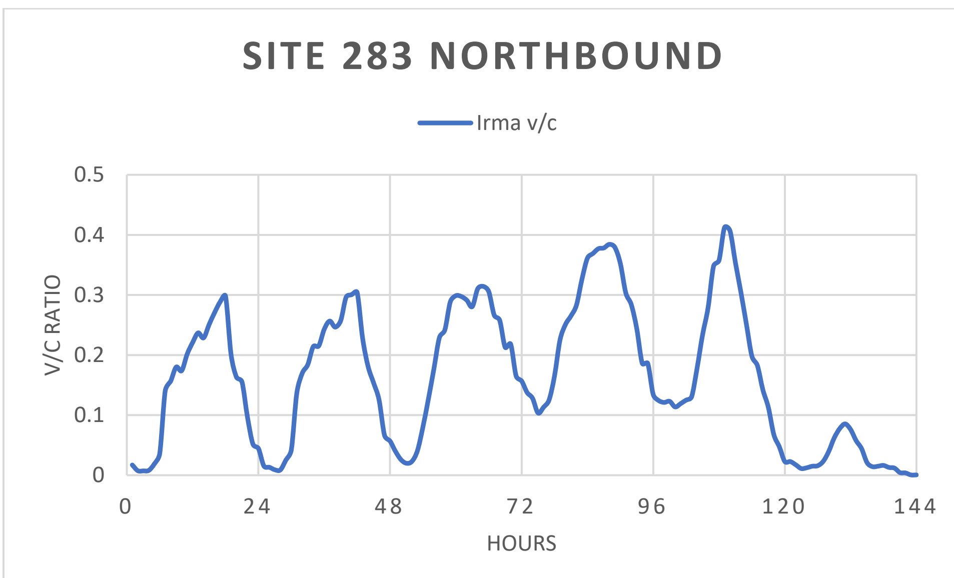

Figure F-56: v/c ratio result of Site 283

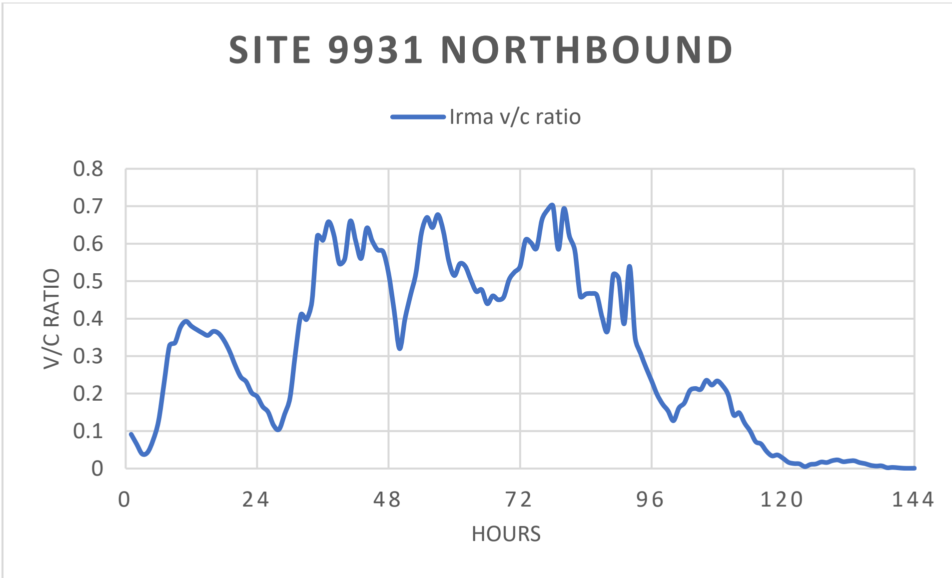

Figure F-57: v/c ratio result of Site 9931

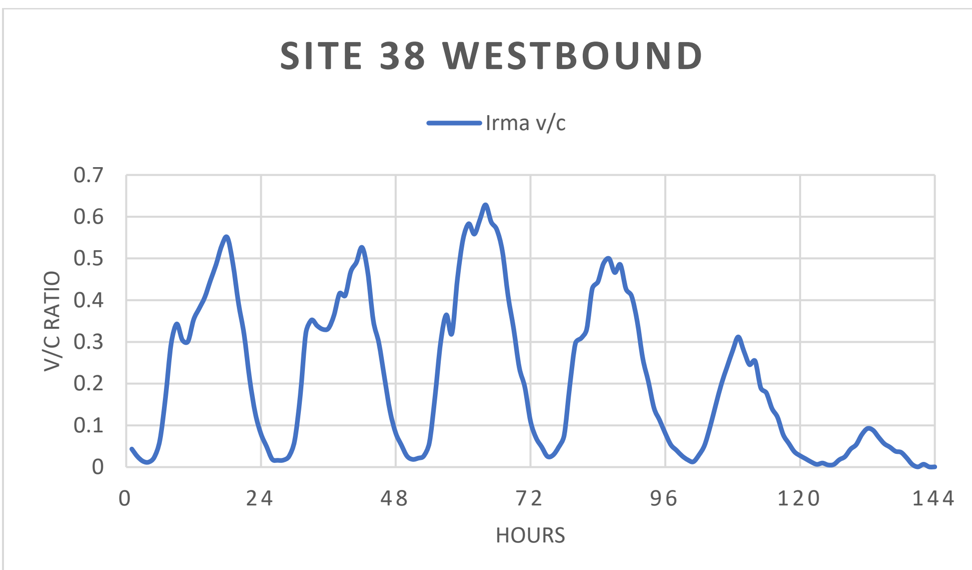

Figure F-58: v/c ratio result of Site 38

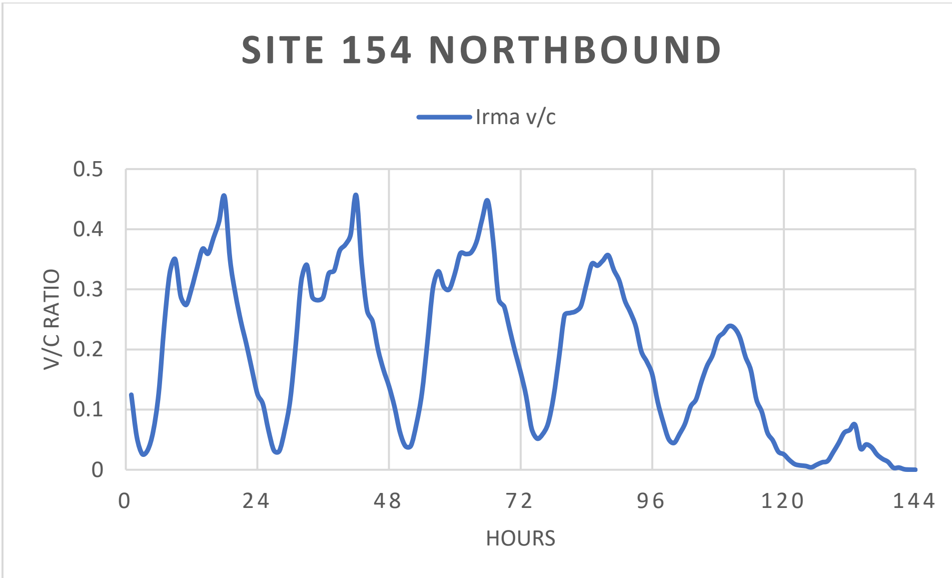

Figure F-59: v/c ratio result of Site 154

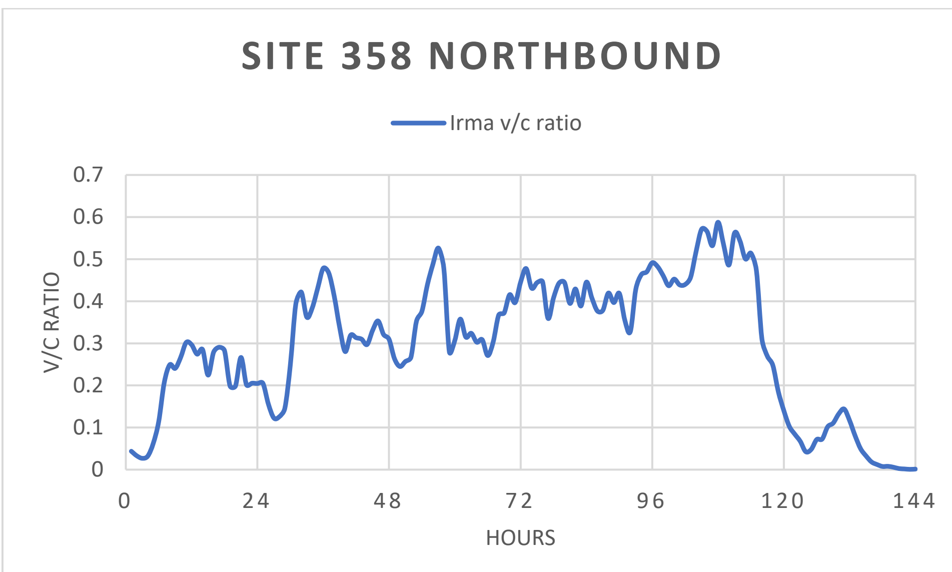

Figure F-60: v/c ratio result of Site 358

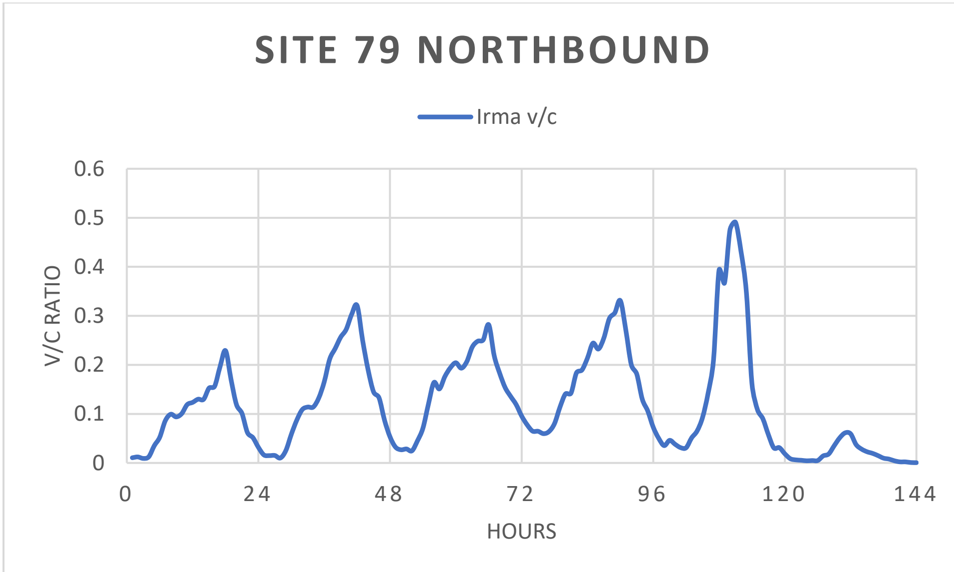

Figure F-61: v/c ratio result of Site 79

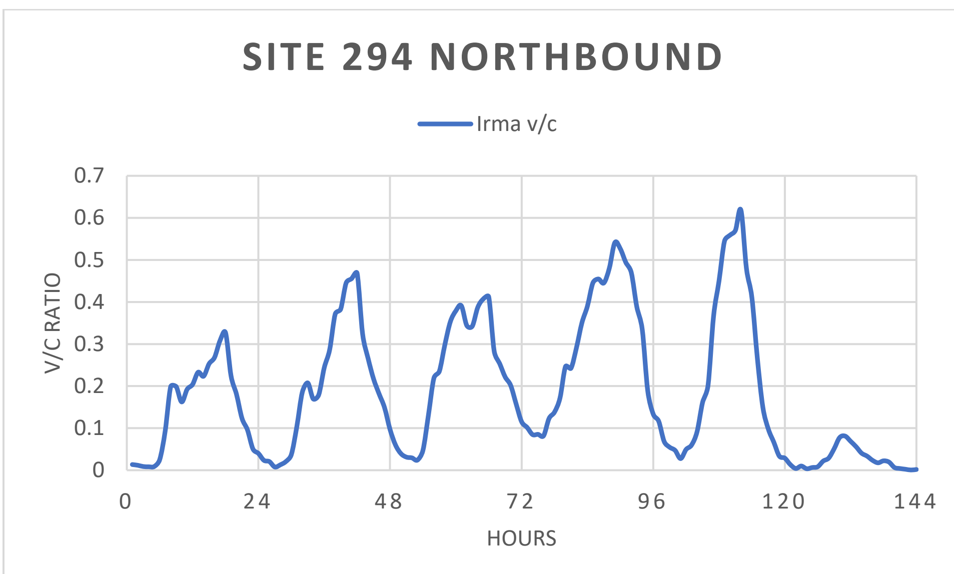

Figure F-62: v/c ratio result of Site 294

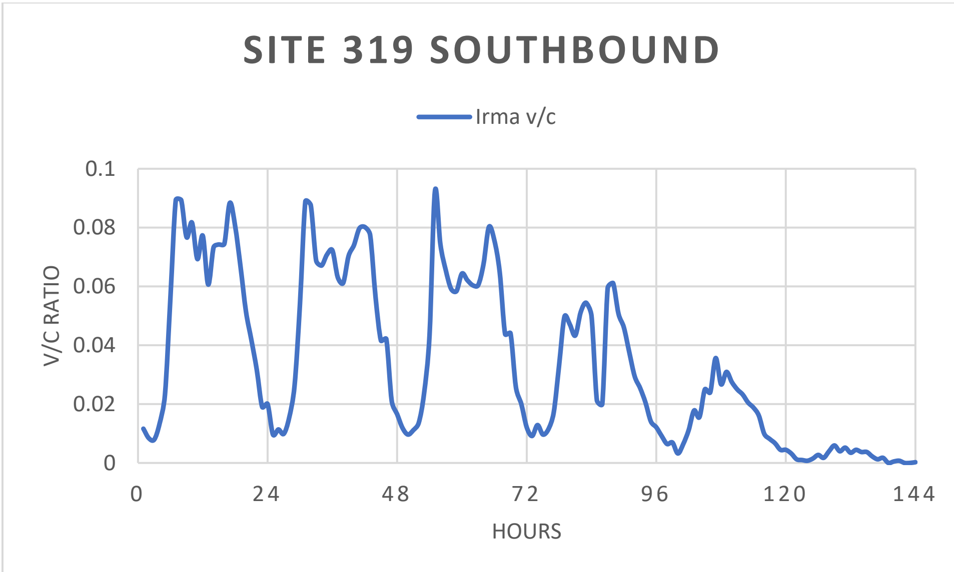

Figure F-63: v/c ratio result of Site 319

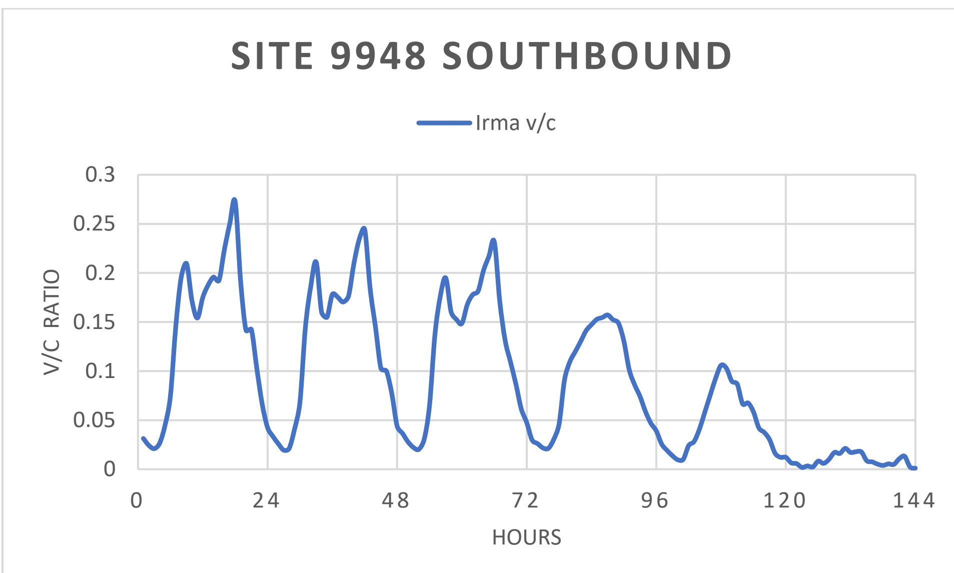

Figure F-64: v/c ratio result of Site 9948

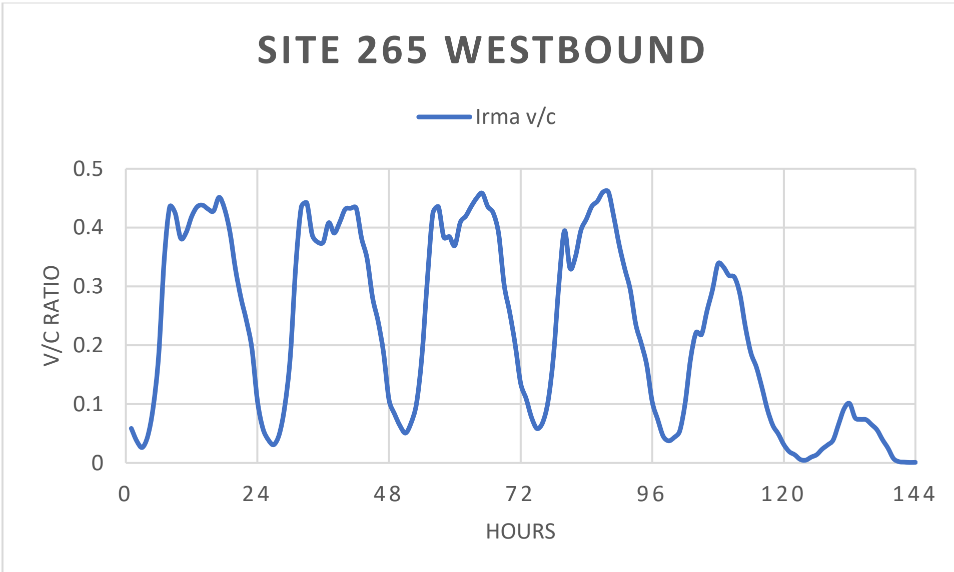

Figure F-65: v/c ratio result of Site 265

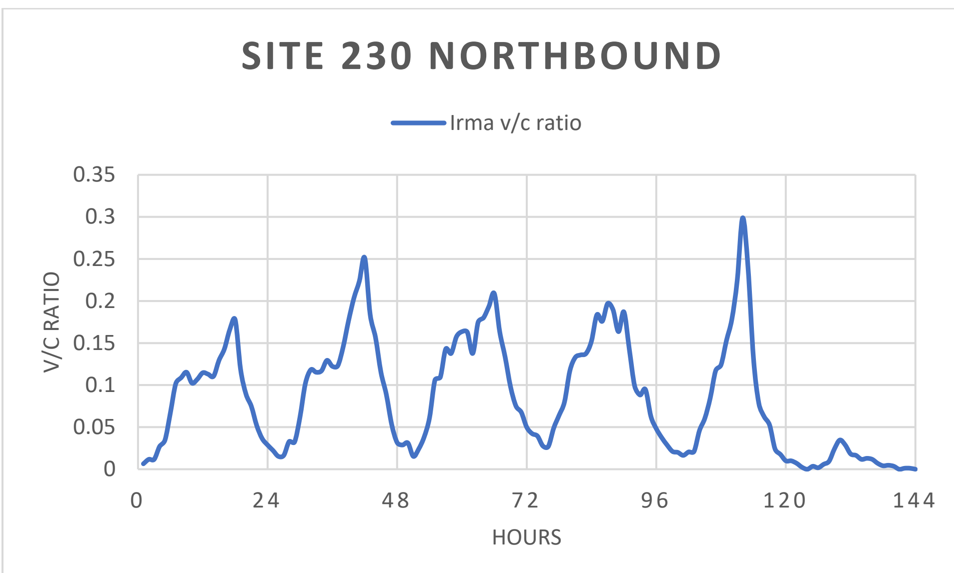

Figure F-66: v/c ratio result of Site 230

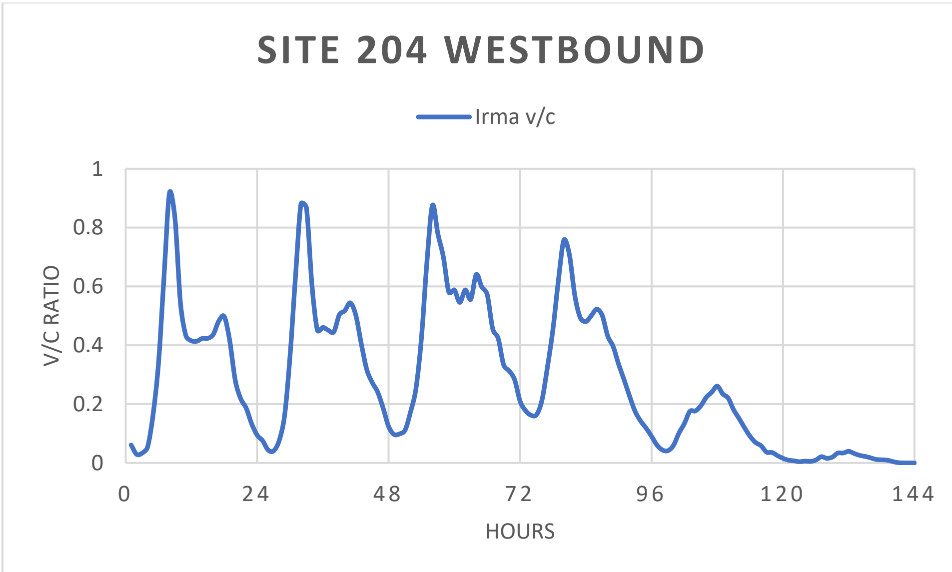

Figure F-67: v/c ratio result of Site 204

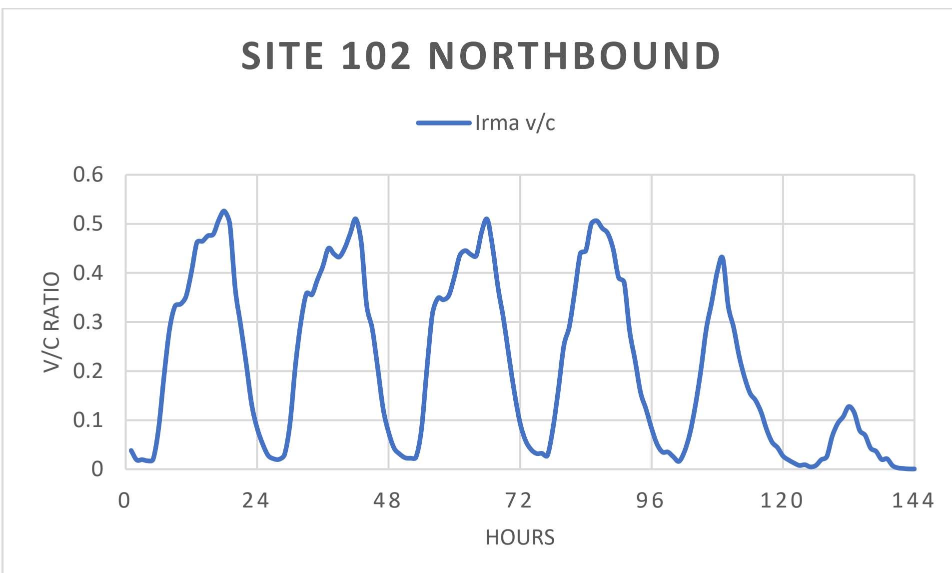

Figure F-68: v/c ratio result of Site 102

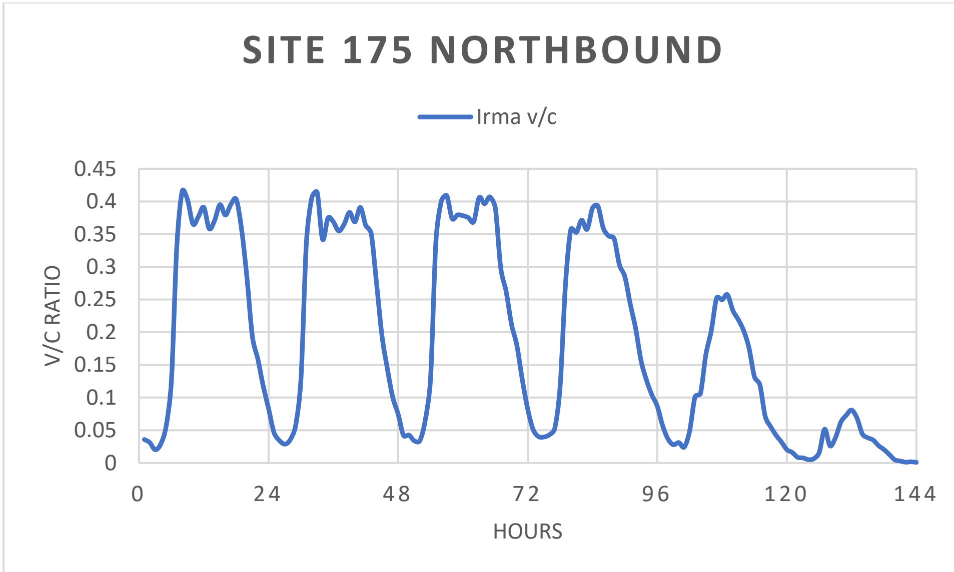

Figure F-69: v/c ratio result of Site 175

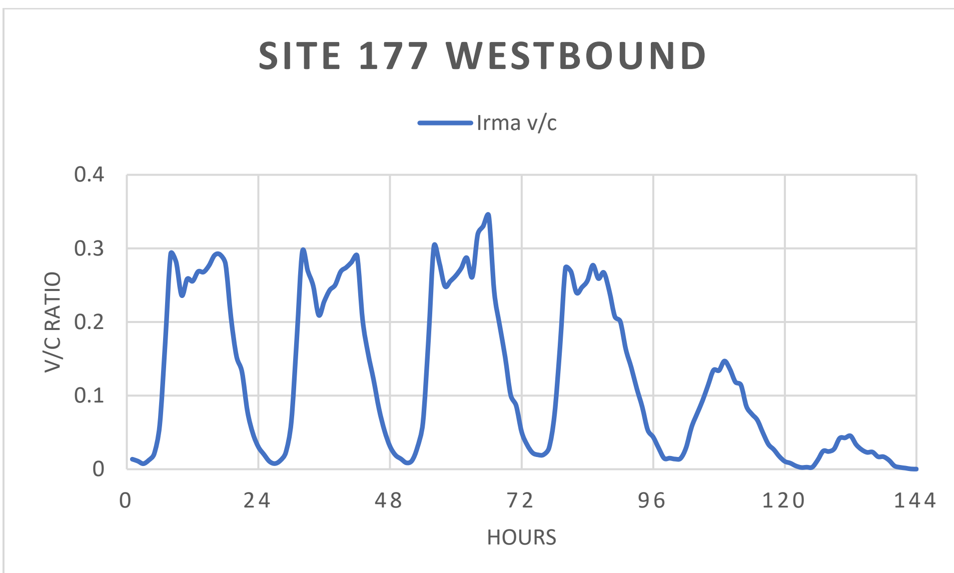

Figure F-70: v/c ratio result of Site 294

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