Louisiana Transportation Research Center

Final Report 605

Diverted Traffic Measurement

by

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16. Abstract

Most people in the US prefer to travel on freeways, but when there is congestion they divert onto local routes to avoid travel delay. This study measures the traffic diversion induced by an increase in congestion on the I-10 freeway in Baton Rouge during congestion, using a Bluetooth Detection System. The main objective of the study was to identify the difference in the level of congestion on the I-10 between the Mississippi River Bridge and the I-10/I-12 split and the level of congestion on local roads that triggers traffic to divert from the freeway to parallel arterials. Other objectives include measuring the time lag between the onset of congestion and diversionary behavior, and observing stability of behavior from incident to incident. The findings of the study indicate that diversionary behavior occurs when the Travel Time Index is 1.5 or above over that on parallel arterials. The time lag observed is 15-30 minutes for incidents occurring on the main section of the I-10 under study (i.e., between Perkins exit and Citiplace), but for incidents occurring on the beginning of the study section (i.e., between Nicholson Drive and Perkins exit), the time lag is between 0 and 15 minutes.

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ABSTRACT

Most people in the US prefer to travel on freeways, but when there is congestion, they divert onto local routes to avoid travel delay. This study measures the traffic diversion induced by an increase in congestion on I-10 freeway in Baton Rouge using a Bluetooth Detection System. The main objective of the study was to identify the difference in the level of congestion on I-10 between the Mississippi River Bridge and the I-10/I-12 split and the level of congestion on local roads that triggers traffic to divert from the freeway to parallel arterials. Other objectives include measuring the time lag between the onset of congestion and diversionary behavior and observing the stability of behavior from incident to incident. The findings of the study indicate that diversionary behavior occurs when the Travel Time Index is 1.5 or above that on parallel arterials. The time lag observed is 15-30 minutes for incidents occurring on the main section of the I-10 under study (i.e., between Perkins exit and Citiplace), but for incidents occurring at the beginning of the study section (i.e., between Nicholson Drive and Perkins exit), the time lag is between 0 and 15 minutes.

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IMPLEMENTATION STATEMENT

The study recommends that DOTD implement traffic management strategies that would encourage motorists to divert from I-10 to Perkins Road when I-10 between the bridge and the I-10/I-12 split gets blocked or starts to back up due to an incident. The Department could consider using variable message signs or the Waze app to inform motorists about possible diversions to Perkins Road.

The study also recommends that DOTD investigate potential improvements that could be made to Perkins Road between the Perkins Exit and Essen Lane to improve mobility and level of service with the aim of making it attractive to motorists traveling east on I-10. Furthermore, the cost of making improvements on Perkins should be compared with cost of widening I-10 between the bridge and the split.

The study recommends that DOTD extend the current study to identify possible alternative routes for traffic traveling west on I-10 when I-10 west between the bridge and 10/12 split gets blocked due to an incident.

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INTRODUCTION

Traffic congestion has existed for centuries and will continue to exist in the future. Government authorities try to alleviate congestion by implementing policies and other traffic management strategies. One popular policy that provides short-term relief from traffic congestion is the widening of roadways. Despite the policy's short-term effectiveness, it is still preferred because of its wide popularity and perceived effectiveness among the public.

Several factors are taken into consideration by transport authorities in justifying a particular policy to alleviate congestion. Loss of productivity and reduced efficiency of the transportation system resulting from congestion are some factors among several others. Traffic congestion that is characterized by lower speeds, longer queues, and longer trip times has typically been measured by induction loops and other radar-based devices. However, with the advent of new technologies such as Bluetooth, traditional technologies are being replaced by Bluetooth-based technology.

Bluetooth is a wireless technology primarily used for data exchange over short distances. Most electronic devices manufactured today come embedded with wireless Bluetooth technology to communicate and exchange information with other similar devices in the vicinity. It comes as no surprise that Bluetooth technology has penetrated the transportation industry because of its ubiquitous nature.

A roadside Bluetooth probe can detect, log, and time stamp the MAC address of a vehicle equipped with a Bluetooth device passing along a roadway segment. When a vehicle with a Bluetooth-enabled device traverses a road segment and is detected at two different points of known distance apart, the logged information is used to obtain a sample travel time for the segment. Multiple vehicle observations can provide an accurate estimate of the average travel time along a roadway segment. Bluetooth detection devices are reliable and can collect samples throughout the day. Also, installation is easy and the devices tend to be relatively maintenance free.

Bluetooth devices are being used more and more to measure travel time. In addition to measuring travel time, these devices can be used to measure the impact of implementing a policy. For example, instead of widening the I-10 between the I-10 / I-12 split and the Mississippi River Bridge in Baton Rouge (hereafter, called the I-10 study segment), the Louisiana Department of Transportation and Development (DOTD) questioned whether local arterials that could be used to divert some of the current traffic on the I-10 study segment thereby reducing the need to widen the freeway. To measure the effectiveness of the diversion, travel time on both the I-10 study segment and major parallel arterials in the vicinity (e.g., Perkins, Highland, LA 30) would have to be measured when severe congestion on the I-10 study segment has grown from its current level and then compared to the level that local arterials substitute for the freeway. However, the problem is that congestion on the I-10 study segment would have to worsen to its future condition to measure the diversionary behavior that would occur. Since it is not possible to observe future traffic congestion on the I-10 study link, an alternative scenario that mimics the conditions that might exist in the future is required. Although it does not produce consistent increased congestion, one possibility, and the one adopted in this study, is to measure diversionary behavior to local arterials when congestion develops due to an incident on the freeway. It is expected that motorists, and particularly those making local trips, are likely to prefer local arterials rather than a freeway with significantly higher congestion.

OBJECTIVE

This project was aimed at measuring the level of diversion that occurs when congestion levels on the I-10 freeway between the Mississippi Bridge and the I-10/I-12 split in Baton Rouge are greater than on parallel arterials. The level of congestion is measured in terms of travel time. Measurements are aimed at identifying level of difference in congestion the diversion of traffic begins to occur, what the time lag between the onset of congestion and diversionary behavior is, and how stable the behavior from event to event is. Incidents on the freeway can provide the conditions in which meaningful measurements can be made.

The objectives of the research are as follows:

1. Identify the difference in the level of congestion on the I-10 between the Mississippi River Bridge and the I-10/I-12 split and the level of congestion on local roads that triggers traffic to divert to Perkins Road, LA-30, and Highland Road from the freeway.
2. Identify the time lag between the onset of congestion and diversionary behavior.
3. Identify the stability of behavior observed in 1 and 2 above.

SCOPE

The scope of the project was limited to the I-10 freeway between the Mississippi Bridge and the I-10/1-12 split because the issue of increasing the capacity of the I-10 in that vicinity is not favored and alternative solutions, such as increasing the capacity of parallel arterials, could be more cost-effective. The scope was also limited to measuring diversionary behavior of traffic traveling east on the I-10.

METHODOLOGY

Literature Review

The purpose of the literature review was to investigate the factors that influence travelers to divert to alternate routes when congestion occurs on their primary route. The Transportation Information Research Database (TRID), Google Scholar, LSU libraries, Research Gate, and other databases were used to find relevant literature.

Importance of Route Choice Study

Route choice investigates the path chosen by network users. This is the most important decision made by the users on a daily basis, since it determines the volume of traffic on each route. Theoretically, traffic flow tends to attain a user equilibrium state wherein "journey times on all routes actually used are equal or less than those which would be experienced by a single vehicle on any unused route" *[1]*. The major shortcoming of this theory is that it assumes perfect knowledge of network conditions by users, that travel time is the sole criterion by which route choice is made, and that users are homogeneous in their perception and evaluation of travel time on the network.

Disproving Shortest Path Assumption of Wardrops' First Principle

A fairly recent empirical test on shortest path assumption by Shanjiang Zhu and David Levinson concluded that two-thirds of commuters did not traverse along the path with least travel time and none of the travelers used the shortest distance path except when it was the same as the least travel time path. This study captures the actual routes traversed by the people living in St. Paul metropolitan area using GPS (Global Positioning System) and GIS (Geographic Information System) road maps during a two-month study period. The shortest route predicted by the route choice model was then compared with the actual routes used by the travelers, to show the difference between observed behavior of humans with ideal assumption of route choice behavior *[2]*. The findings from this study are not consistent with what other researchers found. Hence the results from this study are not accepted as decisive unless confirmed by other researchers.

Stated Preference Studies to Find Factors Influencing Route Choice

Another study evaluated the route choice of commuters using the stated preference survey procedure coupled with GIS to generate the shortest path *[3]*. The goal of this research was to find the factors influencing the route choice behavior apart from shortest path which, as reported earlier, is widely recognized as the most influencing factor. A mail survey was conducted in which questions were asked on the factors that lead the drivers to take their primary route. The questionnaire also included the familiarity of a customized shortest path made using GIS. Shorter distance (37.8%), travel time reliability (37.1%) and traffic safety (28.7%), were the most influencing factors *[3]*. Number of roadway segments, freeway use, trip chaining, neighborhood security, and familiarity were among the other factors *[3]*. Results indicate that commuters tend to avoid routes with a high percentage of freeway links probably because of congestion. Also, commuters avoid routes with a large number of roadway segments. This research explains that shortest path, i.e., the lowest travel time or least travel distance are not the only factors influencing route choice behavior. Factors like freeway percentage and number of segments on a particular road also influence commuter behavior. The research does not consider the dynamic nature of commuter behavior. This research does, however, explain that perceptions vary from actual behavior, and commuters usually overestimate the benefits from a particular route and tend to neglect other routes unless an incident occurs.

A study by Khattak et al., based on a stated preference survey, suggests that drivers would divert to alternate routes if congestion occurs due to an incident and not during recurring congestion *[4]*. Also, drivers are willing to divert if the information was from a radio source as compared to observed congestion, because radio information would give quantitative information whereas the observed congestion would not allow the driver to estimate the congestion accurately *[4]*. Drivers would divert if the trip was from home to work because of their commitment to be at work by certain time. Also, other factors like unfamiliarity, safety, and traffic lights were reported to have a negative impact on diversion. One more interesting fact is that drivers with longer travel times were more willing to divert than drivers with shorter travel times *[4]*.

A pilot study by Carpenter suggests that the factors influencing route choice differ according to trip purpose [5]. For general trips, the most influencing factors were found to be the "general rules" like minimizing distance or minimizing travel time [5]. For work trips in the presence of children, factors such as the knowledge the driver has of the route and route planning information sources were also found to be significant [5]. Several other factors like congestion and messages on variable message signs were found to cause the traveler to divert from their original route.

Research Confirming Travel Time to be the Most Influential Factor for Route Choice
Several studies in the route choice research area confirm that travel time is the most influential factor affecting route selection *[6-9]*. In a behavioral study using a GPS, Spissu et al. found that, in general, car drivers tend to minimize travel distances over short trips and travel times over longer distances (more than 7 km) *[9]*. In a similar study conducted in the Atlanta metropolitan area on morning commuters, Li, Guensler, and Ogle determined that minimizing travel time though significant is not the sole factor that influences the morning commuters' route choice *[8]*. Other factors influencing commuters' route choice are traffic signals, number of idle stops, road

functional classification and percentage freeway distance *[8]*. Another interesting finding was that commuters who usually use the same route had a primary route with shorter distance and travel time, very few idle stops, trip chaining stops, and the least travel time variation compared to commuters using multiple routes *[8]*.

Study on Rationality of Users in Selecting a Route

Many researchers have conducted research on the rationality of users. One such research effort was conducted by Nayakama et al. The findings of this research suggest that drivers are not homogenous as the theory of network equilibrium assumes, but the network system consists of occasonally irrational drivers, indicating differentiation among the drivers *[10]*. Another key finding of the study was that drivers perceive travel time inaccurately which causes a deluded version of equilibrium to prevail while true equilibrium is not achieved *[10]*.

Concept of Bounded Rationality

A few researchers have raised the issue that travelers are subject to bounded rationality. Bounded rationality is the idea that in decision-making, the rationality of people is limited by the knowledge they have, their ability to learn, and the limited amount of time they have to react in and make a choice. In such behavior, the travelers tend to be satisficers; i.e., they tend to choose a route which is satisfactory rather than optimal. Nakayama et al. used a microsimulation model to investigate bounded rationality user equilibrium (BRUE) and concluded that travelers converge to a deluded equilibrium, where they perceive the travel times wrong and assume that their chosen route is the fastest route *[11]*.

Empirical Studies Using Data Collection Methodologies (GPS and Bluetooth) to Address the Dynamic Nature of Route Choice Behavior

With the emergence of new technology like GPS and Bluetooth technology, researchers are able to capture the dynamic nature of route choice behavior. These latest technologies give empirical evidence of route choice selected by travelers to be unlike the choice assumed in user equilibrium models (UE). GPS and Bluetooth technology track the actual path of the vehicles, simplifying the analysis of route choice.

Many researchers have employed GPS in their research [12, 13]. For instance, Lexington GPS data associated with vehicles from various households was analyzed to find if GPS data can be used to improve route/path choice assumptions [13]. This study was based on “matches” of trips, e.g., pairs of trips with similar starting and ending locations. The Path Deviation Index can be calculated for pairs of trips to measure the amount of spatial deviation between routes [13]. The author defined PDI as “the area between paths divided by the distance (in miles) along the shortest time path” [13]. The value of PDI can be 0, but there is no limit to the maximum. The

PDI can show the consistency of route choices of a single driver over a period as well as the consistency of path choices among different drivers in an area.

Path Deviation Index (PDI):

$$Path - Deviation\ Index = \frac{Encompassed\ Area\ (Square\ miles)}{Length\ of\ the\ shortest\ path\ (mile)}$$

In the same study, the PDI for trips made by the same person is only 0.08 miles whereas the PDI is 0.2 mile for the trips made by various drivers within a quarter mile *[13]*. The PDI is calculated to be 0.52 mile for the trips made by dissimilar drivers within half a mile *[13]*.

A similar study was conducted in Atlanta by Li in January 2004. Li used an Event Data Recorder (EDR) which can capture position and speed of vehicles every second. The EDR was installed in 450 vehicles from 250 households in Atlanta *[12]*. A sample of seven days' worth of data of morning commuting activities of 56 drivers was analyzed to find the route switching characteristics of morning commuters. The findings from this study suggest that morning commuters do not switch routes as frequently as they change their departure-time. It is also recognized that for most commuters there exists a usual route *[12]*.

Bluetooth probes when placed on routes of interest can track vehicle paths using the MAC address matching technique. Hainen et al conducted a study using Bluetooth probes in Indiana *[14]*. On November 13, 2009, the Cline Avenue Bridge on Indiana State Road (SR) 912 was unexpectedly closed because of deteriorating structural conditions and the officials decided to assess the route choice of motorists, who normally used the bridge. The main objective was to estimate the distribution of traffic on 4 different alternative routes. Twelve Bluetooth Monitoring Stations (BMS) were installed at various locations along the 4 routes which were named the Indiana Department of Transportation (IDOT) official detour, the unofficial route, the local route, and the hybrid route to distinguish the routes for analysis. It was observed from the Media Access Control (MAC) address matches that 57.4% of the eastbound motorists and 44% of the westbound motorists selected the local route whereas 8.9% eastbound and 11.1% westbound used the official route, 14% eastbound and 18.1% westbound used the unofficial route, and 19.8% eastbound and 27.1% westbound used the hybrid route. Once travel times from the Bluetooth matches were associated with a route, a plot was generated to compare the 25th, 50th, and 75th percentile travel times. Comparing the route choice percentage on each route with the travel times provided an opportunity to validate the assumption that the route with the lowest travel time would have the largest percentage of traffic *[14]*. From the comparison, it was observed that the local route which had the largest percentage of diverted traffic also had the lowest travel time; hence the authors concluded that the local route was widely chosen by the motorists based on their local knowledge of expected travel time on alternative routes.

Impact of Adverse Weather Conditions on the Travelers to Switch Routes. Khattak conducted a behavioral survey in Brussels, Belgium to understand how travelers would behave during normal and severe weather situations. A survey was designed to investigate how travel choices are influenced by individuals' characteristics, travel behavior, situational factors, travel information and how habitual travel patterns are altered. The reported results were based on 57% of the collected sample which constituted regular automobile users. About 54% of travelers change their mode, departure time and/or route choices in response to severe weather situations *[15]*. Respondents were asked to report on a 5 point scale varying from very important to not important as to the importance of weather conditions on their travel decisions; 14% of respondents felt the impact of severe weather on route change to be very important and 22% found it to be important *[15]*.

Drivers felt that changing departure time is easier than changing route, also all routes are adversely affected by weather so route switching is not appropriate for most users *[15]*.

Advanced Travel Information Systems (ATIS) would help travelers a lot during harsh weather conditions and help them avoid icy roads or foggy conditions and, therefore, reduce accidents.

Summary of Literature Review. The literature review examined the factors influencing route choice behavior of travelers during congestion. Researchers employed various methodologies like stated preference choice studies, simulation modeling techniques and collecting route choice data using the latest technology such as GPS, to examine this question. Findings suggest that many factors like travel time, freeway percentage of a route, number of roadway segments, number of intersections, number of turns, time of day, trip purpose, locality of the route, and weather conditions, are influential in route choice behavior, but most of the researchers confirmed that travel time is the most important and influential factor affecting route choice behavior.

Identify Locations to Install Bluetooth Devices and Volume Counters

Before Bluetooth devices could be installed, local arterials parallel to the I-10 between the Mississippi Bridge and the I-10/12 split were identified using Google Maps. The top ranked possible alternative routes were Perkins Road, Highland Road, and LA-30 because they appeared to have the shortest travel times and highest accessibility for drivers traveling east on I-10. The selected routes are shown on the map in Figure 1.

After selecting the routes, the next step was to identify suitable infrastructure on which to mount Bluetooth devices. A field visit was conducted to look for suitable locations (example traffic signal poles, other infrastructure) at intersections on chosen routes. Once the proper infrastructure (mostly traffic poles at intersections) was identified, the corresponding authorities who either maintained or owned such property were contacted for approval to mount the equipment to their infrastructure. Specifically, the City Parish Engineer’s Office and District 61 Office of DOTD were contacted.

Early in the project planning phase, the study team was informed by DOTD's ITS division that they were planning to install a Bluetoad System along I-10 and Airline highway. Thus, a decision to coordinate with DOTD to collect travel times on I-10 was made early in the project planning phase, which eliminated the need to install a separate Bluetoad system on I-10.

The locations identified to install devices along with intersection labels and Bluetooth installation locations are shown in Figure 2.

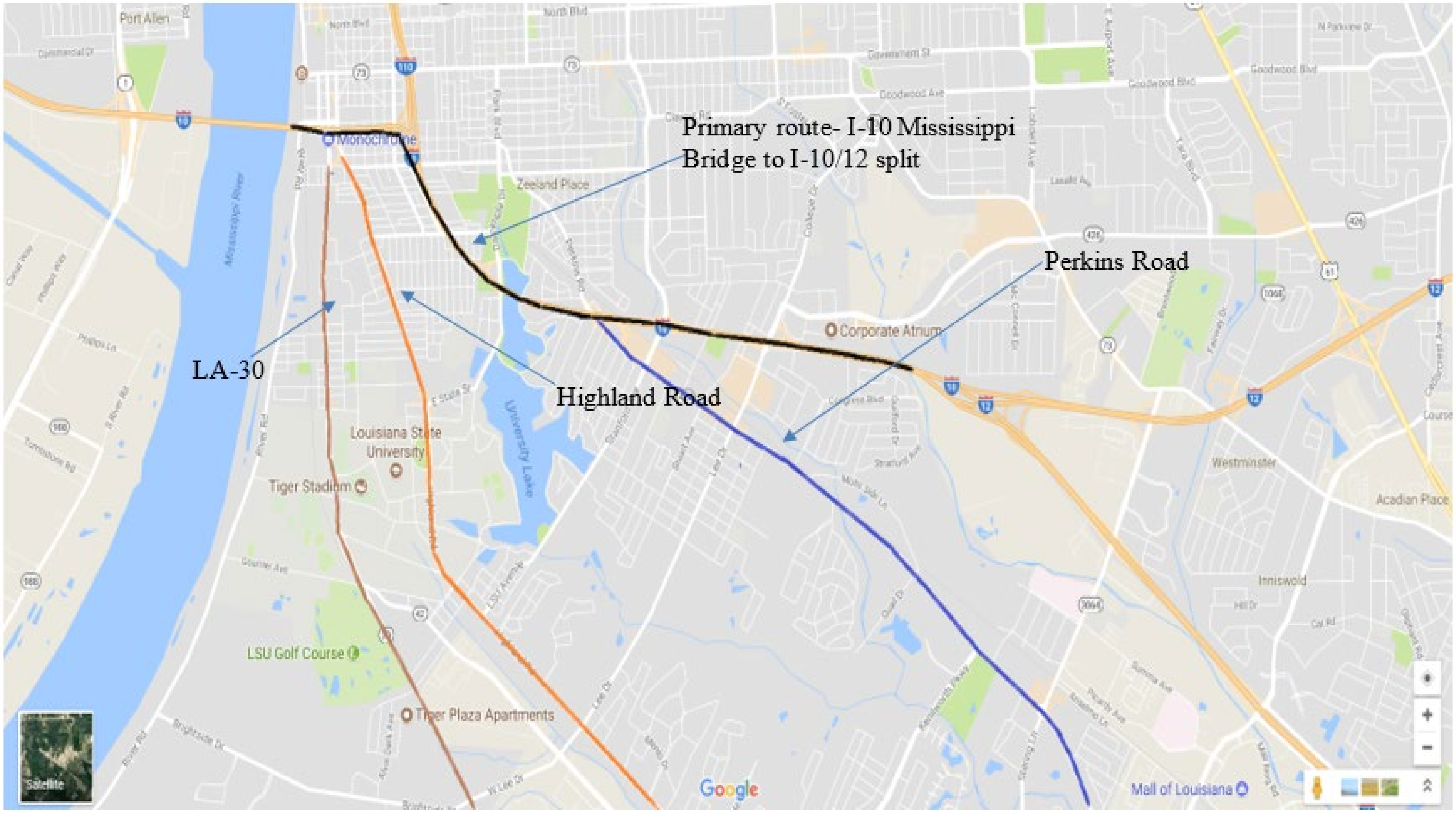


Figure 1
Map showing primary and alternate routes

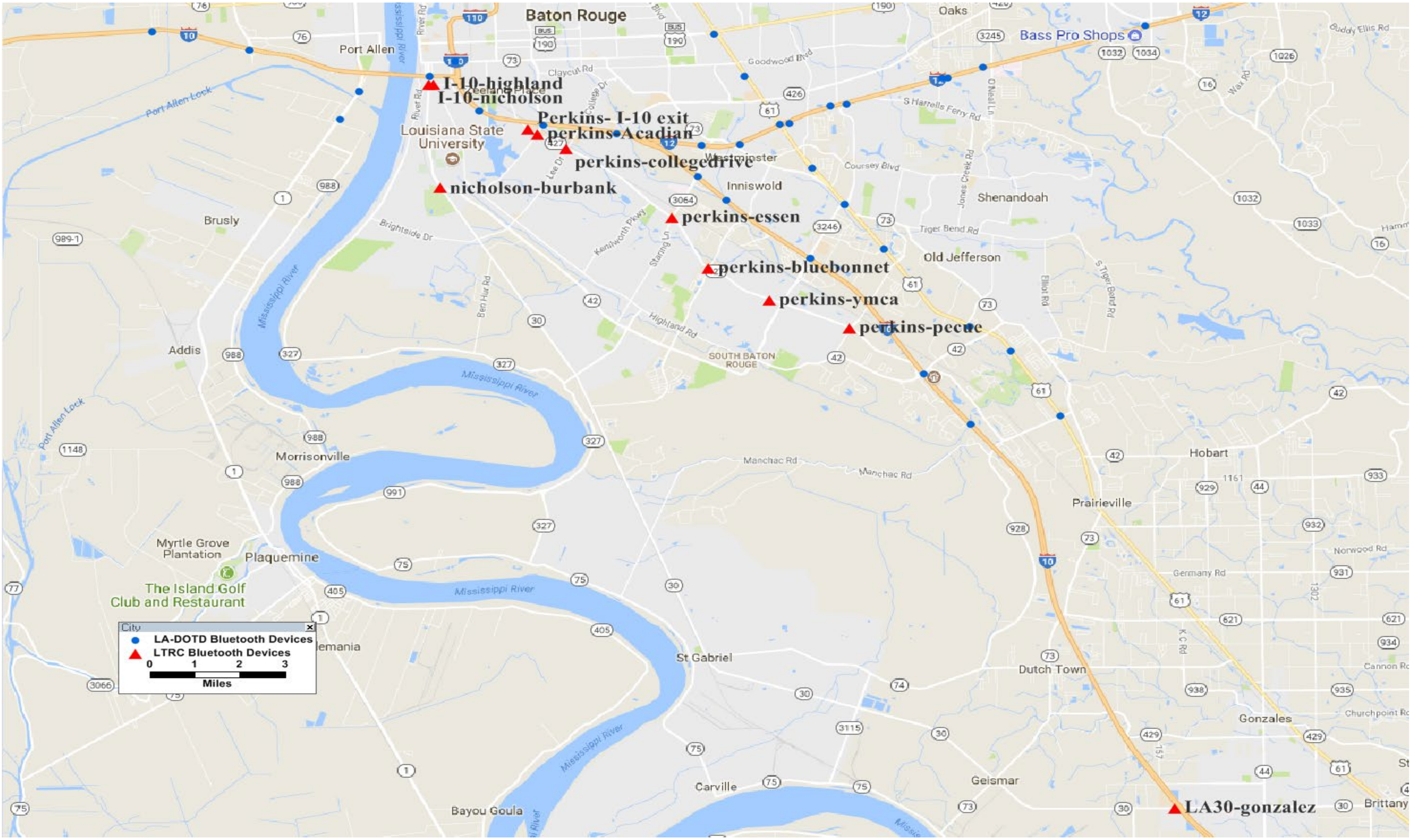


Figure 2
Map showing Bluetooth Detection Devices (both DOTD and LTRC)

Procuring Equipment

The next task was to purchase volume counters which could be installed at chosen locations. Before initiating the purchase of counters two criteria were established to eliminate the need of having to evaluate a long list of counters for their potential use in the project. The first criterion was that the volume counters be capable of non-intrusively recording volume counts every 5 to 15 minutes and the second criterion was that the counters be capable of sending data remotely via a cellular connection.

After conducting a thorough research and contacting multiple vendors, the decision was made to procure and use RTMS (Real Time Microwave Sensor) Sx-300, which is a non-intrusive radar-based device that works both on battery for temporary installation and solar power and battery for long-term installation. The RTMS Sx-300 has the ability to send data in real time through a cellular connection, and it also provides a web interface to interact with the device remotely and to download data in various formats for further analysis. Figure 3 below shows the picture of an RTMS Sx-300 sensor.

Figure 3
Picture showing an RTMS Sx-300 sensor

The current project required long-term installation of RTMS sensors since it was required to collect data for at least 6 months to fulfill project objectives. Thus, a power system capable of drawing power from batteries while simultaneously being charged by solar power during day time was acquired and installed along with RTMS sensor. The power system consisted of solar panels, solar charger, two industrial grade batteries and a cabinet to house batteries. All the equipment is described in detail in the following paragraphs

Solar Panels: Solar Panels with enough wattage to charge batteries were required because each RTMS sensor requires continuous supply of power. Thus, a total of fourteen 120W Ameresco solar panels were bought for the project to accompany the 14 RTMS devices. The dimensions of solar panel are 48.4 x 26.5 x 2 in. and weigh about 10 pounds. Figure 4 below shows the image of a solar panel used for the project.

Figure 4
Picture showing a 120W Ameresco Solar Panel

Two batteries were required at each location to provide power for the sensors continuously, so a total of 28 12v gel deep cycle Deka solar batteries were bought for the project. Each battery weighs about 60 pounds. Figure 5 below shows the picture of a Deka solar battery.

Figure 5
Picture showing a Deka solar battery

Cabinet boxes with customized back plate and an integrated solar charge controller (regulates voltage to prevent batteries from overcharging and overdrawing) are purchased to hold the batteries. The cabinet boxes are made of stainless steel. The dimensions of cabinet box are 22.625 x 19.25 x 19.625 in. and weigh about 32 pounds. Figure 6 below shows the picture of a cabinet box.

Figure 6
Picture showing a cabinet box

Two types of cables were required for the setup. A solar output cable and an RTMS cable. RTMS cables are used to interconnect sensors with communication, and power components. One end of the RTMS cable has a 32 pin MS connector which is connected to the sensor and the other end of the cable has three outputs for communication and power: An Ethernet output for TCP communications, a serial pin for communicating with a computer directly and a power output which is connected to the charge controller for providing power to the sensor from batteries.

The solar output cable is used to connect the solar panel to the charge controller to charge the batteries. Fourteen cables of each type were purchased for the project. Apart from these cables, 28 battery cables were purchased to connect batteries in series. Battery connectors enable two or more batteries to act as a single source for drawing power. A solar output cable and battery cables are shown in Figure 7. An RTMS cable with three outputs- serial, TCP and power is shown in Figure 8.

Figure 7
(a) Solar output cable (b) battery cables

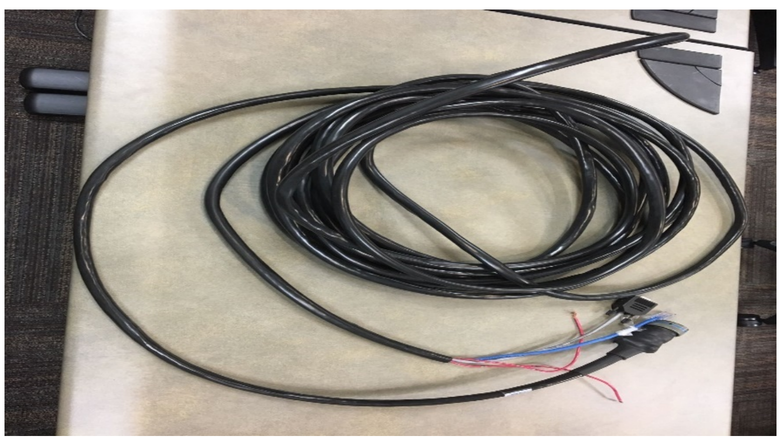


Figure 8
RTMS cable with communication and power outputs

A bracket assembly shown in Figure 9 was supplied along with solar panels. However, to secure the solar panel using banding, T-shaped custom-made brackets with groove to slide in a C-channel were required.

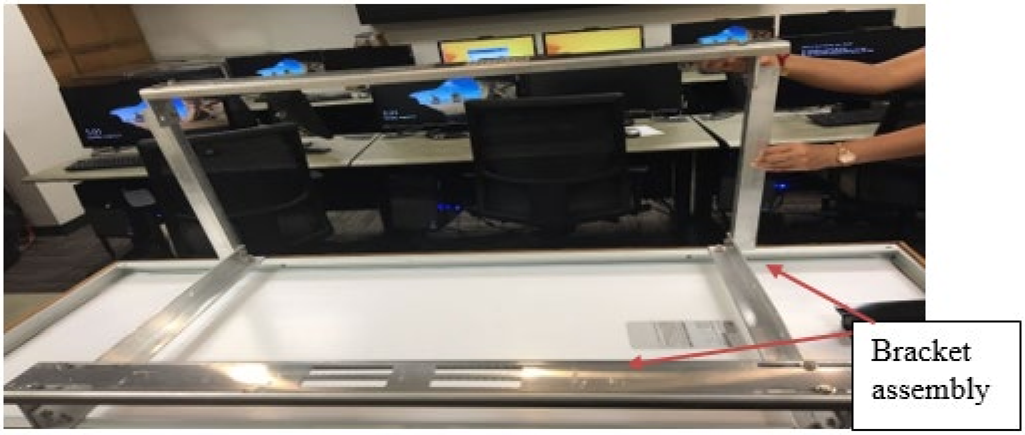


Figure 9
Solar panel bracket assembly

Figure 10(a) shows the T-shaped bracket with C-channel attached to the solar panel bracket assembly. The entire solar panel assembly secured to a pole using banding shown in Figure 10(b).

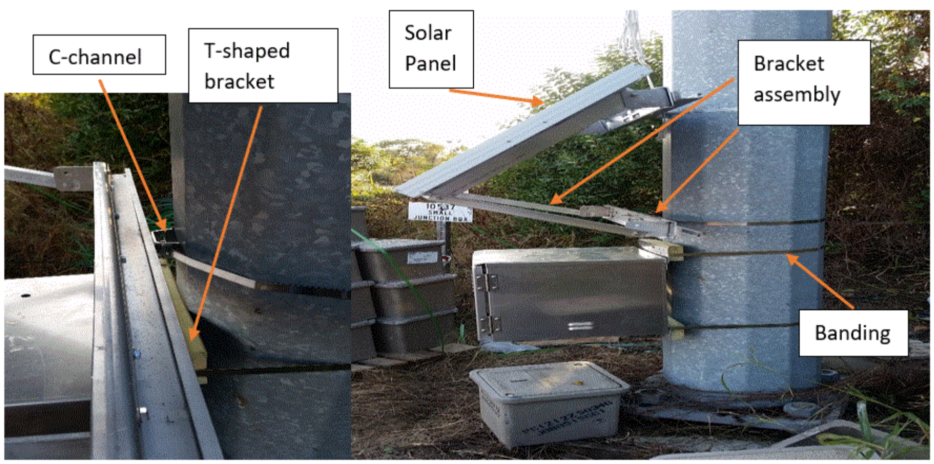


Figure 10
(a) T-shaped bracket with C-channel attached to it (b) solar panel assembly secured to a traffic pole

Two C-channels and two T-brackets were required to secure a single solar panel to a pole and thus a total of 28 C-channels and T-brackets were needed. About 300 ft. of Stainless steel banding with three-fourth of an inch thickness was also bought for use in installation. For securing cabinets, the vendor recommended using a Pole Cat assembly as shown in Figure 11 and accordingly the research team bought fourteen custom made Pole-cat units.

Figure 11
T-brace with Pole-Cat assembly attached to it

Installing and Calibrating Devices

Installing Volume Counters

Because of a lack of resources at LTRC to properly install the devices, assistance from DOTD was sought to install RTMS sensors and Bluetooth devices at planned locations. A series of meetings were organized with the DOTD Section 45 to discuss the installation procedure and request assistance. Before the actual installation, the investigators visited DOTD Section 45 to test and seek technicians' opinion and advice about bracket assembly and banding's ability to hold the equipment safely and securely. Upon receiving safety approval from the technicians, an agreement on a schedule was put in place to install both Bluetooth counters and volume counters at preplanned locations. A detailed list of installation procedures was prepared and provided to the DOTD personnel since there were a lot of components like solar panels, cabinets, sensors involved in the installation. The provision of installation instructions minimized time and effort required to finish the installation. The total time for installing both the RTMS and Bluetooth counters was approximately 2 hours per location. Figure 12 shows the picture of a finished installation for both the devices at the intersection of the Tanger Outlet Mall Road and LA 30 in Gonzalez. It took almost 2 months to install the devices at all locations because of the rigorous schedules and other DOTD priorities the personnel had to attend to. The Bluetooth sensors were activated immediately right after the installation and were ready to transfer data wirelessly. However, the RTMS Sx-300 sensors needed calibration before they started transmitting data and the calibration of RTMS Sx-300 sensor is discussed in next section.

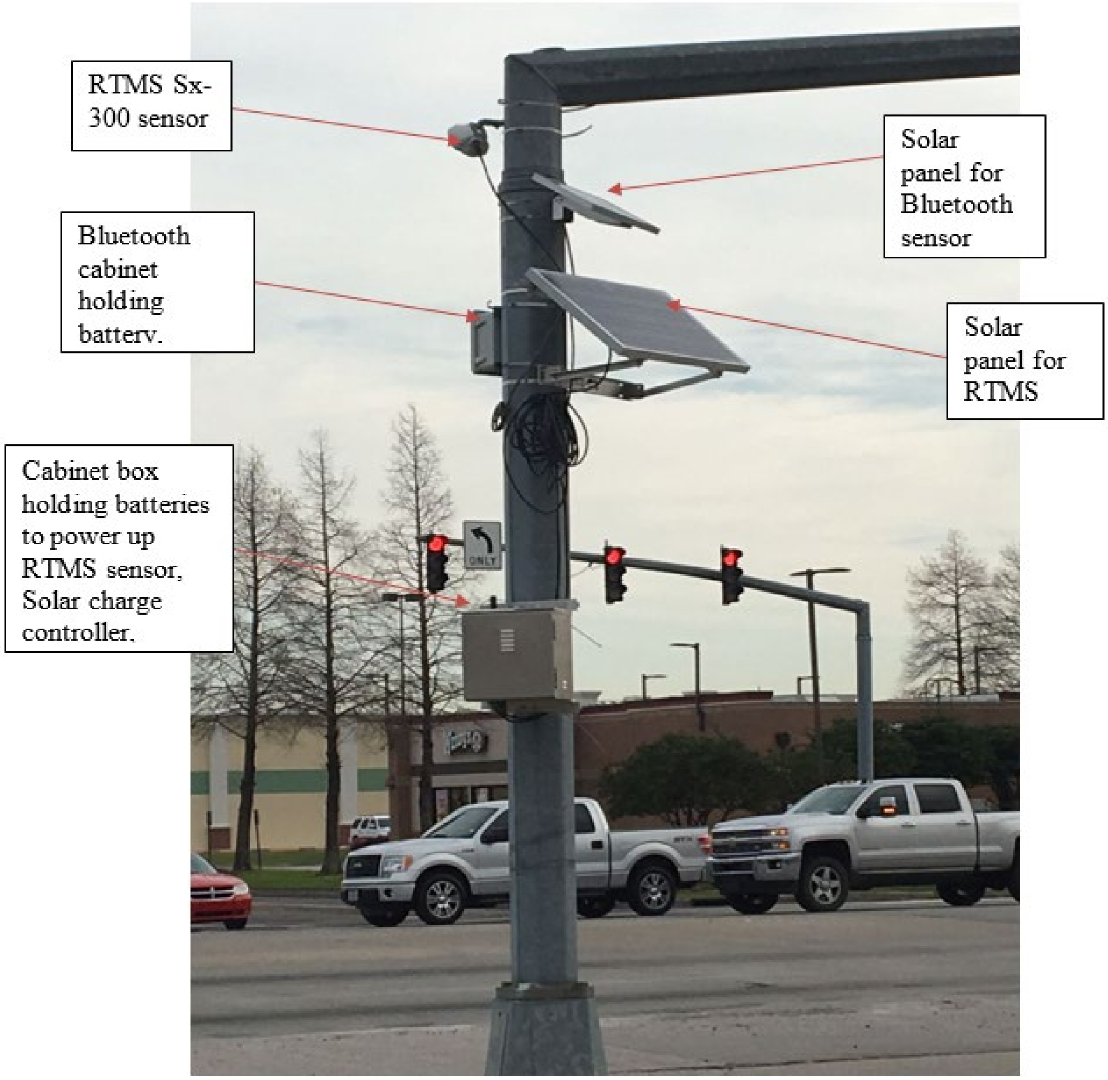


Figure 12
Installation of RTMS Sx-300 and Bluetooth sensor

Calibrating Volume Counters Using RTMS Sx-300 Setup Utility

The RTMS Sx-300 setup utility is the software program which is used to communicate with the RTMS Sx-300. It can be used to communicate with a single sensor or with multiple sensors, when all sensors are on the same communication platform and are in polled mode. It has various menu options which are used to configure and operate the sensor. The latest version of the RTMS setup utility was downloaded and installed on a computer to perform calibration. Once the volume counters are installed and powered up, the devices have to be calibrated using the RTMS setup utility before counters start collecting data. Calibration involves a lot of steps such as setting up number of lanes to be monitored, calibration of speeds to match actual speeds with that of speed calculated by RTMS Sx-300 sensor, adjusting sensitivity to capture vehicles of various sizes and most importantly verification of counts.

Configuration Process. After the RTMS Sx-300 is secured to a pole, it is connected to the serial port of a computer which has the setup utility installed. If the communication is established, a main screen appears which can be used to start the calibration or else a start screen appears which can be used to identify and establish communication with sensors. The main screen and the start screen are shown in Figure 13.

Each sensor in the system is then configured by the user using different menu items available on the main screen. The first step in the process is setting the region for a sensor to ensure its proper operation. The region of a sensor is set using the advanced tab which can be accessed by clicking on the manual settings button on the main screen.

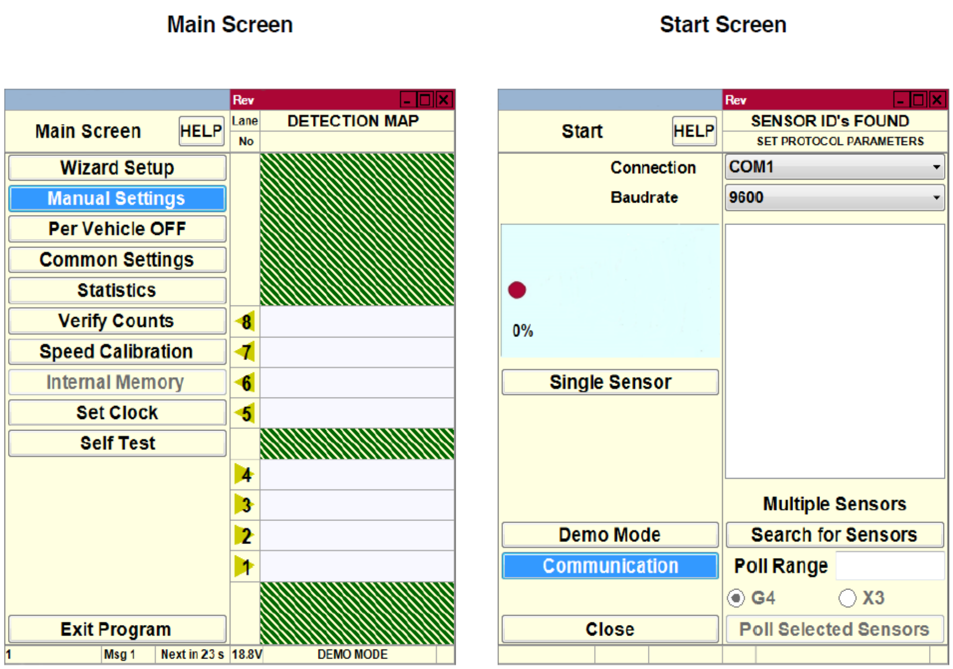


Figure 13
Figure showing functions on main screen and start screen

Once the region is set, the next step is to set application mode, which is accessed by clicking the manual settings button on the main screen. The Application tab consists of several options such as Side fired highway which is used for highway applications and Midblock which is used when traffic is congested, and lanes are narrow. For this project, Midblock is selected as application mode since all sensors for the project are installed on arterials. Figure 14 below shows the Manual setup screen and the application screen which are utilized to set the application mode.

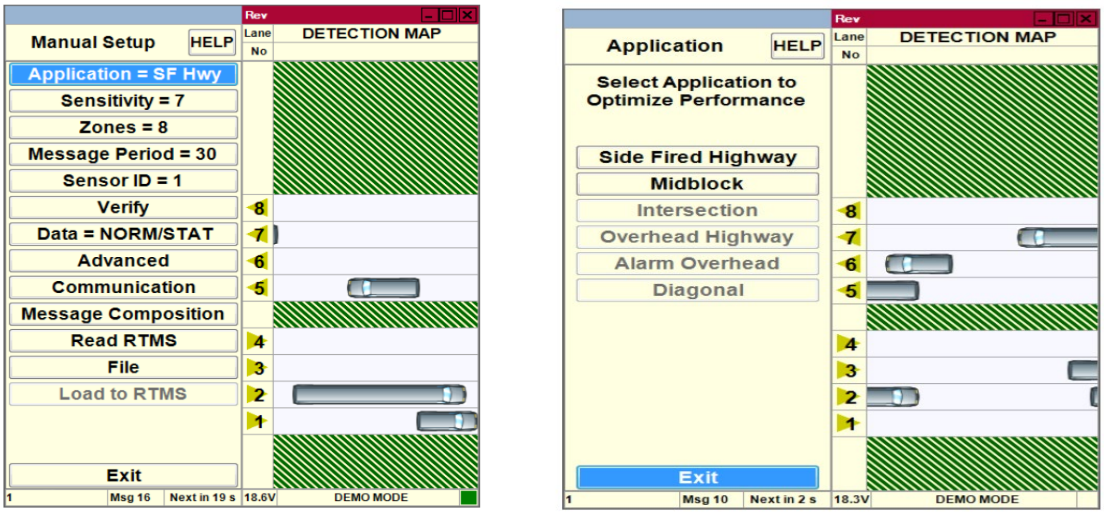


Figure 14
Manual setup screen(left). Application screen(right)

After setting the application mode, the next step is the most important one: setting lanes of interest for monitoring using the wizard setup. Wizard setup is automated and requires free flowing traffic in all lanes of interest. The RTMS sensor can detect up to 12 zones which represents lanes where traffic can be detected. The process is performed in two-steps:

- Step1: Wizard setup finds zones automatically that match lanes with traffic detection.
- Step2: Wizard setup adjusts zone boundaries to match lane widths.

Detecting Lanes Using Wizard Setup. The Wizard setup window can be accessed by clicking wizard setup on the main screen. In the wizard setup window, setup can be initialized by clicking on the start wizard button on top of the screen. The wizard setup window with zone detection map on right side of the window is shown in Figure 15. Once the indicator shows 100% it means that initial setup is completed, and selected zones are displayed. Zones can be added or deleted by using the zone setup button (shown in Figure 15) until the required number of zones are created. Then by clicking continue, the wizard button shown in Figure 15, the user can finish the setup.

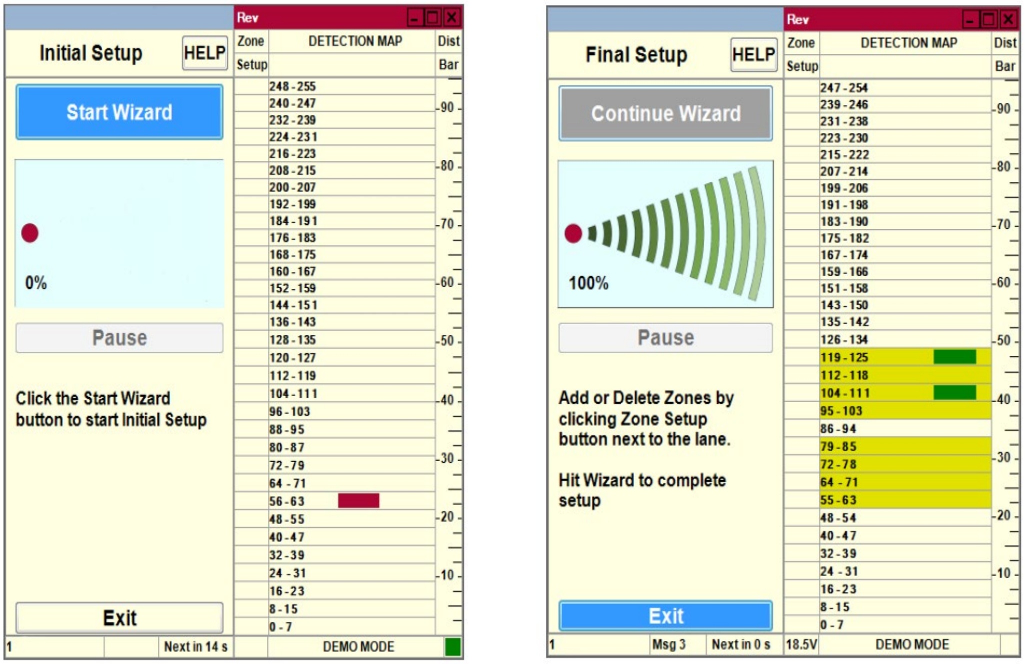


Figure 15
Initial wizard setup window (left), final setup wizard window (right)

Adjusting Zones. After creating zones using the wizard setup, zones can be viewed and adjusted by accessing zones tab from the main settings. The zone setup screen consists of options like labeling (to label zones) and fine tune (to fine tune zones) on the left side and detection map with lane numbers on right side as shown in Figure 16. The user verifies the traffic shown in the detection map is travelling in the right direction for each zone as seen physically. If the vehicles on the detection map does not correspond to the actual traffic, then the user must fine tune the zones using the fine tune button. If the user observes that smaller vehicles are missed or bigger vehicles are counted twice then the user must adjust the sensitivity which can be accessed from the manual settings screen. Once the user is satisfied, the settings can be saved by clicking ok to return to the main screen and proceed further.

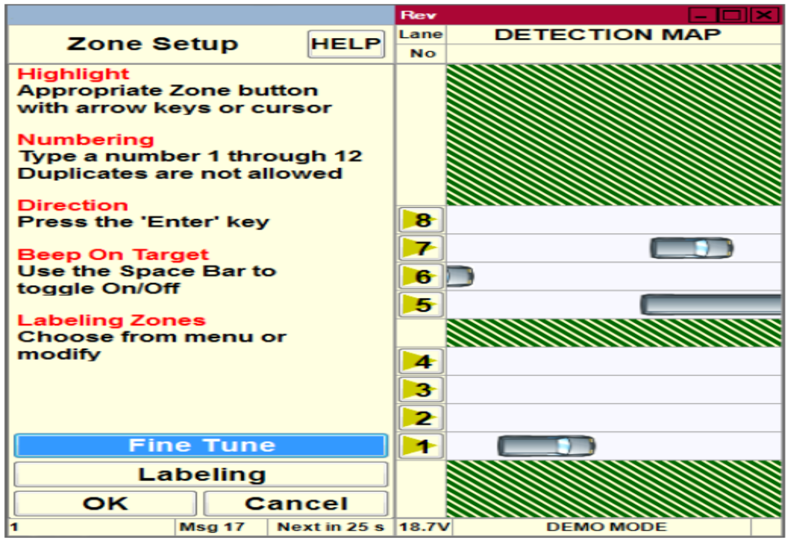


Figure 16
Zone setup screen with options on the left and detection map on the right

After the zones are set, the next step is to verify vehicle counts which is a vital part of calibration. During this process the number of vehicles counted by the RTMS Sx-300 are compared to a manual count for a particular time interval or until a minimum of 50 vehicles are counted. If there are a sufficient amount of people to conduct the manual counts, then all the zones/lanes can be verified simultaneously.

The verify counts window is accessed from the main screen. On the right side of the verify counts window, sensor counts are updated for the respective lane numbers as soon as a sensor detects a vehicle. Also, there are columns to input manual counts, calculate difference in counts and percentage deviation in counts. The verify counts window with numbers populated in respective columns is shown in Figure 17 below. If percentage deviation is more than 5%, then the zones are adjusted for accuracy. The process is repeated until percentage deviation is less than 5%. The user can return to the main screen by pressing exit if the results are satisfactory.

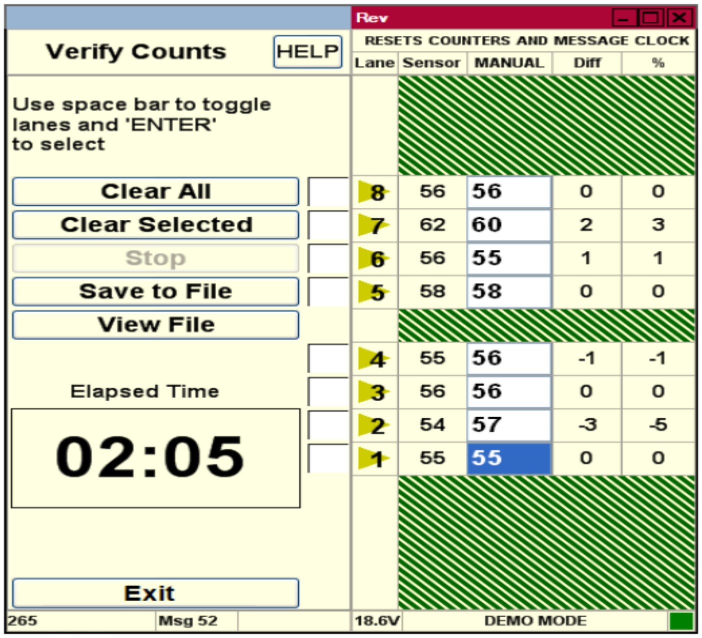


Figure 17
Verify counts window showing difference between sensor and manual counts

After the configuration/calibration process is finished, settings are saved in a file for backup. The configuration process mentioned above is repeated for all devices and settings for each device are saved with separate file names respectively. Devices are used for data collection after successful calibration.

Communications

After the devices are installed, the next step is to collect data. The traffic count data recorded by RTMS sensors is stored temporarily locally before it is transmitted to a desktop/laptop computer wirelessly using cellular communications. To establish cellular connections, cellular modems and a cellular subscription for modems are required. Microhard Bullet-LTE modems were used in this project to establish an internet connection between each RTMS sensor and internet. Static IP addresses are assigned to each modem provided by internet connection provider AT&T. Each modem is configured by following the instructions in the manual provided by Microhard systems for continuous communication with the remotely located computer that collects data. A picture of Microhard Bullet-LTE modem is shown in Figure 18(a). The cellular modem draws power from the same batteries which are used to power up the RTMS Sx-300 sensor. The cellular modem comes with an antenna which is shown in Figure 18(b) attached to the cabinet.

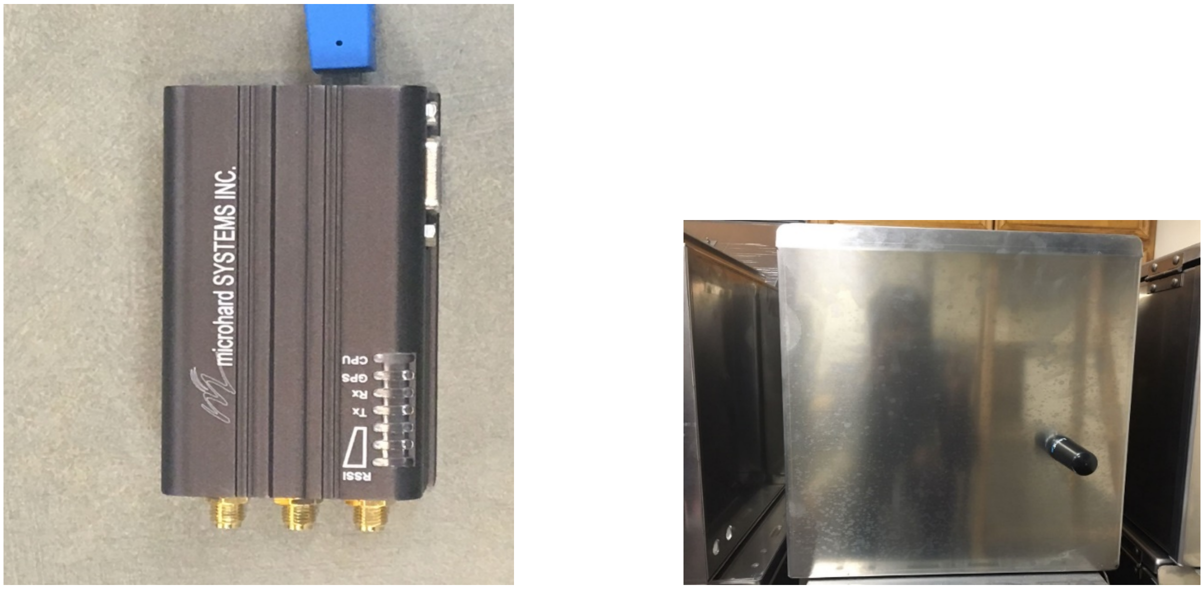


Figure 18
(a) Microhard Bullet-LTE cellular modem
(b) antenna of cellular modem attached to cabinet

Configuring Cellular Modems

Cellular modems need to be configured in order to communicate with internet and transmit data collected by RTMS sensors. The configuration process involves following steps.

Accessing Web User Interface. The configuration of a Bullet Cellular modem consists of a Web User Interface method. Accessing the interface involves following steps.

- Connecting Bullet Ethernet(LAN) port to PC using an Ethernet cable.
- Applying power to the Bullet modem and waiting for 60 seconds for the bullet to load.
- Opening a web browser and entering the default IP address (192.168.168.1).
- A log on window appears after entering the default IP address. A default username: admin and a password: admin, should be typed in the logon window.
- After entering the credentials, the system summary page as shown in Figure 19 below is displayed showing all the system settings and status of various functions of the Bullet.

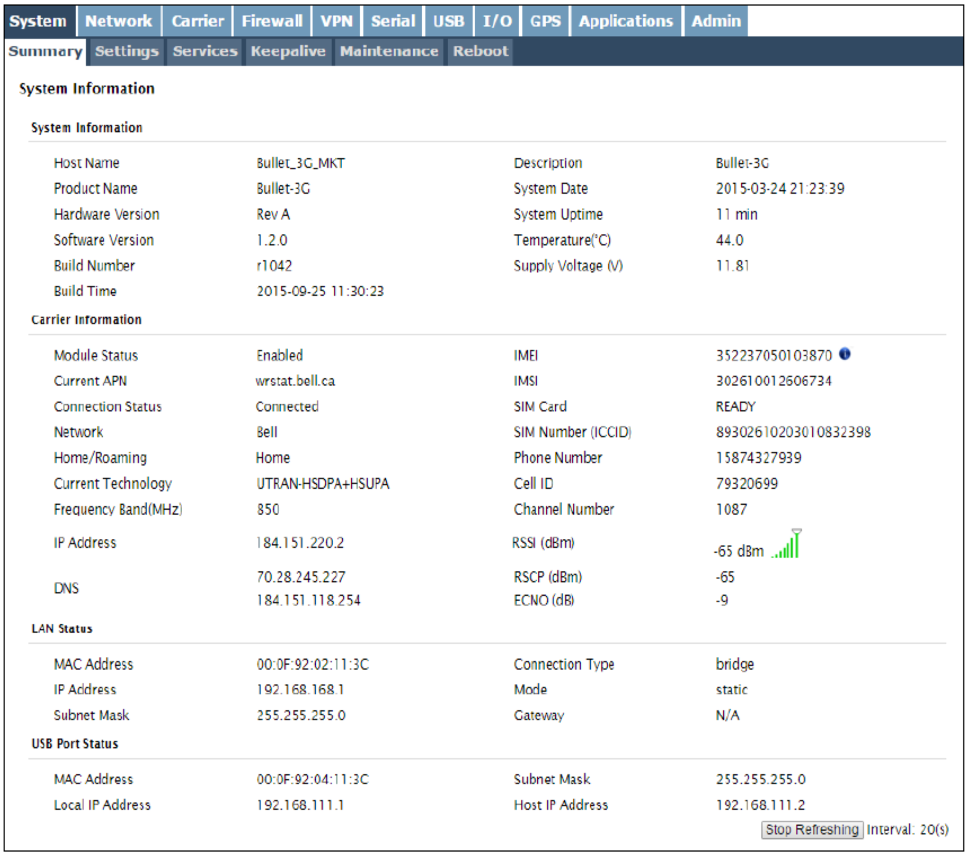


Figure 19
System summary

System Configuration. The main category tabs located at the top of the navigation bar separate the configuration of the Bullet modem into different groups based on function. The System Tab contains the following sub menus.

The system settings tab is used to configure Host name, Description, console timeout and System Log server settings. The settings used are shown in Figure 20 below.

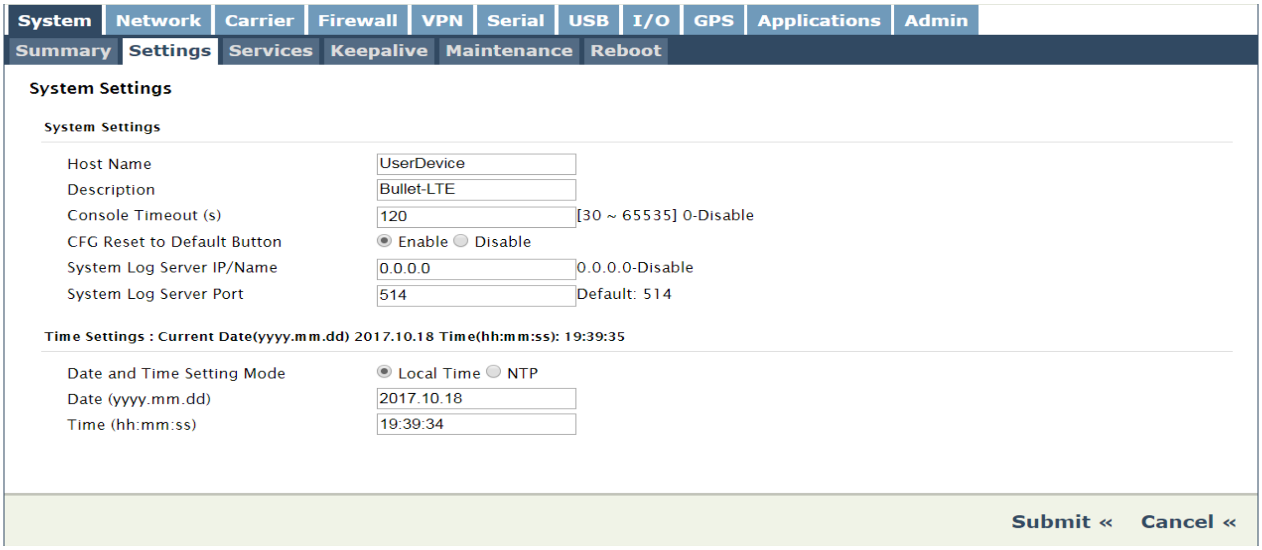


Figure 20
System settings window

The services tab is used to enable or disable a few services for security reasons as shown in Figure 21 below. The changes made here are applied after a system reboot.

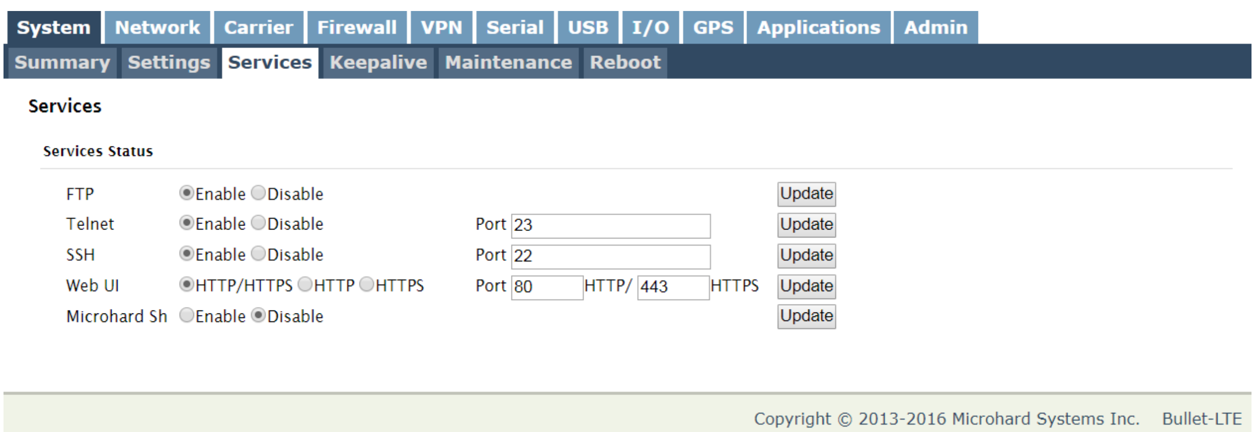


Figure 21
System services window

The keep alive tab is used to configure the keep alive features of the Bullet modem and check for activity on several interfaces shown below in Figure 22. If the Bullet modem does not recognize any activity on any of the interfaces shown below, it will reboot itself to resolve any issues.

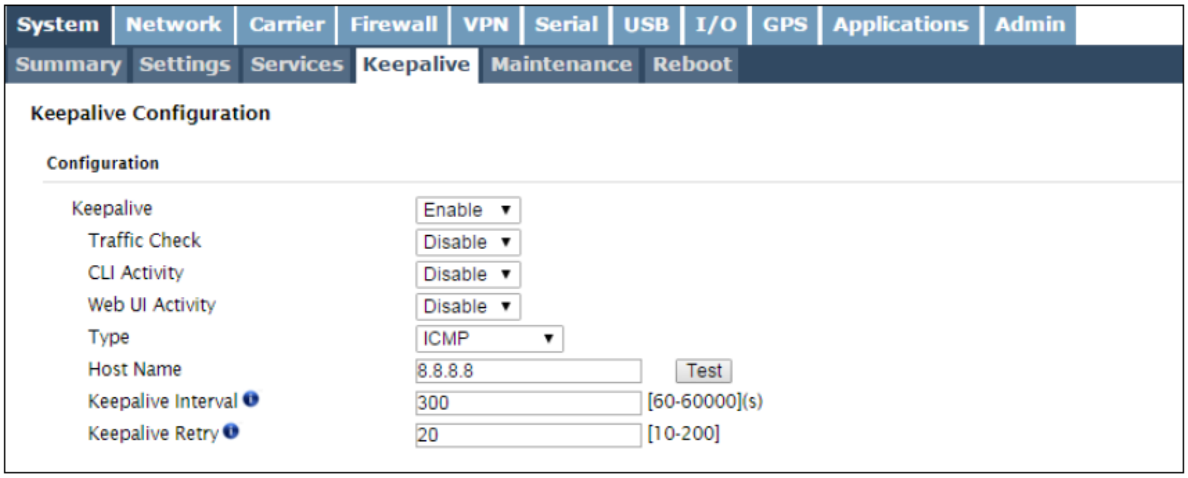


Figure 22
Keep alive settings window

The maintenance tab is used to upgrade to the latest firmware released by Microhard systems and reboot tab is used to reboot the cellular modem remotely.

LAN Port Configuration. There are several tabs available under network settings menu. But when the carrier issues a static IP address, then only the LAN settings should be configured and the remaining tabs should be left unchanged. By default, the LAN port of the cellular modem which is used for connection of devices has a static IP address. By default, it also runs a DHCP server to provide IP addresses to the devices which are connected to the LAN port. If 'static' connection is selected, a valid IPv4 address should be entered in the field. Under DHCP settings, the DHCP service should be enabled to provide IP addresses for the devices connected to the modem. A start IP address and a maximum number of IP addresses that can be assigned to the modem should be configured. The settings used are shown in Figure 23 below.

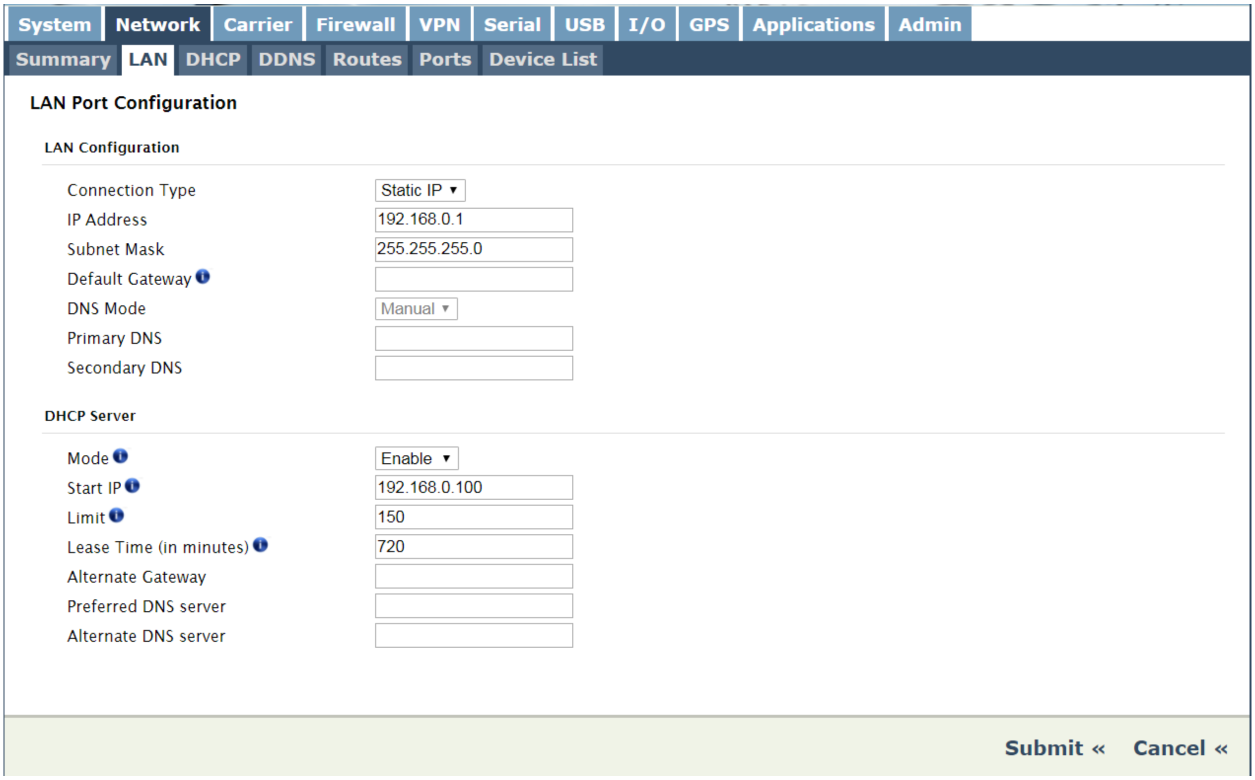


Figure 23
LAN settings window

Carrier Configuration. Carrier menu has several tabs of which two are useful; the tabs are described below. Other tabs have parameters which do not require configuration.

The Carrier status window under the Carrier menu shows a summary of information related to the carrier as shown in Figure 24. A variety of information is displayed here such as network name, activity status, signal strength, data service type and phone number.

The Settings tab under the Carrier menu allows configuration of very important parameters like APN which is necessary for network connectivity. The settings required are shown in Figure 25.

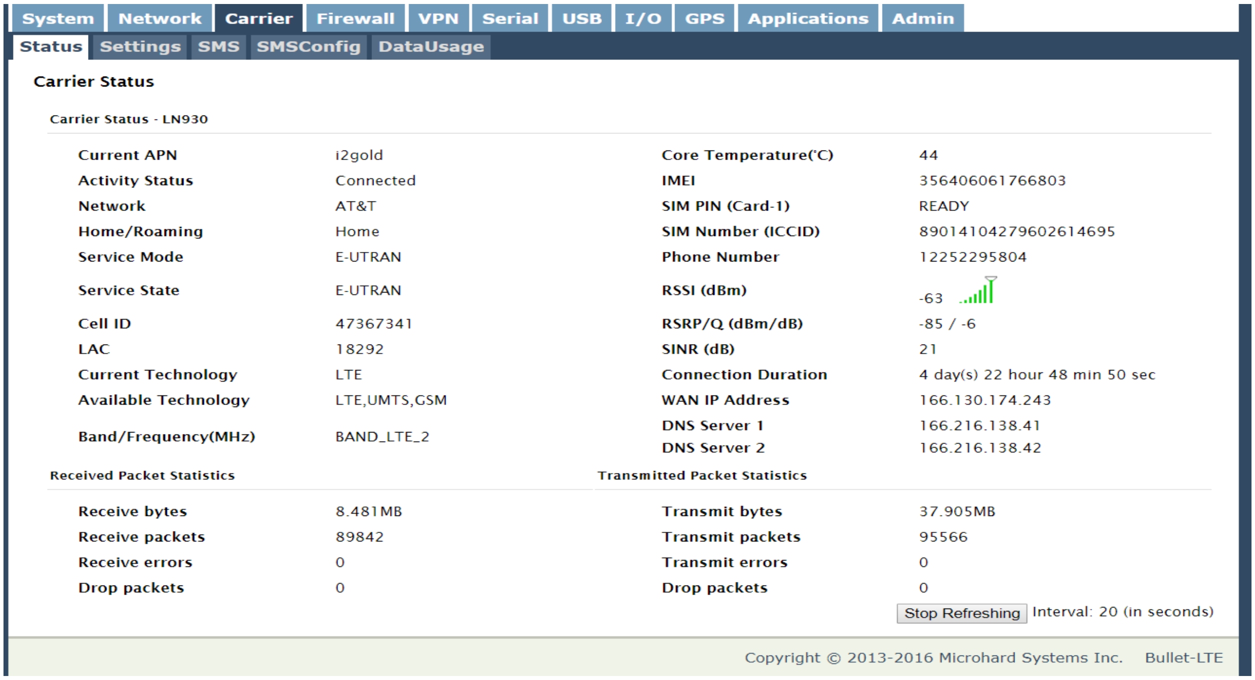


Figure 24
Carrier status window

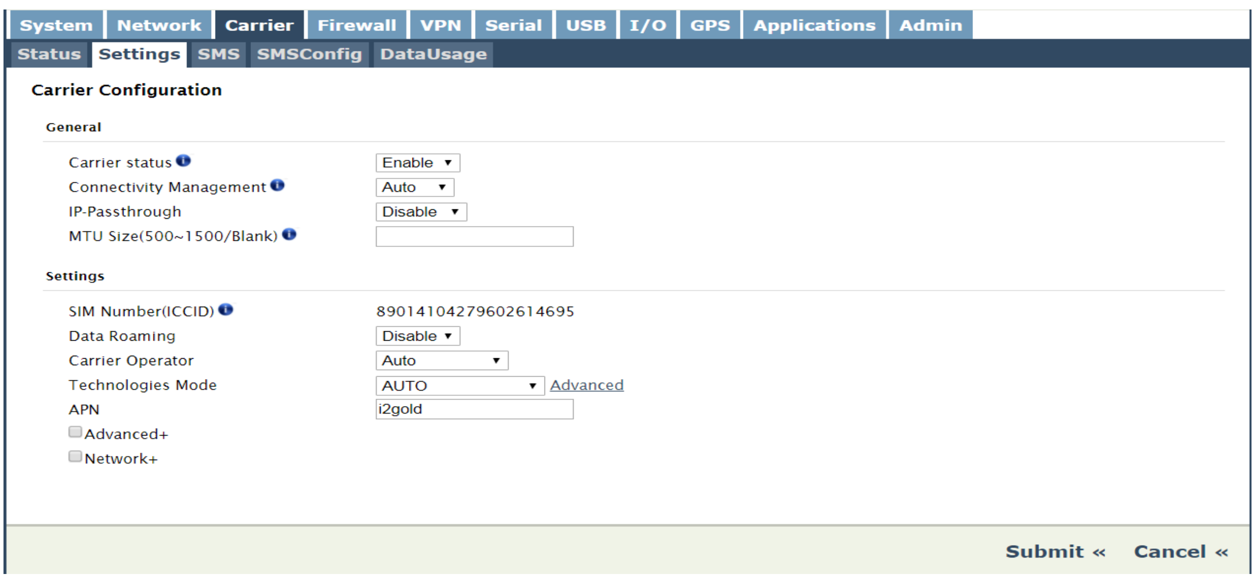


Figure 25
Carrier settings window

Firewall Configuration. Firewall settings should be configured to protect devices connected to the modem and to control the data usage. Several tabs from the firewall menu, which are used for configuration, are described below.

The General tab allows users to enable/disable various parameters like carrier request, LAN to carrier Access control etc. The settings used are shown in Figure 26.

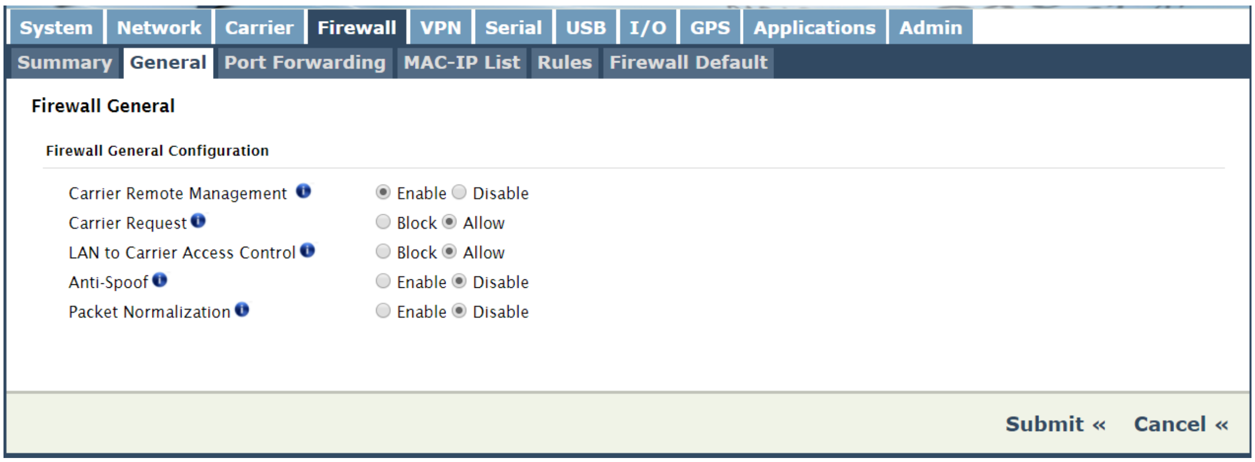


Figure 26
Firewall general settings

The port forwarding tab is used to configure settings to enable remote access of the devices connected to the modem. In this case RTMS Sx-300 can be accessed remotely by configuring the settings as shown in the firewall port forwarding summary section of Figure 27.

The rules tab is used to set rules to define how the remote devices access different ports and services. Since the carrier issues a public IP address, it is highly recommended to allow traffic from only trusted IP addresses. Otherwise it could result in unpredictable data charges from the carrier. The rule configured for the project is shown in the firewall rules summary section of Figure 28.

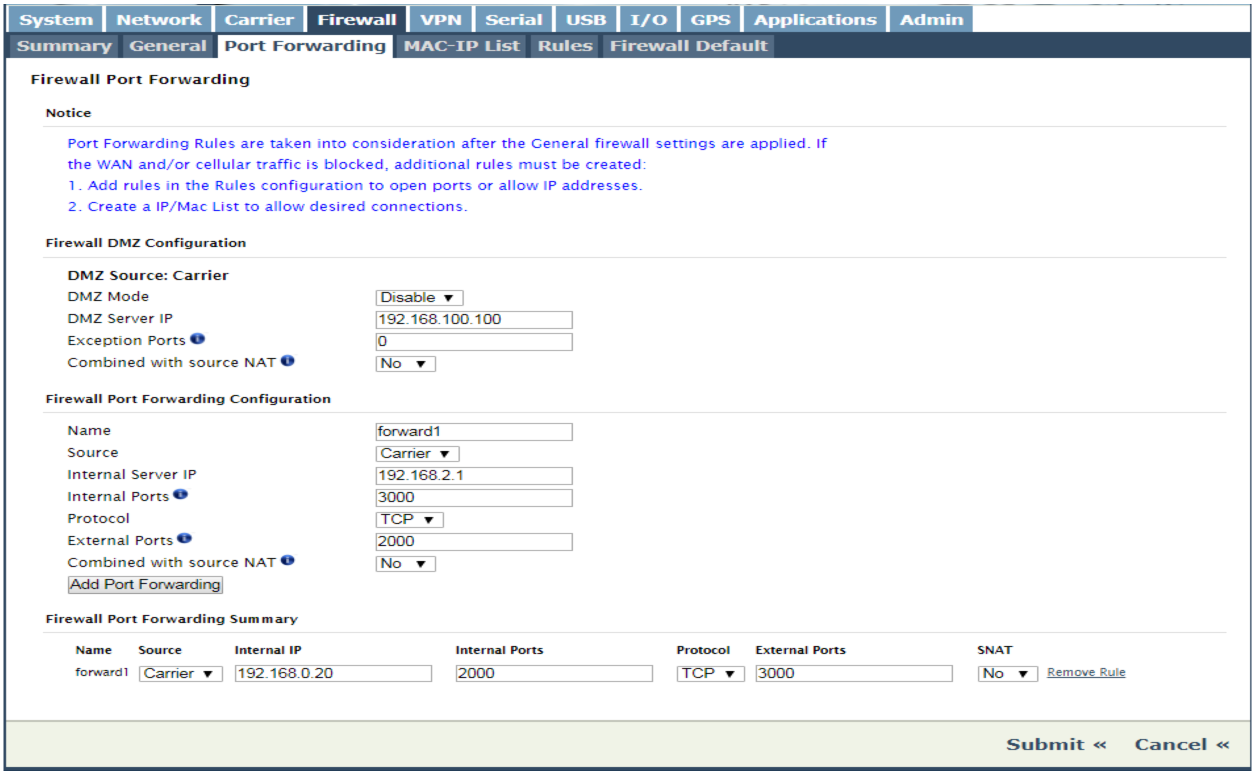


Figure 27
Port forwarding configuration

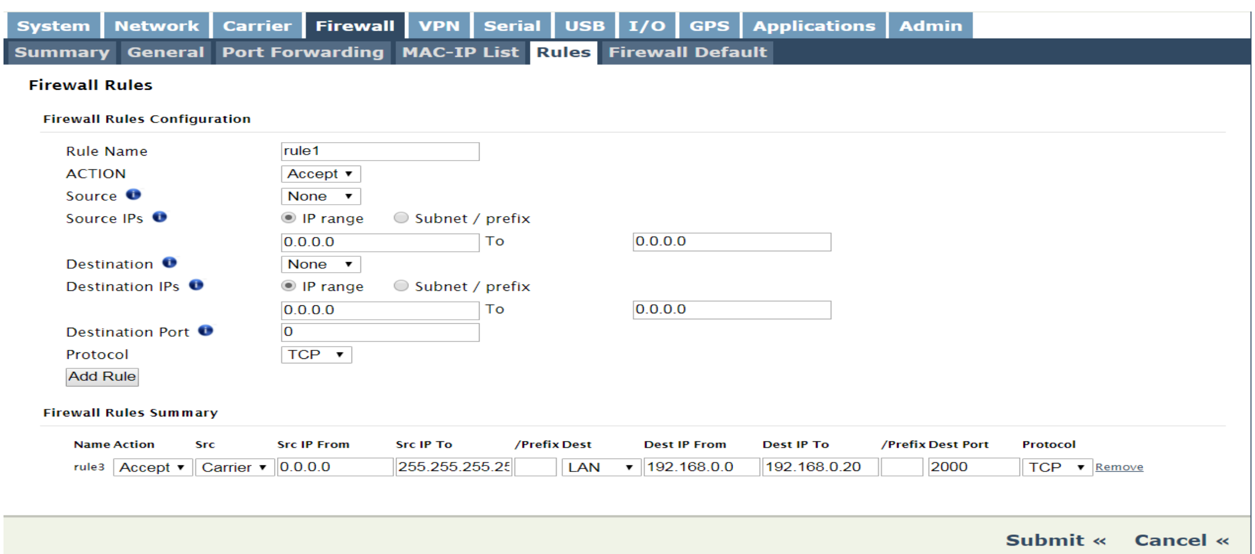


Figure 28
Firewall rule configuration

Metro Traffic Suite

Metro Traffic Suite is used to download the data collected from the RTMS sensors. The Metro Traffic Suite supports multiple devices and the data is collected in real time from all the devices which are set up in the software. The Metro software interface consists of function tabs on the left side and list of devices being monitored on the right side as shown in Figure 29. To add a device to the system, the add device tab is utilized. Clicking on the add device tab brings up a settings window where details of the sensor are populated. The details include the IP address associated with a particular RTMS sensor, location of the sensor, port number being used by the sensor for port forwarding, number of lanes being monitored, and other sensor related information. As an example, settings in metro manager related to the sensor located at Bluebonnet and Perkins intersection are shown in Figure 30. Devices can be modified/deleted using modify device or remove device tabs.

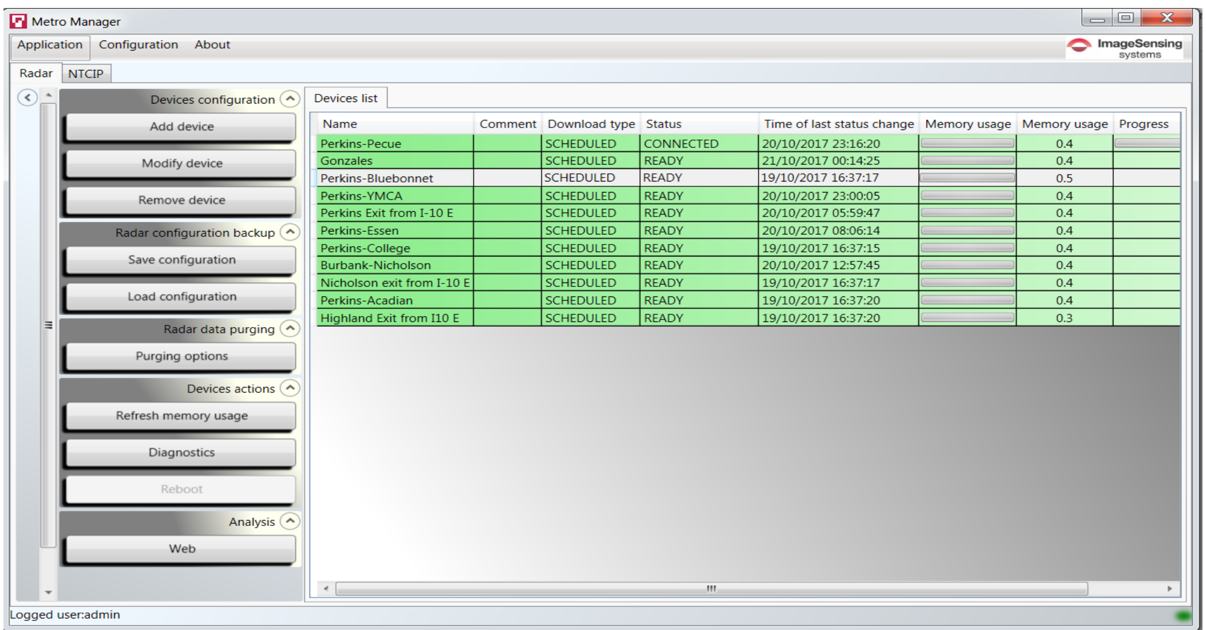


Figure 29
Metro manager interface

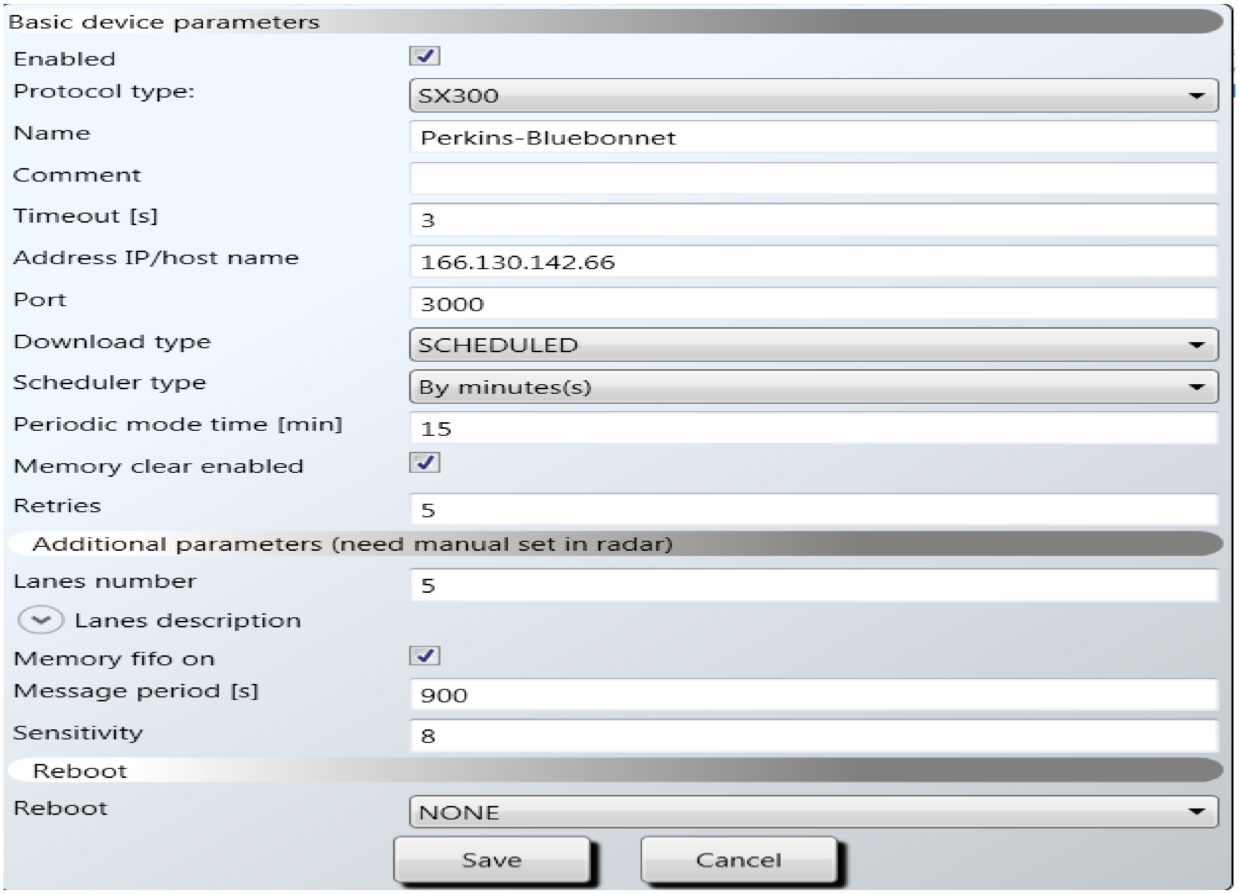


Figure 30
Settings to add a sensor to the system

The settings of a device can be saved for backup using the Save Configuration tab and can be loaded using the Load Configuration tab. The Refresh Memory Usage tab is used to clear the internal memory of the sensor and Web tab is used to download the data collected by the sensors. The Web tab brings up a web interface where data can be downloaded in a csv/graph format. The web interface also allows the user to customize the report according to his/her needs. For example, a user can specify what kind of data should be included in the report such as speed, volume, occupancy etc. While generating a report of volumes, the data can be aggregated to different intervals of time by using the Data Time base option. Data for this project is aggregated to 15 minute intervals. The user can also specify the dates for which the data should be downloaded by using the options: Time From and Time To. The web interface with all the options is shown in Figure 31.

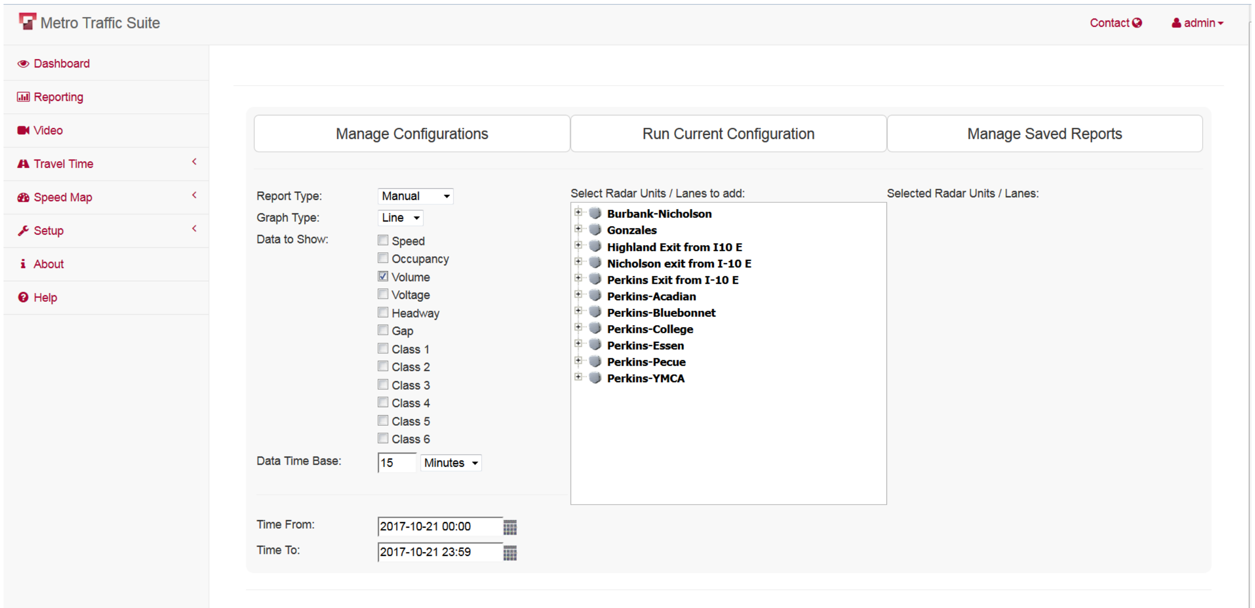


Figure 31
Metro traffic suite web interface

Data Acquisition

Acquiring Travel Times and Volumes

The raw data which is collected in real-time gives the travel times of all vehicles traversing the study sections. The raw data is bound to have significant outliers because vehicles may stop within the section for different lengths of time and for different purposes. Thus, the data needs to be processed before making any further analysis. The data is first received by the Traffic Cast server through a cellular connection where the data is filtered to eliminate outliers. TrafficCast has developed several algorithms such as, an 85th percentile smoothing method, a median smoothing method, and a two stage smoothing method to minimize the impact of outliers on the estimated flow speeds and travel times *[16]*. The smoothed data is then archived and can be downloaded from the interactive web interface provided by TrafficCast.

Acquiring Incident Information

Apart from travel times and volume data, the study requires data on traffic incidents that have caused congestion and might have induced diversionary behavior. Incident data was gathered directly from the DOTD's Traffic Management Center (TMC). Data provided by TMC is reliable and has all the details needed for analyzing an incident such as start time, end time and location of the incident. The incident database consists of all incidents across Baton Rouge, but only incidents which occurred on east bound I-10 between the Mississippi Bridge and the I-10/I-12 split are used in the final analysis. Incidents with duration of at least 30 minutes were considered for the project because the investigators felt that 30 minutes would be significant to cause traffic diversion. So, the appropriate incidents which lasted for more than 30 minutes were filtered out from the databased and used in the final analysis.

Duration of Data Collection

Initially the plan was to collect travel times and volumes until 30 incidents are observed for achieving statistical significance *[17]*. However, only 14 incidents with evidence for diversionary behavior were observed between July 1, 2017, and March 28, 2018, when observations were terminated due to the expiration of the contract with the cell phone communication provider and software analysis provided on the Bluetooth observations.

DISCUSSION OF RESULTS

Data Analysis

There are many congestion indices available which could be used to measure level of congestion on a roadway. However, the Travel Time Index (TTI) was chosen for this study since it is the most widely used index to measure congestion. The Travel Time Index is defined as the ratio of peak travel time to free-flow travel time. For example, a TTI value of 1.6 indicates that a 15-minute trip during free flow conditions would require 24 minutes during a congested period. The Travel Time Index is unitless since it is a ratio of travel times. TTIs were calculated using continuous data available from all the devices from July 1, 2017, to March 28, 2018. Travel time data was available in 15-minute intervals for each section for the entire duration of the study period.

Level of Congestion

The Travel Time Index was used to identify the difference in level of congestion on the I-10 between Mississippi River Bridge and the I-10/I-12 split that triggers traffic to divert to local roads from the freeway. Computing the Travel Time Index required the measurement of travel times during congested conditions and during free flow conditions for both the I-10 freeway system and parallel arterial roads. Free-flow travel times were calculated as the 85th percentile of travel times during the 12 a.m.-6 a.m. period.

Computing the difference in level of congestion involved several tasks. First, all the incidents were checked for their impact on freeway TTIs. Second, if any incident had an impact on freeway TTIs, then whether there was any diversion during the incident was investigated. Finally, if diversion was confirmed, the difference in level of congestion which triggered diversion was computed. All the three tasks are described in the following sections.

Confirming the Impact of Incident on Freeway Travel Time Indices. To observe the impact of an incident on freeway TTIs, base TTIs were required for comparison. Base TTIs were established separately for weekdays, Fridays and weekends (Saturday and Sunday) respectively. For weekdays, base TTIs were established by averaging TTIs during all 15 minute intervals in a day over all weekdays during the study period. Travel time observations during incident periods were included while computing averages. Similarly, base TTIs were established for Fridays and weekends over the study period. After establishing base TTIs, TTIs during incident periods were compared with base TTIs to see if there is any sudden increase in TTIs due to rise in congestion levels on freeway.

During an incident on the freeway, the immediate freeway segment upstream of the location of the incident would be congested due to reduction in capacity of the freeway. Hence, TTIs upstream to the location of an incident were considered for observing an increase in congestion levels on the freeway during an incident.

A sample plot of a TTI during an incident versus a typical base period for a section of I-10 between Dalrymple and Acadian is shown below in Figure 32. The incident occurred near the eastbound off-ramp to Exit 157B: LA 427; South Acadian Throughway on September 1, 2017, at 5:34 p.m. and was cleared at 6:40 p.m. A clear rise in TTI can be observed during that period on the incident day relative to traffic on a typical day. Therefore, we can confirm that a significant rise in TTI is observed during an incident versus regular recurring traffic conditions.

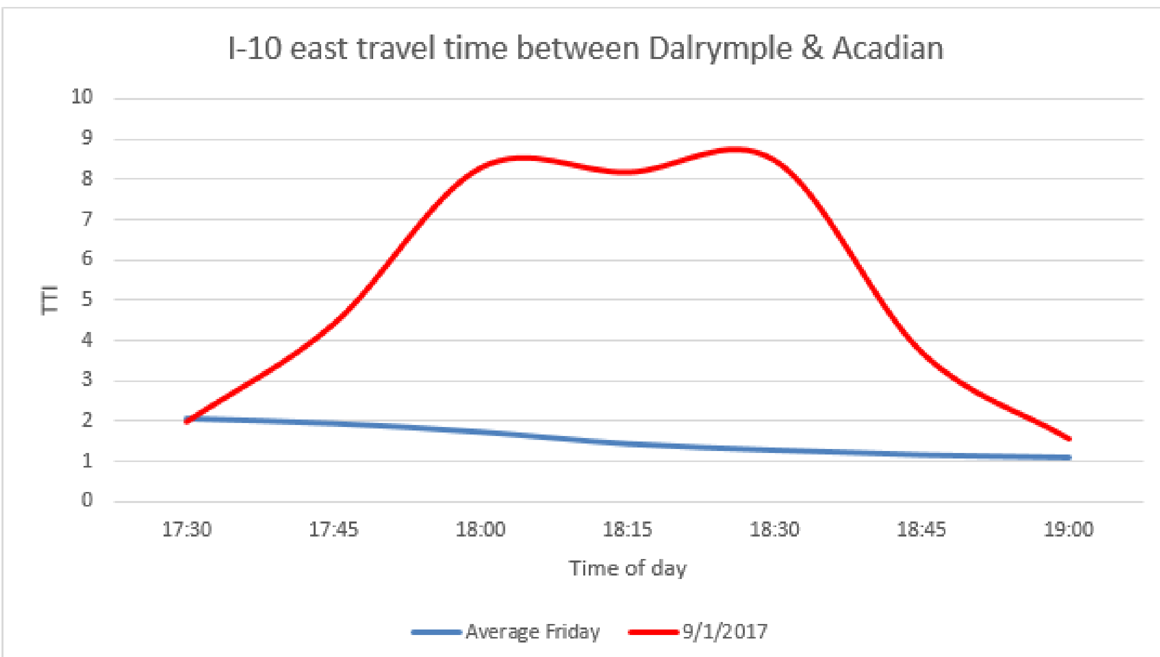


Figure 32
Comparison of travel time with an incident day to a typical day

Confirming Diversion. To check for diversion, base traffic counts on arterials were established in order to compare them with the volumes during an incident for verification of an increase in volumes. Base volumes were established separately for weekdays, Fridays and weekends (Saturday and Sunday) respectively. For weekdays, base volumes were established by averaging volumes during all 15 minute intervals in a day over all weekdays during the study period. Volumes during incident periods were included while computing averages. Base volumes for Fridays and weekends were established in a similar manner.

During an incident, volumes from the device nearest the closest off ramp upstream of the location of the incident were observed. Traffic diversion was confirmed, if there was an increase in volumes when compared to base volumes. Similarly, the volumes at subsequent upstream locations of off-ramp were observed to see if there was an impact on volumes at those locations.

Difference in Level of Congestion. If diversion was confirmed with an increase in volume counts, then the next step was to the relative difference in congestion levels between the I-10 and parallel arterials which triggered the diversion. Bluetooth observations of travel time on the I-10 were compared with Bluetooth observations of diverted traffic on parallel arterials. TTIs for arterials were expected to be similar to TTIs on the I-10 during normal conditions. However, when an incident occurred, it was expected that TTIs on I-10 would be a lot higher than TTIs on arterials before diversion occurred. For identical incidents, a pooled two sample one-tailed test was conducted on samples of TTIs (during the incident) from similar stretches of I-10 (upstream to location of incident) and parallel arterials to confirm that the TTIs on I-10 are significantly higher than TTIs on arterials.

Time Lag Calculation

After the onset of congestion, the travelers did not start diverting immediately. It took some time for them to learn about congestion, and then they decided to divert or not. So, a time-lag between the onset of congestion and diversion was expected. To calculate this time-lag during an incident, two things were required: the time stamp at which TTI started to increase and the time stamp at which there was a clear indication of diverted traffic on parallel arterials.

Plots of TTI and volumes against time during an incident were plotted and required time stamps were noted. After gathering the time stamps, the time lag was computed as the difference between the time stamp at which there is a clear indication of increased volume and the time stamp at which the TTIs started to increase. The time lag could conceivably vary for different incidents depending on its severity, therefore the difference in time stamps was calculated for all incidents.

Stability Measurement of Diversionary Behavior

Stability is defined as amount of variation in the time lag of diversionary behavior from one incident to another. It represents the total variation in measurements of the same metric measured over incidents. This was computed as the statistical variance of the time lag.

Results and Discussion

All the incidents were analyzed and the results were divided into two categories distinguished by the degree of evidence (strong evidence or mild evidence) available to prove that there was diversion during the incidents. The two categories are described below.

Category 1 Incidents

In this category, evidence was strong enough to prove that there was diversion during the incidents and the probable route chosen by diverted travelers could be identified. There were four incidents in this category. The first incident occurred on August 1, 2017 at Exit 157A: Perkins Road at 1:56 p.m. and lasted until 2:54 p.m. The incident occurred at mile marker 157.1 which is just past the exit at Perkins Road, the location of incident is identified on the map in Figure 33. So it was expected that travelers would divert onto Perkins Road, because it is the first exit upstream of the location of incident.

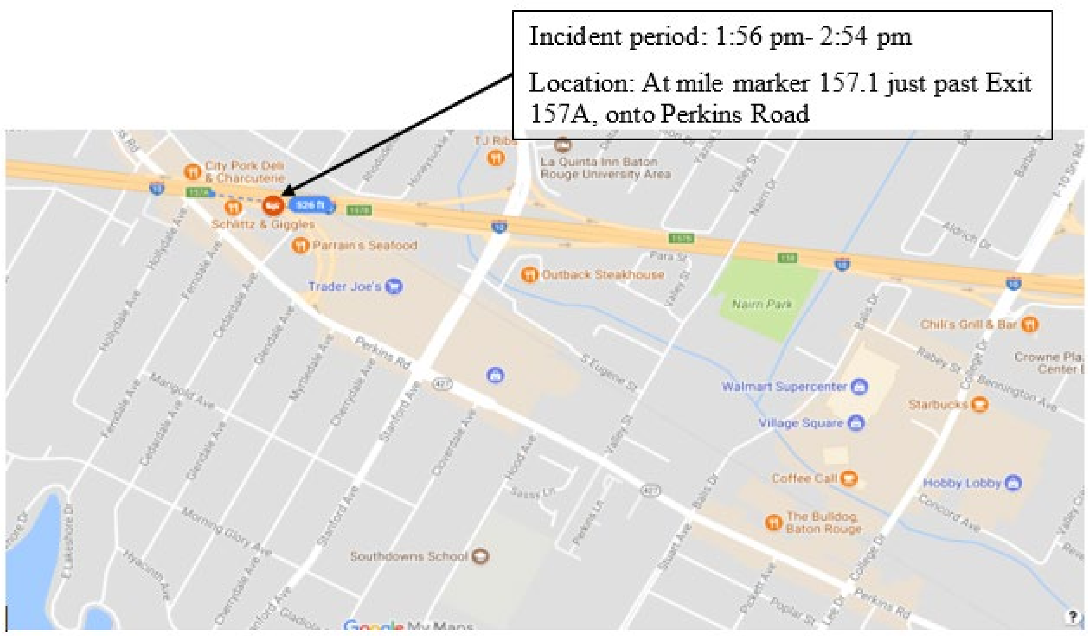


Figure 33
Map showing location of incident

Figure 34 shows the travel time index plots for the stretch Dalrymple to Acadian on the I-10 which is upstream of the location of incident. It can be clearly seen, that the TTIs upstream of the location of incident increased considerably during the incident and that congestion developed on the I-10 immediately following the incident at 1:56 p.m.

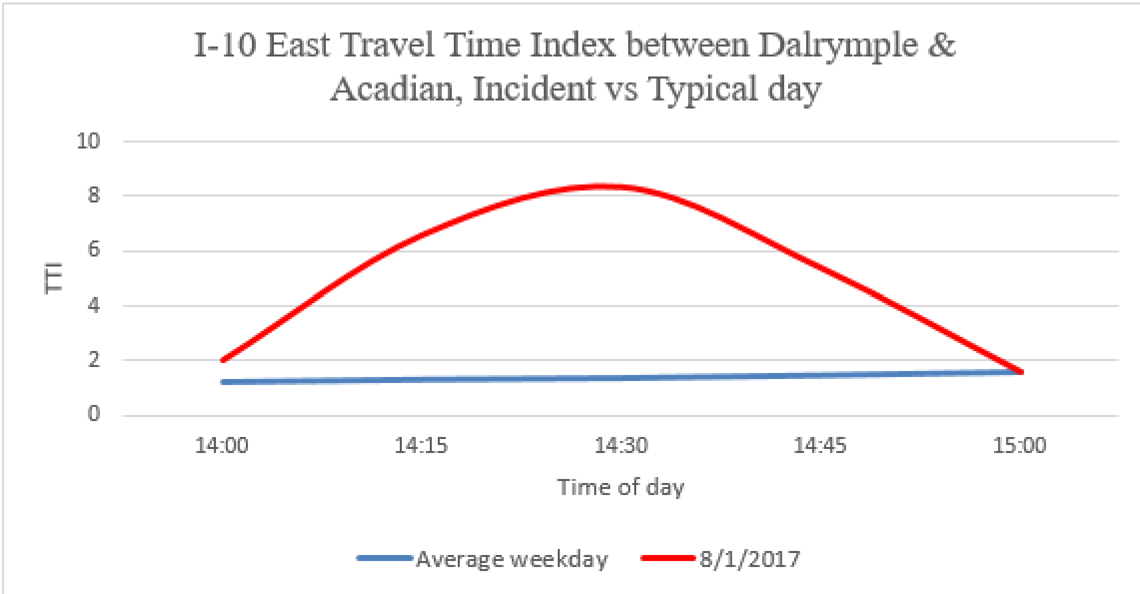
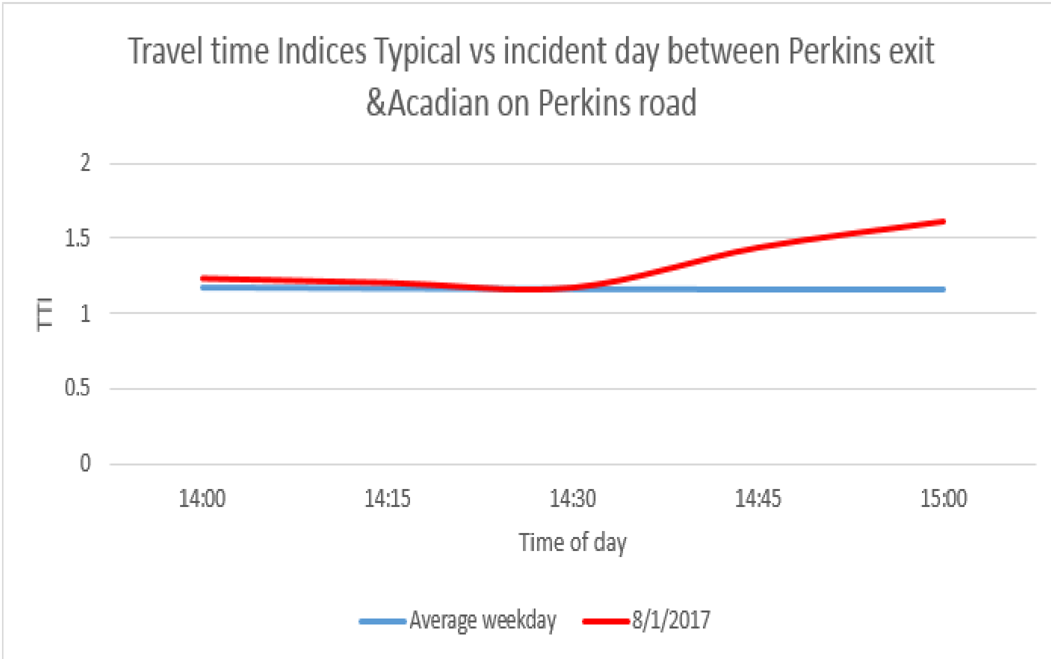


Figure 34
Trend of travel time indices on I-10 between Dalrymple and Acadian, 8/1/2017 vs. typical weekday

At the same time the TTIs on Perkins Road did not increase much, as shown in Figure 35, suggesting that the arterial was free of congestion. This is confirmed by the low TTI on both the I-10 and Perkins (slightly above 1) immediately before the incident. From the literature review it is known that people tend to minimize travel times and hence it was expected that people would divert onto Perkins Road to avoid congestion. The expectation was supported by sudden rise in volumes counts shortly thereafter at three different locations along Perkins Road during the incident as shown in Figure 36.

It is interesting to note that traffic volumes on Perkins Road begin to increase almost immediately after the incident but they take about 15 minutes to reach an initial maximum of twice the normal flow. However, after 30 minutes past the incident time the volume begins to increase again, possibly, due to motorists beginning to realize the incident is not temporary (see Figure 36). Another interesting result was how the added traffic dissipates over distance (i.e., from the off-ramp at Perkins, to Acadian, and then to College) and over time.

To address the first objective which is measuring the difference in level of congestion which triggers diversionary behavior, the difference of average TTIs on I-10 and Perkins Road during the incident was computed and it was computed to be 4.3. The time lag between the onset of congestion and the clear indication of diverted traffic was observed to be 15 minutes.



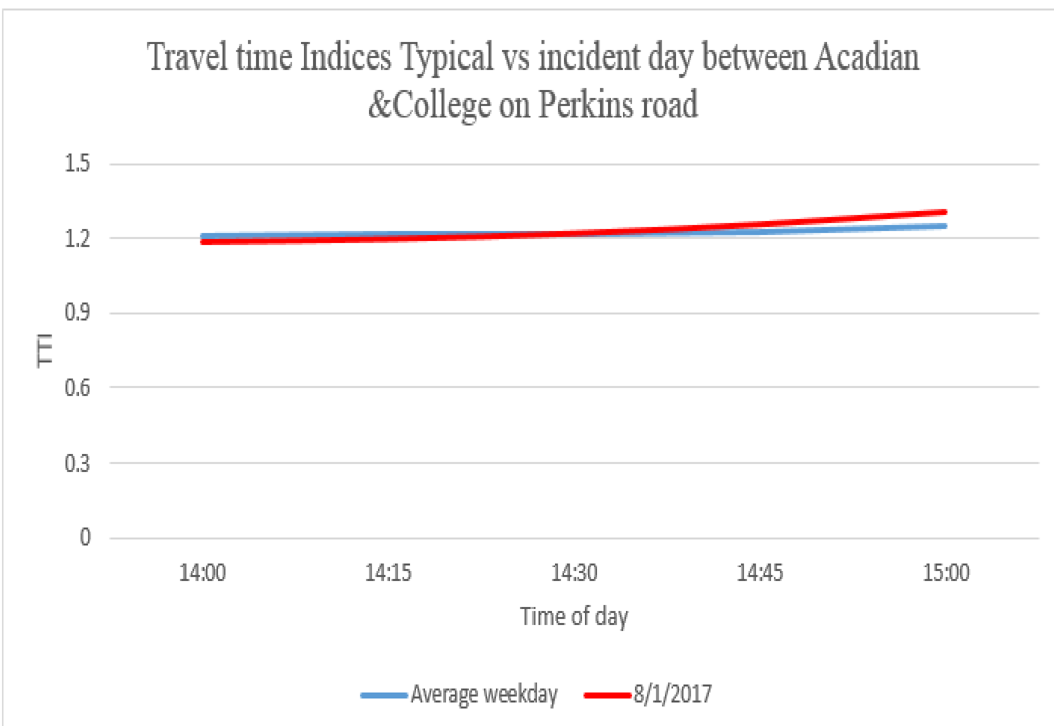


Figure 35
Trends of travel time indices on Perkins Road, 8/1/2017 vs. typical weekday

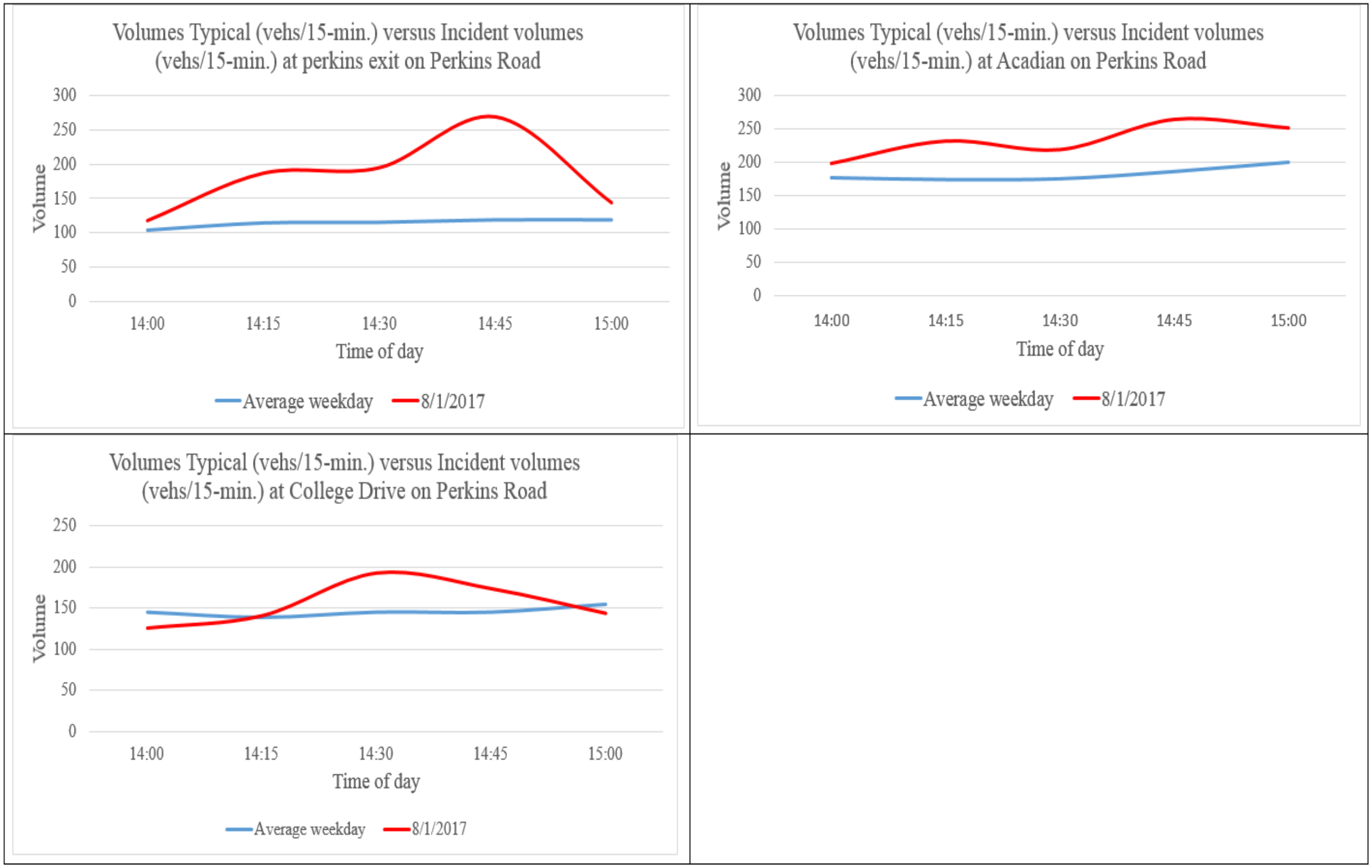


Figure 36
Trend of volumes on Perkins Road, 8/1/2017 vs. typical weekend

Similar observations were made for the second incident which occurred on August 7, 2017, at Exit 157B: LA 427 (at mile marker 157.49); South Acadian at 9:40 a.m. and lasted until 10:39 p.m. The incident location is very close to the location of the first incident and similar kind of behavior was observed for this incident too. As seen previously, the TTIs increased on the freeway during the incident (shown in Figure 37) and the TTIs on Perkins Road did not change much initially (shown in Figure 38) thus attracting travelers to divert to it. The later increase in volume on Perkins Road is shown in Figure 40 and shows that diversion occurred. Also, the incident did not show any impact on volumes at Essen on Perkins Road, suggesting that people diverted back onto freeway since the freeway downstream of the incident location was less congested than Perkins Road. An assumed route that people could have chosen is shown in Figure 39. The difference of average TTIs on I-10 and Perkins Road during the incident was computed and it was measured to be 3.07. The time lag between the onset of congestion and the clear indication of diverted traffic was observed to be 30 minutes.

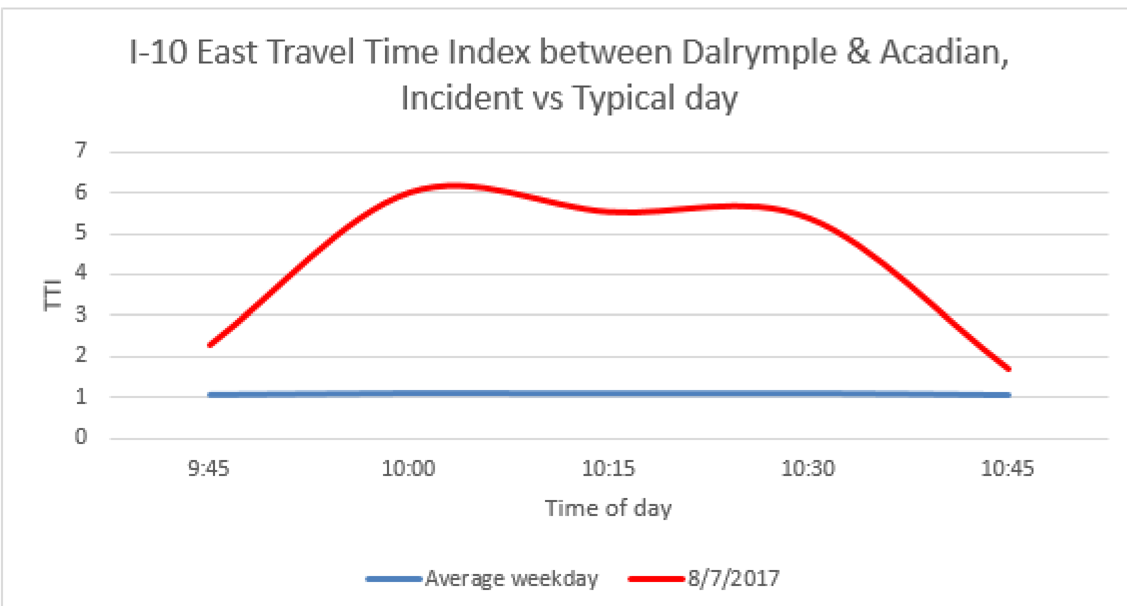
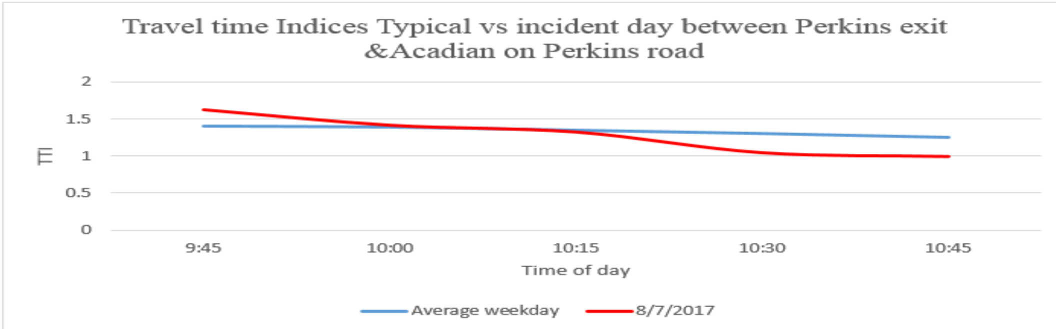


Figure 37
Trend of TTIs on I-10 between Dalrymple and Acadian, 8/7/2017 vs. typical weekday



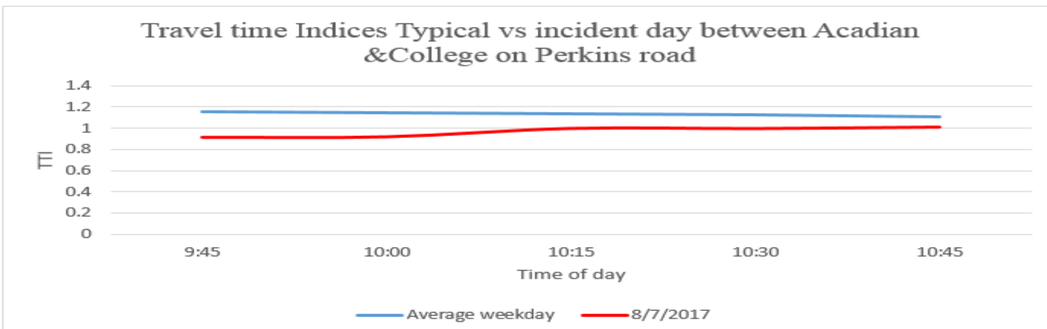


Figure 38
Trend of TTIs on Perkins Road, 8/7/2017 vs. Typical Weekday

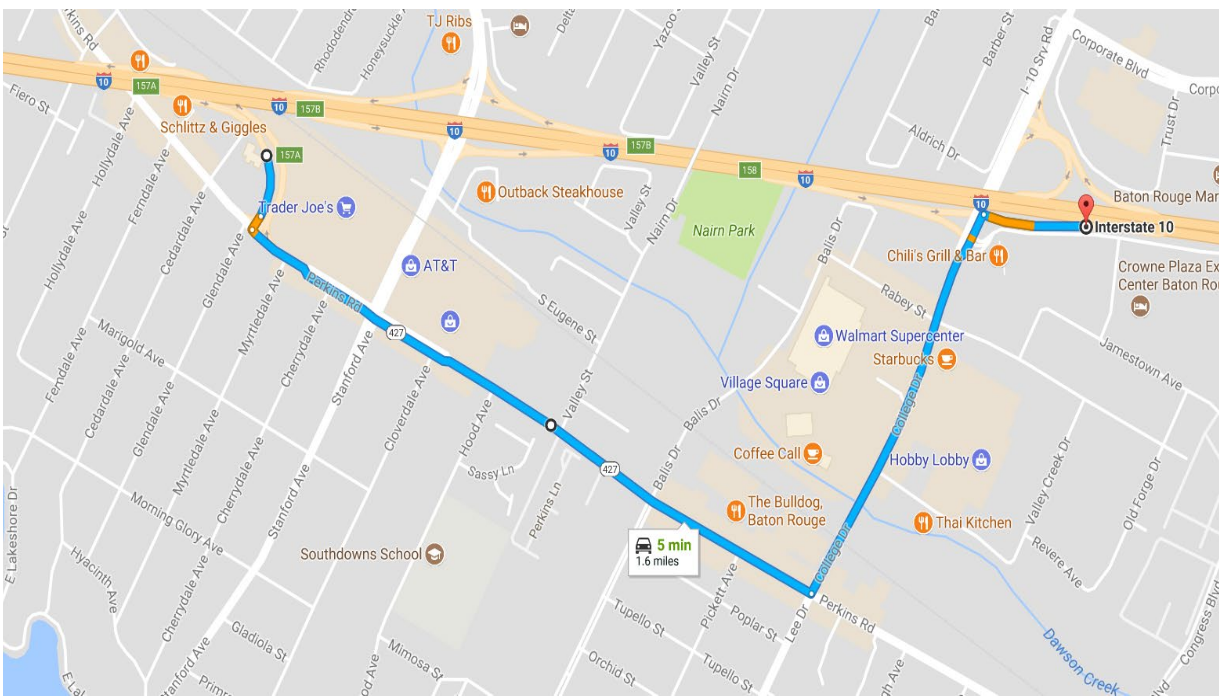


Figure 39
Alternate route onto I-10 via Perkins Road to avoid congestion due to incident

Figure 40
Trend of volumes on Perkins Road, 8/7/2017 vs. typical weekday

The third incident in this category occurred on September 1, 2017, at Exit 157B: LA 427 (at mile marker 157.43); South Acadian at 5:34 p.m. and lasted until 6:40 p.m. All the observations made were similar to what were observed for incident 2. The difference of average TTIs on I-10 and Perkins Road during the incident was computed and it was measured to be 4.7. The time lag between the onset of congestion and the clear indication of diverted traffic was observed to be 30 minutes.

The fourth incident in this category occurred on February 8, 2018, at Exit 157A: Perkins Road (mile marker 156.95) at 3:35 p.m. and lasted until 4:42 p.m. The route taken by the ones who diverted is shown in Figure 44, and the similar trends as the other incidents are shown in Figures 41 through 43. The difference of average TTIs on I-10 and Perkins Road during the incident was computed to be 3.67. The time lag between the onset of congestion and the clear indication of diverted was observed to be 15 minutes.

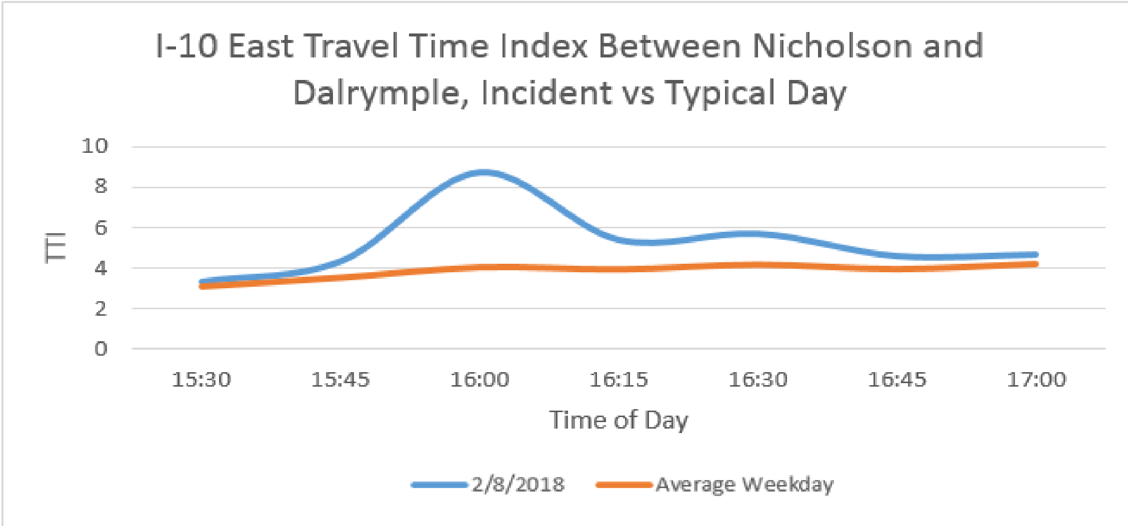


Figure 41
Trend of TTIs on I-10 between Nicholson and Dalrymple, 2/8/2018 vs. typical weekday

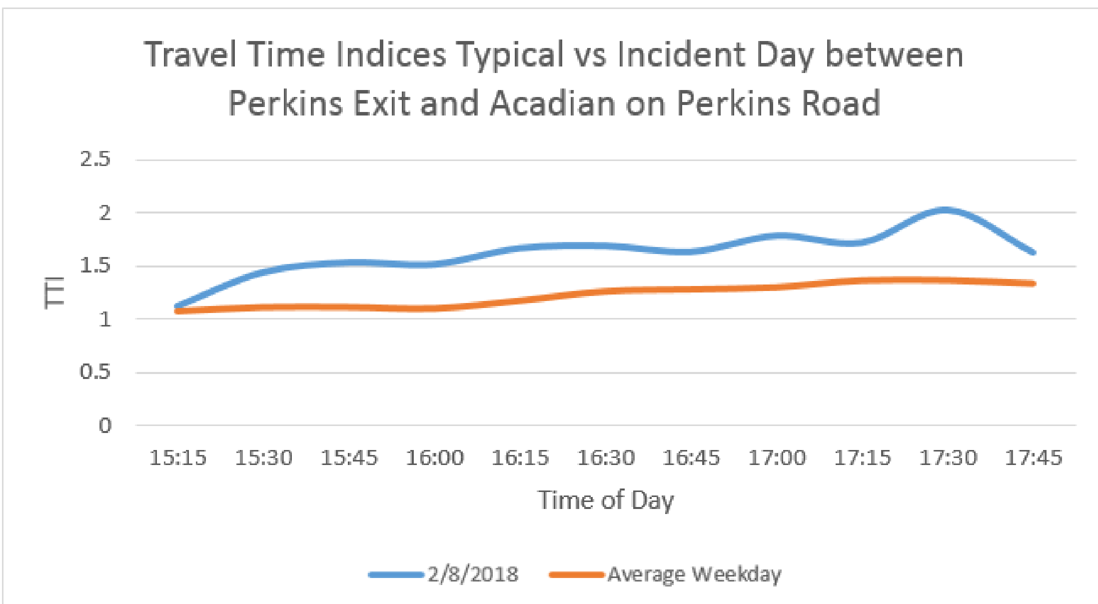


Figure 42
Trend of TTIs on Perkins Road, 2/8/2018 vs. typical weekday

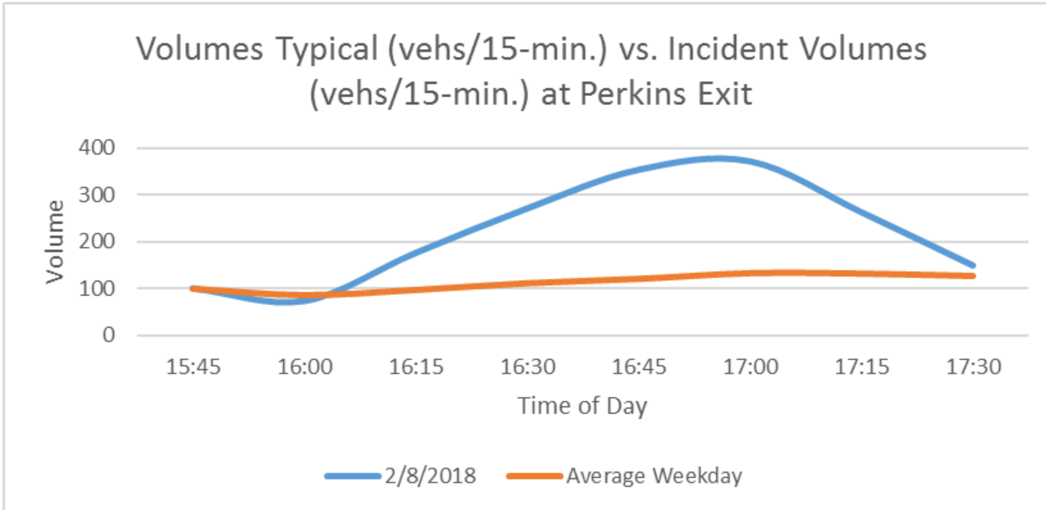


Figure 43
Trend of volumes on Perkins Road, 2/8/2018 vs. typical weekday

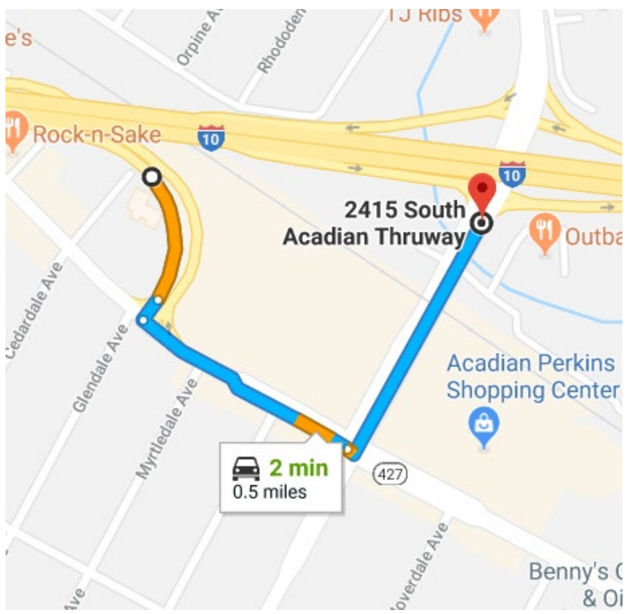


Figure 44
Alternate route onto I-10 via Perkins Road and S Acadian to avoid congestion due to incident

Category 2 Incidents

Evidence for diversion is partial in this category of incidents. It was observed that people diverted onto local routes during incidents but the route chosen by the diverted travelers was not discernible. The authors identified 10 incidents in this category. For demonstration purpose only two incidents are shown below. The first incident occurred on July 18, 2017, at Exit 156B:

Dalrymple Drive at 7:55 a.m. and lasted until 8:59 a.m. From Figure 45 it can be seen that TTIs on I-10, upstream to the location of incident increased considerably. The nearest volume counters on the off ramp upstream to the incident location were at Nicholson exit and Highland exit. As a result, volumes at these two locations were plotted to see if there was any diversion. Volumes at Highland increased during the time of incident which is shown in Figure 46 but there were no volume counters along Highland Road to identify the route chosen by the travelers. The travelers would most likely have continued on Highland Road and turned left onto Stanford Avenue to be able to take the on-ramp at Acadian Thruway to get on to the I-10 again. This likely route is shown in Figure 47. However, the authors do not have sufficient evidence to prove that this route is the one chosen by the travelers.

The difference of average TTIs on I-10 and Highland Road during the incident was measured to be 2.91. The time lag between the onset of congestion and the clear indication of diverted traffic was observed to be 15 minutes.

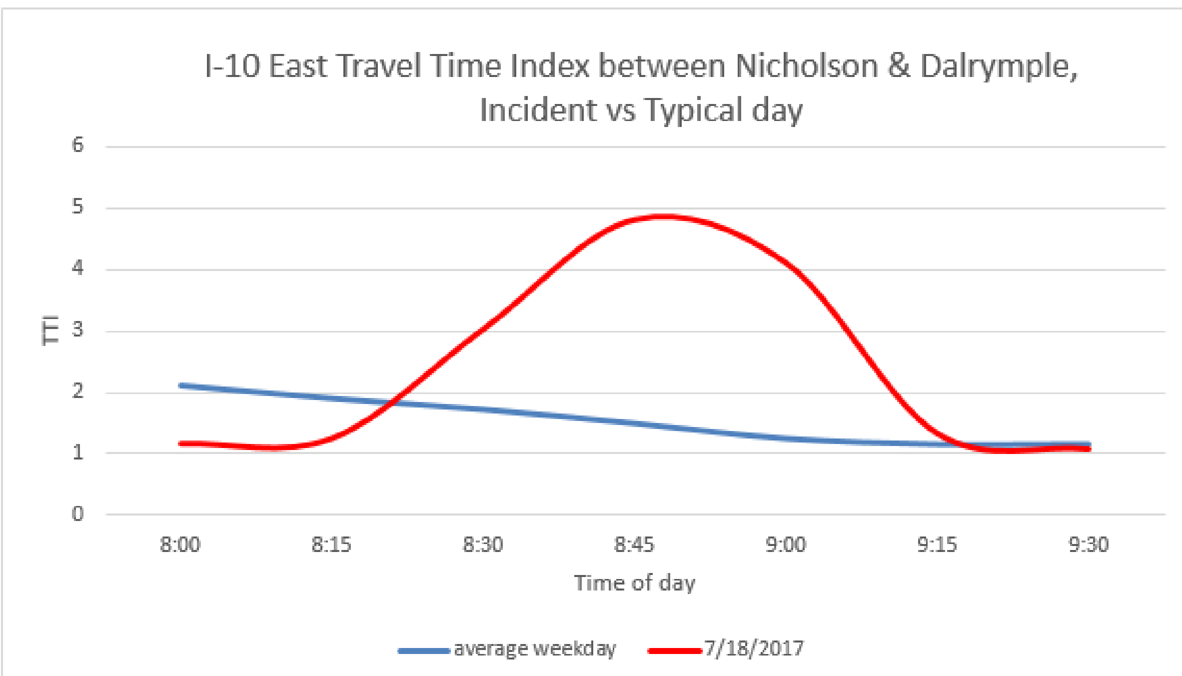


Figure 45
Trend of travel time indices on I-10 between Nicholson & Darlymple, 7/18/2017 vs. typical weekday

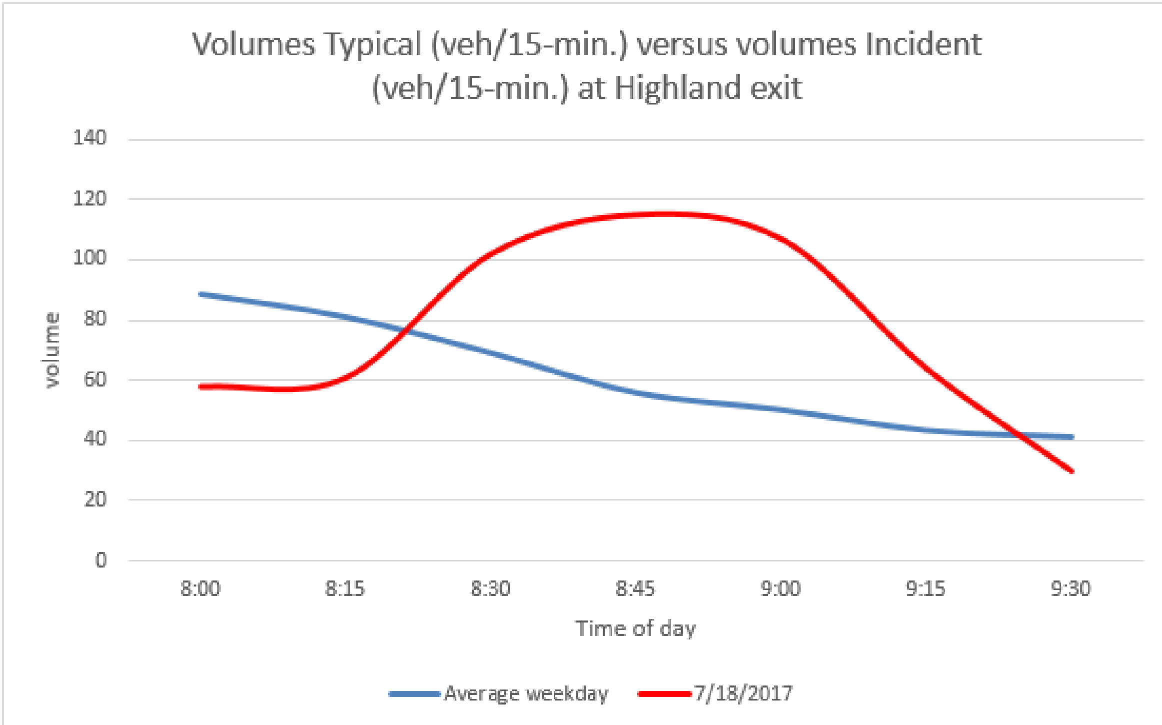


Figure 46
Trend of volumes at Highland exit, 7/18/2017 vs. typical weekday

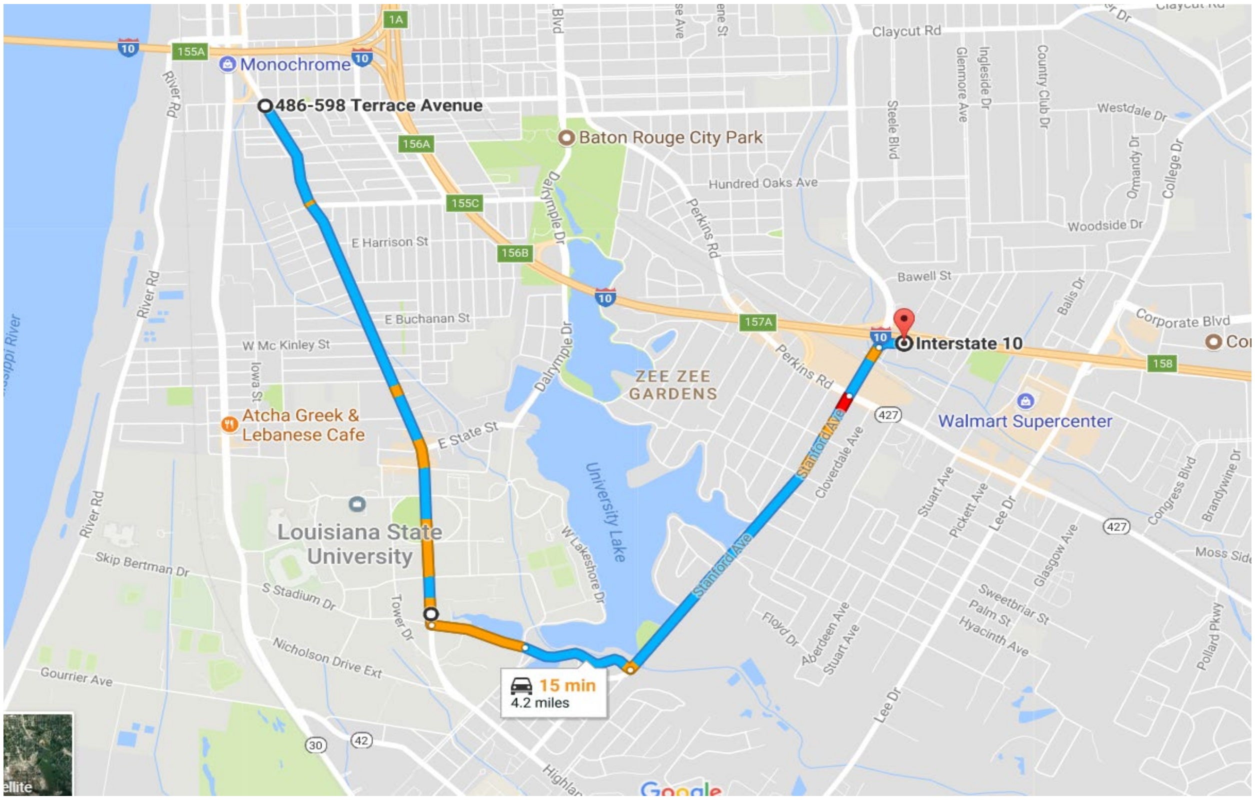


Figure 47
Alternate route onto I-10 via Stanford Avenue to avoid congestion due to incident

The second incident occurred near the Exit 155A: I-110; Terrace Avenue on September 12, 2017, at 9:30 a.m. and lasted until 10:04 a.m. The stretch of I-10 between Nicholson and Dalrymple which is upstream to the location was congested as we can see from the plot in Figure 48. They diverted onto Highland Road as proved by the rise in volumes on Highland Road during the incident shown in Figure 49. But the route chosen by the travelers after diversion is unknown, the travelers might have continued on Highland Road and turned left onto Louise Street, and then taken the on-ramp to get onto I-10 again. This route is shown in Figure 50 below. The difference of average TTIs on I-10 and Highland Road during the incident was computed and it was measured to be 1.51. For this incident, there was no time lag between the onset of congestion and the clear indication of diverted traffic.

From the literature it is known that travelers tend to divert more during morning peak due to the commitment of reaching their workplace on time. Hence, travelers might have diverted immediately onto Highland Road as soon as they were aware of the incident.

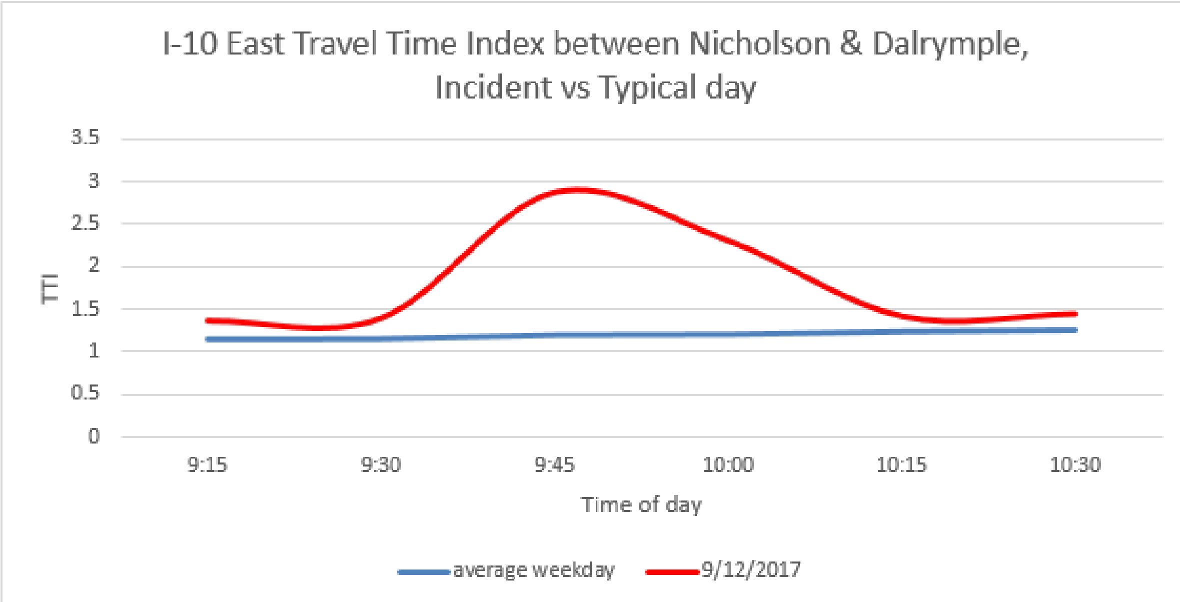


Figure 48
Trend of travel time indices on I-10 between Nicholson and Dalrymple, 9/12/2017 vs. typical weekday

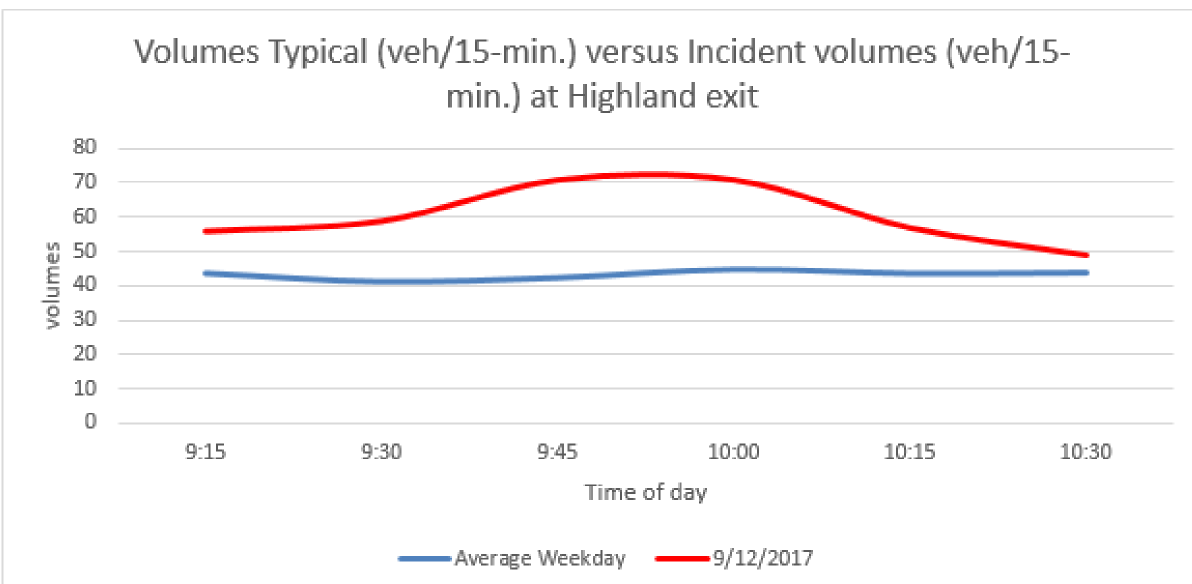


Figure 49
Trend of volumes at Highland exit, 9/12/2017 vs. typical weekday

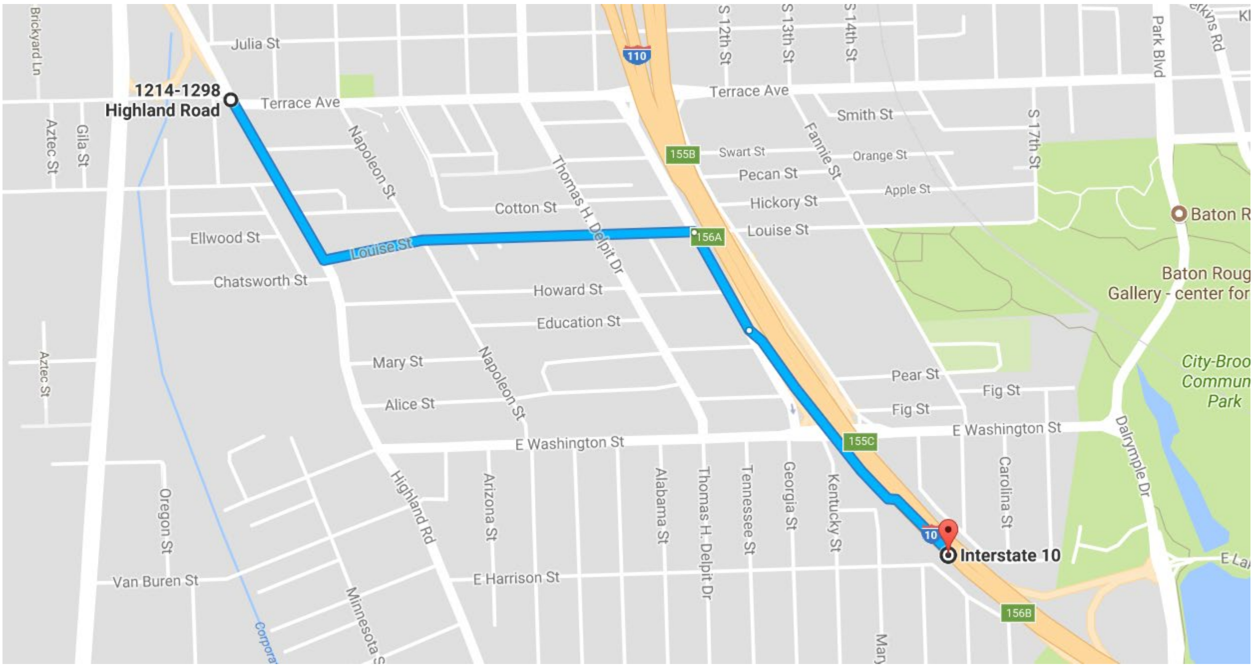


Figure 50
Alternate route onto I-10 via Louise Street to avoid congestion due to incident

T-test on Difference in Level of Congestion

A pooled two-sample one-tailed test was conducted on samples of TTIs (during the incident) from similar stretches of I-10 (upstream to location of incident) and parallel arterials to confirm that the TTIs on I-10 are significantly higher than TTIs on arterials during incidents. Incidents were divided into three categories based on location of incident and available alternate route as shown in Table 1 below and a t-test was performed separately for each category. The samples for each test consist of respective TTIs on I-10 upstream to the location of incident and TTIs on alternate route. P values from all the three tests from Tables 2, 3, and 4 suggest that the TTIs on I-10 during the incident are significantly different from TTIs on alternative routes. The mean difference in level of congestion for categories 1, 2, and 3 are 4.01, 4.71, and 1.86, respectively.

Category	location	Alternate route
1	Exit 157A: Perkins Road (or) Exit 157B:LA427; South Acadian Throughway	Perkins Road
2	Exit 156B: Dalrymple Drive	Highland Road
3	Exit 155A: I-110; Terrace Avenue	Terrace Avenue

Table 1
Incident categories based on location and available alternate route

	TTI on I-10	*TTI on Perkins Road*	TTI Difference
Mean	5.446212971	1.429311237	4.01
Variance	5.731541599	0.135596235	
Observations	14	14	
Hypothesized Mean Difference	0		
df	13		
t Stat	6.562681777		
P(T<=t) two-tail	1.81744E-05		
t Critical two-tail	2.160368656		

Table 2
A one-tailed two sample t-test on samples from I-10 (I-10 at Dalrymple to I-10 at Acadian) and Perkins Road (Exit on Perkins Road to College Drive on Perkins Road)

	TTI on I-10	*TTI on Highland Road*	TTI Difference
Mean	5.791654765	1.075	4.71
Variance	4.686425416	5.3786E-32	
Observations	12	12	
Hypothesized Mean Difference	0		
df	11		
t Stat	7.547512787		
P(T<=t) two-tail	1.13125E-05		
t Critical two-tail	2.20098516		

Table 3
A one-tailed two sample t-test on samples from I-10 (I-10 at Nicholson to I-10 at Dalrymple) and Highland Road

	TTI on I-10	*TTI on Terrace*	TTI difference
Mean	2.935648997	1.075	1.860648997
Variance	0.441553377	0	
Observations	7	7	
Hypothesized Mean Difference	0		
df	6		
t Stat	7.408356414		
P(T<=t) two-tail	0.000310843		
t Critical two-tail	2.446911851		

Table 4
A one-tailed two sample t-test on samples from I-10 (I-10 at Nicholson to I-10 at Dalrymple) and Terrace Avenue

All the incidents are tabulated below with characteristics of each incident. The information includes factors influencing diversionary behavior such as duration; day and time of incident; location of incident and quantifiable results pertaining to diversionary behavior like difference in level of congestion; time lag between onset of congestion and diversion; and stability of behavior in terms of variance in time lag from incident to incident. From Table 5, it is clear that the diversionary behavior was observed for incidents with duration of at least 50 minutes or more apart from one incident which lasted for 30 minutes. The difference in level of congestion that triggered diversion is at least 3 or more for incidents occurring at exits near Perkins road and Dalrymple Drive, and a relatively less difference of 1.5-2.0 triggered diversion for incidents occurring at exit near Terrace Avenue. For category 1 incidents variance was measured to be 50 and for category 2 incidents variance was measured to be 54.

Table 5
Table of incidents

Category	Location of incident	Mile marker	Date and time of incident	Duration of incident	Day of week	Alternate Route	Difference in Level of Congestion	Time lag	Variance in time lag
1	Exit 157A: Perkins Road	157.13	08/01/2017, 13:56	58 min	Tuesday	Perkins Road	4.325186101	15 min	50
1	Exit 157B: LA 427; South Acadian Throughway	157.49	08/07/2017, 09:40	59 min	Monday	Perkins Road	3.071512594	30 min	50
1	Exit 157B: LA 427; South Acadian Throughway	157.43	9/1/2017 17:34	1hr 6min	Friday	Perkins Road	4.710633169	30 min	50
1	Exit 157A: Perkins Road	156.95	2/8/2018	1hr 7min	Thursday	Perkins Road	3.669280803	15 min	50
2	Exit 156B: Dalrymple Drive	156.51	07/18/2017, 07:55	1hr 4min	Tuesday	Highland Road	2.913479263	15 min	54
2	Exit 155A: I-110; Terrace Avenue	155.51	9/12/2017 9:30	34 min	Tuesday	Highland Road	1.512155963	0 min	54
2	Exit 155A: I-110; Terrace Avenue	155.79	10/8/2017 10:30	1hr 14min	Sunday	Highland Road	2.000046211	15 min	54
2	Exit 156B: Dalrymple Drive	156.47	10/18/2017 18:49	1hr 24min	Wednesday	Highland Road	5.91375038	0 min	54

Category	Location of incident	Mile marker	Date and time of incident	Duration of incident	Day of week	Alternate Route	Difference in Level of Congestion	Time lag	Variance in time lag
2	Exit 156B: Dalrymple Drive	156.51	10/25/2017 18:37	54 min	Wednesday	Highland Road	4.125639038	0 min	54
2	Exit 156B: Dalrymple Drive	156.45	1/2/2018	1hr 2min	Tuesday	Highland Road	2.073760938	15 min	54
2	Exit 155C: Louise Street	156.23	1/9/2018	1hr 34min	Tuesday	Highland Road/ Nicholson Drive	4.086493359	15 min	54
2	Exit 155B: LA 30; Nicholson Drive	155.23	1/23/2018	43 min	Tuesday	Highland Road	1.004619395	0 min	54
2	Exit 160: LA 3064; Essen Lane	160.48	2/5/2018	1hr 16min	Monday	Perkins Road	1.063249758	1 hr	54
2	Exit 157A: Perkins Road	157.35	2/11/2018	2hrs 14min	Sunday	Perkins Road	2.424054223	0 min	54

CONCLUSIONS

The findings of the study indicate that diversionary behavior occurs when the Travel Time Index is 1.5 or above that on parallel arterials. The time lag observed is 15-30 minutes for incidents occurring on I-10 between Perkins exit and Citiplace, but for incidents occurring on I-10 between Nicholson Drive and Perkins exit, time lag measured is between 0 and 15 minutes

The stability of diversionary behavior was defined in terms of variance in time lag observed from incident to incident. The variance in time lag behavior for category 1 incidents was 50, and the variance in time lag behavior for category 2 incidents was 54. Values 50 and 54 are considerably high, which implies that diversionary behavior is not stable from incident to incident.

From an application perspective, it is suggested that these results can be used by government authorities to implement traffic management strategies that encourage motorists to use parallel arterials when freeway gets congested. The results observed in this research effort may not be relevant to other areas since they are based on data from the Baton Rouge area. Finally, it is important to conduct the study on a larger scale to see if the conclusions made in this study regarding traffic diversionary behavior can be generalized.

Also, the diversionary behavior observed in this research demonstrates that the road network used in this study is resilient to disruptions caused by accidents. Future researchers can identify and quantify other factors apart from the availability of alternate roads and quantify the resilience of the road network used in this study.

RECOMMENDATIONS

Due to the limitation of funds, only 11 devices could be deployed on various arterials. For a few incidents, the route chosen after the diversion was not observed, due to the absence of counters on arterials where traffic diversion was observed. In the future, deploying more devices on arterials like Highland Road (where traffic diversion was observed for many incidents) would provide more evidence to identify the route chosen by travelers.

Installing devices proved to be a tedious and time consuming task. It took around 4 months to procure and install the devices. In the future if any study requires installation of counters, it would be better to approach a consultant for installation.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ATIS	Advanced Travel Information Systems
BMS	Bluetooth Monitoring Stations
BRUE	Bounded Rationality User Equilibrium
Cm	centimeter(s)
DOTD	Louisiana Department of Transportation and Development
FHWA	Federal Highway Administration
ft.	foot (feet)
in.	inch(es)
LTRC	Louisiana Transportation Research Center
lb.	pound(s)
m	meter(s)
DOT	Department of Transportation
EDR	Event Data Recorder
GIS	Geographic Information System
GPS	Global Positioning System
MAC	Media Access Control
PDI	Path Deviation Index
RTMS	Real Time Microwave Sensor
TMC	Traffic Management Center
TRID	Transportation Information Research Database
TTI	Travel Time Index
UE	User Equilibrium Models

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