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Final Report 557

Travel Time Estimation Using Bluetooth

by

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16. Abstract

The objective of this study was to investigate the feasibility of using a Bluetooth Probe Detection System (BPDS) to estimate travel time in an urban area. Specifically, the study investigated the possibility of measuring overall congestion, the trend in congestion, the location of congestion "hotspots," and finally measurement of the level of congestion at the hotspots using a BPDS. A secondary objective was to assess the possibility of obtaining travel time from other quicker and cheaper methods such as simply purchasing it from a commercial vendor. The findings of the study indicate that a BPDS can reliably be used to measure travel time and estimate congestion in terms of indices such as travel delay, planning time index, and travel time index. However, the acquisition of a BPDS includes certain overheads such as installation costs, maintenance costs and monitoring costs. Purchase of travel time from a commercial vendor might be a viable option if the travel time data is not needed on a day-to-day basis and over an extended period of time. However, one of the disadvantages of purchasing travel time data is limited flexibility in using the data because of contractual issues. The study recommends using BPDS for collecting travel time if real-time data are needed on a constant basis and over a period of one or more years. If the data are not needed in real time and are needed for limited purposes and for less than a year, then it would be preferable to acquire the data through a commercial vendor.

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ABSTRACT

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IMPLEMENTATION STATEMENT

It is recommended that Department Of Transportation and Development (DOTD) and Baton Rouge Metropolitan Planning Organization consult the Urban Mobility Report (UMR) published annually by the Texas Transportation Institute (TTI) to gain an overview of congestion levels in the Baton Rouge area and to make comparisons of congestion levels with other cities that are comparable in size. However, to identify congestion hotspots and to prioritize highways for application of congestion alleviation measures, it is recommended that DOTD use the image analysis technique developed in the research study.

It is also recommended that DOTD deploy Bluetooth Probes on freeways and major arterials to measure effectiveness of implementing a policy, such as not to widen the I-10 stretch between the Mississippi River Bridge and the I-10/I-12 split. The travel-time measurements thus obtained can be used to determine the extent to which local arterials can substitute for lack of capacity on urban freeways.

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INTRODUCTION

Travel time estimates are useful measures of congestion in an urban area. The current practice involves using probe vehicles or video cameras to measure travel time, but this is a labor-intensive and expensive means of obtaining the information. A potentially more efficient and less expensive way of measuring travel time is to use Bluetooth technology to track vehicle movement in a network. The kind of information this study wanted to obtain from the measurement of travel time is:

1. Overall congestion in an urban area
2. The trend in overall congestion in an urban area
3. Individual locations where congestion is high (i.e., identification of "hotspots")
4. The level of congestion at hotspots

When conducting research into the use of novel technology such as Bluetooth to obtain travel-time measurements, it is necessary to consider whether there are other means of obtaining the information quicker and cheaper. Some possibilities are time-related travel speeds on major networks from sources such as Google's traffic maps and information on overall congestion in major cities published in TTI's annual UMR *[1]*. It was found from a preliminary investigation that the type of information sought in Items 1 and 2 above can be effectively gathered using TTI's annual UMR and consecutive annual UMRs, respectively. Item 3 could possibly be identified using Google's traffic map information. However, one of the purposes of the research was to test whether using secondary data sources is quicker and cheaper than using Bluetooth technology when identifying overall congestion, the trend in congestion, and individual hotspots.

The study used probe detection systems capable of detecting Bluetooth devices to measure travel time on major arterials. The study includes a literature review; identification of the current state-of-the-practice in the US regarding the measurement of travel time; a review of secondary means of obtaining travel time in urban areas; determination of the instruments needed to collect data, procurement of the hardware, identification of hotspot locations on the most congested major arterial in Baton Rouge, Louisiana; formulation of a deployment strategy of instruments to measure congestion at the hotspots; deployment of instruments; estimation of travel time; and finally measurement of congestion using indices such as travel time, travel delay, and planning time indices.

OBJECTIVE

The main objective of the study was to investigate the possibility of measuring congestion intensity and duration using travel-time data measured by a Bluetooth Probe Detection System. The secondary objective was to find out if there are better ways of acquiring travel-time information without having to deploy a Bluetooth Probe Detection System.

SCOPE

The scope of this project is limited to the Baton Rouge Metropolitan area and is confined to major arterials. Travel-time data was measured on a corridor that was identified as the most congested of all major arterials in the city.

METHODOLOGY

Literature Review

The purpose of the literature review was to learn how Bluetooth sensors are used to measure travel time and how Bluetooth systems function in detecting traffic conditions. The Transportation Information Research Database (TRID), Google Scholar, Scopus, and other databases were utilized in the search for literature related to Bluetooth.

Bluetooth was invented in 1994 by engineers from Ericsson, a Swedish company. It is a telecommunications industry specification that defines the manner in which cellphones, computers, personal digital assistants (PDAs), touchpads, home and car entertainment systems, etc., share digital data like music and images wirelessly over a personal area network *[2]*. Bluetooth operates on a frequency of 2.45 GHz (2.402 GHz to 2.480 GHz). This frequency band has been set aside by international agreement for the use of industrial, scientific, and medical devices (ISM) *[3]*. Since Bluetooth utilizes a radio-based link, it does not require line-of-sight in order to communicate *[4]*. However, signal attenuation of a Bluetooth device is influenced by the presence of physical objects *[5, 6]*.

Bluetooth technology has become very popular and is embedded in most modern portable electronic devices such as cell phones, tablets, headsets, and GPS devices. In addition, they are often embedded in motor vehicle entertainment systems and in-vehicle mobile phone hands-free systems. Each Bluetooth device contains a unique identifier known as a MAC (Media Access Control) address, assigned by the manufacturer of the device. The standard format for a MAC address is six groups of hexadecimal digits separated by hyphens or colons. No two MAC addresses are the same.

As a Bluetooth-enabled device travels along a roadway, a road-side Bluetooth receiver can detect and log the MAC address of that device along with a time stamp using the internal clock of the device. When the same MAC address is detected at distinct points on a roadway segment, travel time can be determined by calculating the difference in detection times at those points. Since the distance between readers is already known, travel speeds can be determined. This data can then be transmitted to a server over a wireless 3G network or Ethernet cable. The server matches the addresses and their respective time stamp to the same MAC address from any Bluetooth detector along the corridor. The matching can also be done manually. Figure 1 shows a schematic of the layout of a BPDS to collect travel time and speed information.

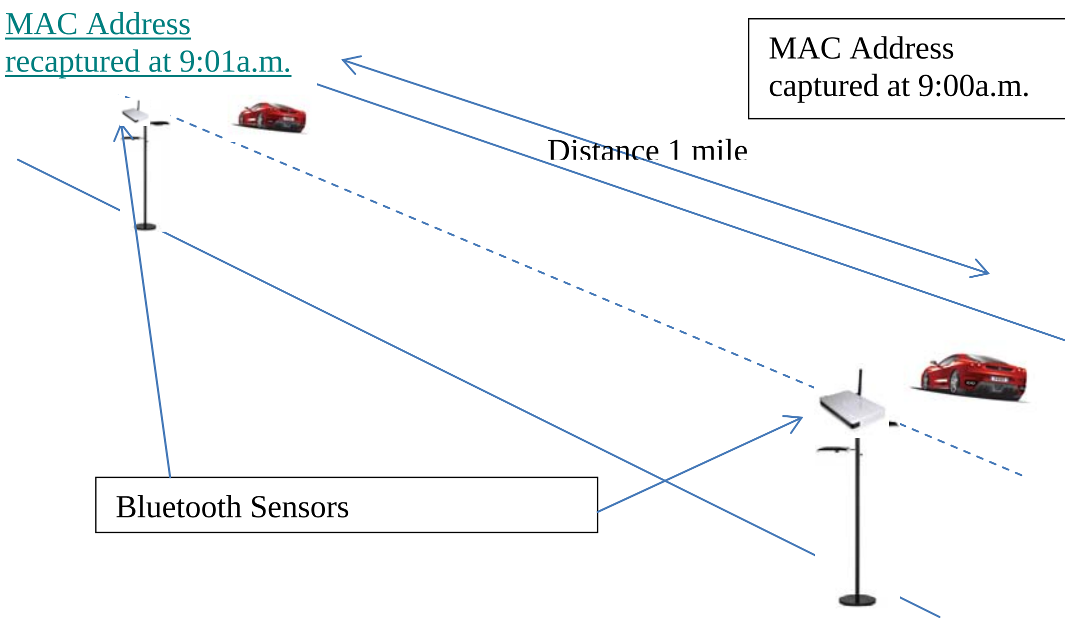


Figure 1
Vehicle monitoring with Bluetooth sensors

The range of Bluetooth wireless technology is application specific. The Bluetooth specification mandates operation over a minimum distance of 1 meter or 100 meters depending on the Bluetooth device class, but there is not a range limit for the technology. Manufacturers may set their own limits to appropriately meet the needs of their product's intended users. The three radio classes of Bluetooth which distinguish the range of different instruments are shown in Table 1 *[7]*.

Table 1
Bluetooth radio classes and their respective ranges

Radio Class	**Range**
Class 3	3 ft. (1 m)
Class 2	33 ft. (10 m)
Class 1	330 ft. (100 m)

A typical self-enclosed Bluetooth monitoring device would have the components and accessories shown in Figure 2.

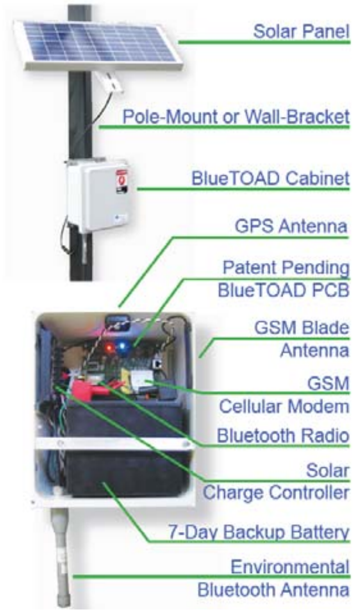


Figure 2
A self-enclosed Bluetooth traffic monitoring device (TrafficCast)

There are some factors that influence detection of Bluetooth monitoring devices. Among them is the height at which the Bluetooth detector is installed plays a significant role. Brennan et al. recommended a mounting height of at least 8 ft. for a Bluetooth antenna and stated that the lower the antenna mounting height on a bi-directional corridor, the more directional bias was observed in the near lane *[8]*. In a similar vein, a study by the University of Kansas suggested that antenna placed between 3 and 16 ft. height had a greater detection rate than sensors placed at ground level *[5]*.

Figure 3 and Figure 4 show an example of Bluetooth monitoring devices installed on a light pole and steel truss at a height of 10-12 ft.

In addition to vertical placement, other factors were also studied in the study in Kansas *[5]*. They found that the set back distance of the detector from the road did not have an effect on the detection rate unless the detector was intentionally placed at a disproportionately large set back distance. The research team also noted that vehicles traveling at 30 mph have significantly higher detection rates than those traveling at 45 mph or 60 mph. Placement of devices emitting Bluetooth signals on the dashboard of vehicles yielded more detections than when placed near the console. They also tested the effect of large vehicles between the signal and the detection device. They were able to observe mobile phone Bluetooth signals from 30 ft. away in spite of having a shipping container placed without any clearance on the ground between the detector and a mobile phone.

Figure 3
Bluetooth device mounted on a light pole

Figure 4
Bluetooth device mounted on a truss

Bullock et al. tried to estimate passenger queue delays at security areas of the Indianapolis International Airport using Bluetooth detection *[9]*. His investigation concluded that closely spaced detection units need to have clearly delineated areas of detection.

In addition to the comparison between different technologies mentioned before, the use of Bluetooth technology in estimating travel times as compared to floating car methods and Radio Frequency Identification (RFID) readers is cost effective and accurate *[10-13]*. A 2010 study which measured the performance of Bluetooth device on interstates, state highways, and arterials found that travel times produced by the Bluetooth method matched those from the floating car method *[11]* . Another study compared the performance of Bluetooth readers to Radio Frequency ID (RFID) readers and INRIX data (a traffic information system that reports real-time data) *[12]*. They were tested on the I-287 in New Jersey and used instrumented probe vehicles for ground truth data. Compared to RFID and INRIX, Bluetooth data produced travel times that matched closely with what they used as ground truth data.

The cost of using Bluetooth to measure travel times is relatively low. Phil Tranoff, the current chairman of the board at Traffax Inc., estimates the cost per travel-time data point of Bluetooth to be 1/300th of the cost of comparable floating car data *[10]*. Another study estimates Bluetooth data to be 500 to 2500 times more cost-effective than floating car data in terms of number of data points obtained *[13]*.

Sample size of data is one of the most critical parameters in providing accurate travel times. Not all vehicles on the roadway carry Bluetooth devices. Two important parameters are noteworthy in this regard—match rate and detection rate. Match rate is defined as the percentage of Bluetooth devices that are detected at two or more Bluetooth sites out of the total traffic volume. Detection rate is the fraction of Bluetooth devices that are detected out of the total traffic volume. A study published in 2008 produced match rates of 1.2% and 0.7% *[14]*. In a private communication in 2014, Neal Campbell, senior vice president at TrafficCast, stated that their Bluetooth-based traffic monitoring system achieves match rates in the range of 3 to 6%. An evaluation of Bluetooth systems from this vendor captured approximately 4% of traffic stream in Pennsylvania *[15]*. During a.m. and p.m. peak hours match rates of 1.5% to 4.5% were observed in Portland, providing enough data to reliably estimate travel time *[16]*. In a study conducted by the University of Akron, the number of matches on arterials was found to be much lower than on freeways *[10]*. This is probably due to the increased opportunity for vehicles to turn off or enter the facility between observation points, but even on freeways the New Jersey study on the I-287 came to the conclusion that Bluetooth stations should not be separated by more than 2 miles *[11]*. In a validation test by the University of Maryland, Bluetooth systems in 16 states had match rates ranging from 2 to 5.5% *[17]*. In a 2010 study conducted by Wang et. al, a match rate of 2.2% was observed *[18]*. In all these cases, the match rates were considered sufficient to produce accurate travel times according to the authors of the study.

Based upon research conducted at Maryland State University, a general rule of thumb is to achieve three matched pairs for every 5 min. or nine for every 15 min., 36 matched pairs an hour, or 864 a day. Sensors, when well-placed, should be able to capture 4% detection rate, for a roadway of 36,000 annual average daily traffic (AADT) or greater. To capture travel time with enough confidence, a 2% match rate on a roadway of 100,000 AADT would provide enough data *[15]*.

It is conceivable that the percentage of vehicles with discoverable Bluetooth devices may be specific to an area and may vary by time of day as well. For instance, lower income areas may have lower detection rates than affluent areas, and higher detection rates may occur during business hours than when social/recreational activity predominates in the early evening. Haghani and Young estimate that 5% of vehicles in the United States have discoverable Bluetooth devices *[17, 19]*. Hainen et. al. estimate this value to be 7 to 10 %, while Brennan Jr. et al. suggests a value between 5 to 10% *[8, 20]*

Currently, in Baton Rouge, Louisiana, there are 11 Bluetooth monitoring devices on I-12 between Walker and Essen Ln. They capture Bluetooth signals from west-bound traffic on this corridor. They are BlueToad^{TM} instruments from TrafficCast. Data is collected in real time and can be accessed on their website.

As mentioned earlier, the Texas A&M Transportation Institute, in collaboration with Texas A&M University System, have produced a report every year since 1982 called the Urban Mobility Report *[1]*. In the report, the research team evaluates several traffic and allied parameters in 498 urban areas including Baton Rouge, Louisiana. Their primary source of data is INRIX, which provides speed data continuously at 15-min. intervals. The research team also uses the Highway Performance Monitoring System (HPMS) for volume data and the EPA's Mobile Vehicle Emission Simulator (MOVES) model for vehicle emission estimates. For each of the 498 urban areas, the report provides estimates of travel time reliability (only in 2012), delay per auto commuter, fuel wasted, and CO_2 released due to congestion. In addition, it also provides estimates of the cost of congestion to both auto commuter and truck traffic. On the other hand, the research team also estimates travel delay saved by operational treatment and public transportation *[1]*. Though this report presents interesting information, estimates are calculated at a very aggregate level. The purpose it could serve in this project, is to compare congestion in Baton Rouge relative to other cities of similar size in the nation, to observe the trend in congestion in individual cities over time, and to validate analysis at aggregate level.

Bluetooth technology is currently being used in several cities in the US. The following studies and deployments of these devices give a scope of its use and trend in usage.

Sarasota County hosted and participated in an independent study to evaluate the functionality of BlueTOAD devices by testing its ability to collect accurate data and calculate travel times of vehicles in real time *[21]*. They planned to develop an implementation plan to deploy BlueTOAD devices as part of their Advanced Traffic Management System (ATMS) should the technology prove to generate accurate data. Data was collected on Fruitville Road for three weekdays using two Bluetooth devices on an approximately 2-mile stretch. Bluetooth devices were placed 10-12 ft. high on light poles to prevent vandalism. In addition to these devices, the team also placed Nu-Metrics vehicle detection (vehicle magnetic imaging technology) at approximately the same locations as the BlueTOAD devices to generate spot speed data and total volumes that could be used to validate the speeds and matches produced by the Bluetooth monitoring devices. Also, floating car data was collected to further analyze the speeds produced by the Bluetooth monitoring devices.

Four primary factors were evaluated in this study:

- **Distribution**: The first was the spread of matches across time to see whether the devices were consistently reading vehicles. The distribution of matches showed an even spread through each time interval (15 min.).

- **Match rates**: They obtained an average match rate of 3.45%, even though a 4% minimum match rate was required. It was, however, concluded that based on the spread of matches, and how close the % of total volume being matched is to the requirements, the number of matches being achieved was within reason.

- **Flow speeds**: Speeds provided by the Nu-Metric devices and the floating car method were compared with Bluetooth data for the same 3 days and they were observed to have a differential of 2 mph and 6 mph, respectively. In terms of time, on the 1.97 mile with an average travel time of 172.4 sec, the average time differential was 13.8 and 33 sec. respectively. Because there were so few floating car data results, the speed data provided by the Nu-Metric devices was considered to be the most accurate representation of actual travel conditions for comparison. Hence it was determined that the speeds and travel times reported using BlueToad devices were comparable to actual travel conditions on the corridor.

- **Cost comparison**: The total cost of the BlueTOAD devices were observed to be less than half the cost of comparable toll pass readers and less than one tenth the cost of license plate readers (LPRs). Field maintenance was estimated to be lower due to the lack of the need for bucket trucks for installation and maintenance. However, additional cost is incurred by the Bluetooth monitoring device's vendor's services to filter data and put reports on their web interface.

As a result of this study, the investigation team concluded that the use of Bluetooth devices within the Sarasota County ATMS (Advanced Traffic Management System) was an acceptable means of collecting travel-time data. Since this county was planning on constructing an ATMS, they wanted to use Bluetooth monitoring devices to collect county-wide travel-time data to evaluate the performance of ATMS once it is deployed. The team noted that the Bluetooth monitoring devices have sufficiently low energy demands to draw power from existing signal cabinets without any concern.

The Florida Department of Transportation (FDOT) commissioned a study to identify the current traffic patterns on S.R. 23 in Jacksonville, Florida in response to recent changes to the corridor *[22]*. They needed to update their travel demand model along the corridor. In order to accomplish this, 14 Bluetooth monitoring devices were deployed for one week to: (1) develop origin-destination (OD) matrices summarizing the travel movements between each sensor and (2) compute mean travel-time information for the travel movements between each sensor. Bluetooth technology was able to successfully provide the required data. FDOT compared the results with estimated travel patterns from their travel demand model and used the comparison to adjust model estimates for future year forecasts.

In Pennsylvania, 146 Bluetooth devices were employed to collect and analyze O-D data needed to support a regional modeling effort *[23]*. The units were deployed for 28 days along approximately 50 miles of the I-95 involving 38 interchanges. Data was transferred via cellular modem. Travel times were calculated by hour for all segments along with the turning movements at interchanges. O-D trip matrices were developed for average weekday a.m. and p.m. peak periods and specific hours on the weekend for all links in the corridor. It was felt that the project demonstrated that Bluetooth technology and its allied software is capable of collecting and analyzing data for large-scale modeling.

In Charleston, South Carolina, Stantec Inc. needed an O-D matrix for use in a project model *[24]*. They used Bluetooth monitoring devices to capture data that could also have been collected using license plate matching but at higher cost. While the methodology only collects a sample of all vehicles traveling the corridor, the sample size was determined to be statistically significant.

Bluetooth monitoring devices were deployed at the intersection of I-95 and I-695, just south of Baltimore *[25]*. Typically one Bluetooth device would be sufficient for each approach but here depending on the median width and other obstructions, two sensors were placed at each approach. Travel times of each of the 12 turning movements were estimated. All devices were placed on the right hand side of the freeway, generally against, near or under a guard rail section. Data was collected for six days using Bluetooth sensors. Travel times were successfully measured. The team also measured turning movement counts but since there was a split in the number of detections for turning movements, volume counts were needed to verify the results.

In Maryland, Bluetooth monitoring devices were used to evaluate the impact of signal timing changes on a signalized four-lane arterial corridor (Route 24 north) *[26]*. The length of the section was approximately 2 miles on which five Bluetooth sensors were deployed. The devices were placed at the base of sign posts or guard rails. Before implementing the new timings, 2.5 days of data were collected. After the new timings were implemented for a.m. peak and p.m. peak, two days of traffic data was collected again for comparison. Data were analyzed for three periods in a day: the a.m. peak, mid-day, and p.m. peak. Substantial improvement was observed in the northbound traffic during the a.m. and p.m. peaks. Figure 5 below shows improvement in travel time after retiming the signals. There was slight improvement in the p.m. peak travel times in the southbound direction, however, the a.m. peak travel time in the southbound direction degraded slightly. Two hundred samples were captured before and after the signal retiming. Apart from the cost savings resulting from using this method rather than the floating car method, the study team felt more confident estimating other benefits as well, such as a reduction in vehicle emissions or traffic delay.

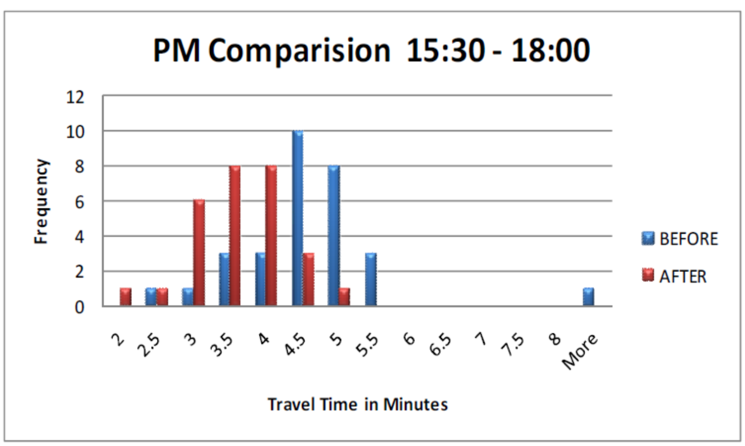


Figure 5
Before and after travel-time histograms for northbound MD 24

In Flagstaff, Arizona, US 180 experiences heavy congestion during the winter season because of a popular ski area north of Flagstaff *[27]*. In recent years the condition has worsened, overloading intersections and creating operational and safety concerns for local agencies. To measure the level of delay, 16 Bluetooth monitoring devices were deployed to provide travel-time information to the traveling public to popular destinations.

The Pennsylvania Department of Transportation (PennDOT) wanted to evaluate the Bluetooth technology's ability to collect and report travel times *[15]*. As such, the test was conducted along I-76 at locations coincident with EZPass tag readers. Two road sections were used in this study. TrafficCast was their vendor and it provided a 15-min. travel time and speed data as well as matched pairs. Two days worth of data were used in the study. In addition, traffic volume data was obtained from RTMS (Remote Traffic Microwave Sensor) stations. Several parameters were analyzed in this study with regard to Bluetooth monitoring devices:

- **Travel Time Results Comparison:** Travel time was slightly different between technologies (Bluetooth and EZPass). However, it was determined that the travel time produced by Bluetooth monitoring devices were comparable to that of EZPass tag readers.

- **Match Rate:** Bluetooth monitoring devices had match rates of approximately 4% compared with EZPass tag readers which ranged between 10-37% of the daily traffic. The minimum number of data points to accurately depict traffic conditions, per general guidelines, was collected by each traffic monitoring system. The true through volume in the eastbound direction could not be estimated because of entry and exit points between the sensors. Clearly, this also affected the match rates.

- **Cost:** The cost of the BlueTOAD equipment including pole, but excluding power, communication, data formatting, and system integration was approximately $9,700 to $12,200 per device, nearly one-third the cost of EZPass.

- **Constructability and Usability:** The installation and maintenance of the BlueTOAD device was relatively simple. Devices were installed at about 6-10 ft. on structures on the shoulder (of overhead sign boards) with solar panels for power. The range of the reader was 175 ft. It could easily cover one direction of a multi-lane highway.

The literature review on the use of Bluetooth Probe Detection System (BPDS) showed that it is currently being used by several state DOTD's for acquiring travel time. There is a general consensus among users that BPDS is easy to use and is a useful means of acquiring travel-time measurements in real time. Given this state of affairs, it was considered a worthwhile effort in this study to acquire BPDS and investigate its potential in estimating congestion indices and other useful information that helps in mitigation of congestion.

Acquisition of BPDS

Bluetooth Probe Detection Systems are sold by several commercial vendors and are available in different models. After conducting the literature review and some research into the latest available technology, a set of specifications that served the needs of the current study were developed. Along with the research into the BPDS technology, the potential vendors of the technology were also identified and approached for an initial quote of desired instrumentation. After receiving the initial quotes, an invitation to bid was prepared with LSU’s accounting office assistance and posted on LSU’s procurement services website. A total of four responses were received in response to the invitation and the lowest bidder, Econolite, which is a local distributor of BlueTOAD, was selected as the supplier. A total of 11 BPDS units were bought for a total price of $49,522. All the BPDS units were dual powered (solar and battery power), capable of sending raw data using cellular service to a central website that processed the data to produce travel-time estimates. The price charged for the units also included the charges for providing cellular service and raw data processing services for a year through a web interface developed and maintained by Trafficast, the parent company supplying BlueTOAD equipment.

The major instrumentation needed to detect Bluetooth signals sit in an 8-in. × 14-in. × 6-in. box as shown in Figure 6. The components inside the box are shown in Figure 7. Figure 8 shows the solar panel supplied with the BPDS.

Figure 6
Bluetooth probe detection system cabinet

Figure 7
Components of Bluetooth probe detection system

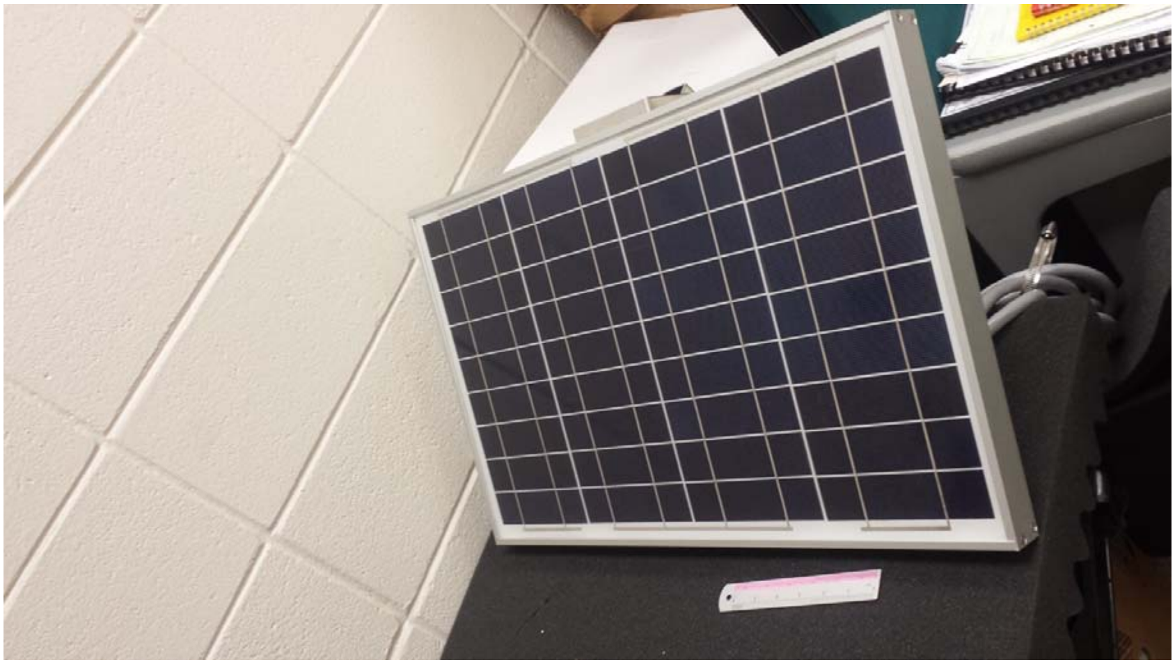


Figure 8
Solar panel supplied with Bluetooth detection system

Identification of Congestion Hot Spots

Congestion hot spots are defined as locations along arterials or freeways that experience recurrent congestion. To identify hotspots, one can use a variety of methods. One of them is to deploy BPDS throughout the metropolitan area and measure travel time at each location. However, with a metropolitan area as large as Baton Rouge, which has 283 lane-miles of freeway and 1,457 lane-miles of arterials, it is not only cost-prohibitive to deploy BPDS but also a time-consuming task. Another alternative is to use records of past complaints regarding congestion in the city, and use this information to deploy BPDS to the locations that have experienced the most complaints. However, the approach is neither comprehensive in its consideration of all problem areas in the region nor is it equitable. To overcome this problem a new method was devised to identify hotspots using freely available historical traffic data from Google. The method uses a combination of image analysis and historical traffic maps to identify locations of chronic congestion.

The method developed in this study uses Google Map images of Baton Rouge to demonstrate the process, but it is applicable to any area covered by Google Maps. Because Google provides traffic data for freeways and arterials only, the method cannot be use to estimate hot spots on local roads. Figure 9 shows the sample geographical area used in demonstrating the process in this study.

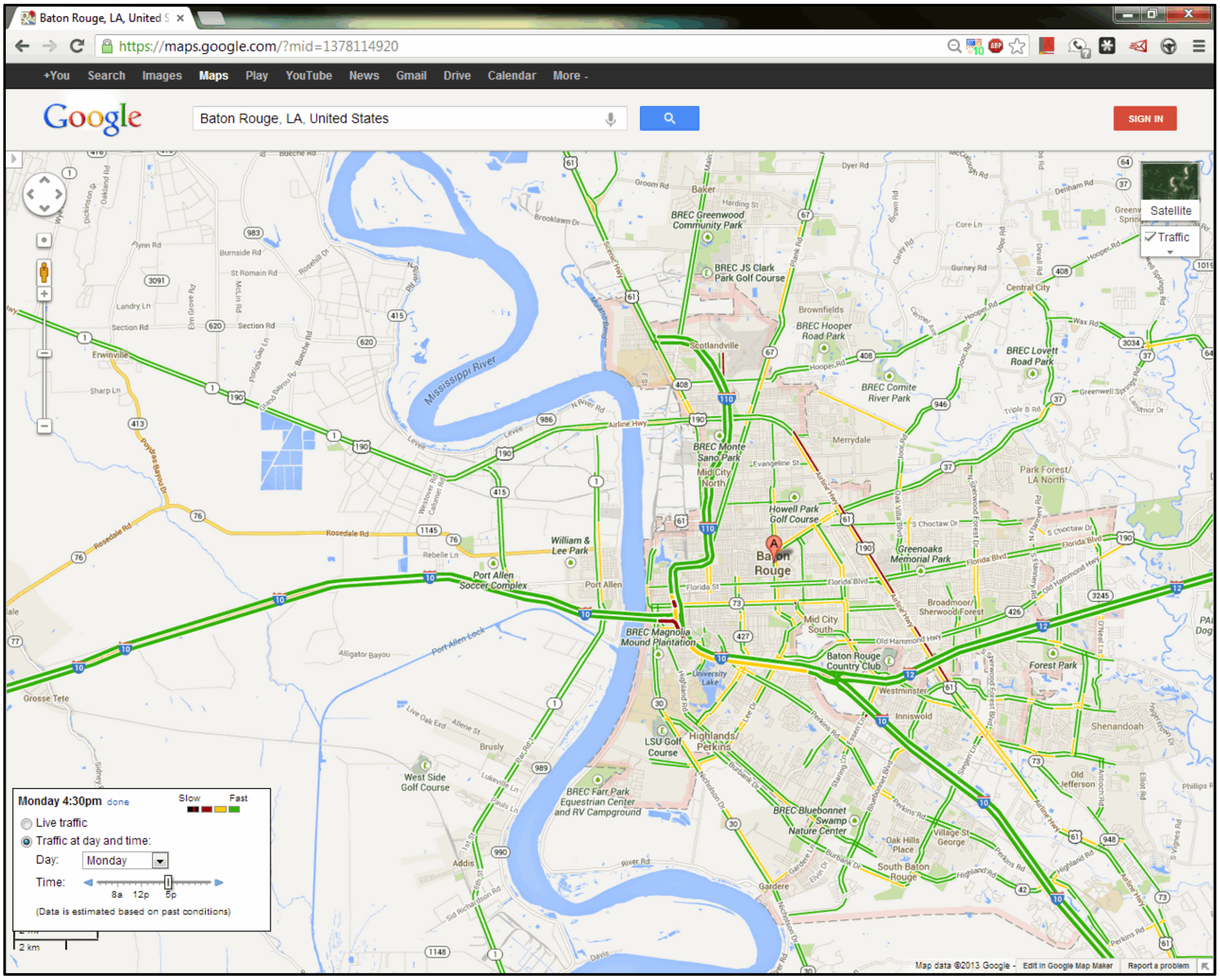


Figure 9
Geographical boundary of the study area

The following sections describe how historical traffic speed information is stored in Google Map's traffic layer, the method used to access and download historical traffic image data from Google Maps, the steps involved in analyzing these images to extract historical speed information for identification of congestion hotspots, definition of a new congestion index derived using the image analysis technique, and, finally, the approach adopted in identifying and displaying congestion hotspots.

Data Collection

A Google Map is capable of displaying both current traffic conditions and historical traffic conditions. The historical traffic maps can be accessed by opening Google Maps in a web browser and turning on the traffic layer. The historical maps are available for each day of the week and provide traffic conditions at a resolution of no less than 15-min. intervals. The maps are color coded using five different colors that represent varying average travel speeds. For freeways the colors signify the following speed conditions:

- Green: more than 50 mph (80 kmph)
- Yellow: 25 - 50 mph (40 - 80 kmph)
- Red: less than 25 mph (40 kmph)
- Red/Black: very slow, stop-and-go traffic
- Gray: no data currently available

For arterials roads, the above mentioned speed ranges do not apply. The colors only give an indication of the severity of the traffic. Green implies that traffic conditions are good, yellow implies fair, and red or red/black implies poor traffic conditions.

The red/black color that represents very slow or stop-and-go traffic is often seen in the Google Map representation of live traffic data. However, the chances for it to appear in a 15-min. interval historical map, which represents an average of several days' traffic conditions during that period, are very slim on either road type. Therefore, effectively, there are four colors that appear in the historical traffic maps on Google: green, yellow, red, and gray. Among these, red is of importance since it signifies poor traffic conditions on arterials and slow speeds on freeways. Figure 10 displays all the four colors in a map that portrays average historical traffic conditions during a 15-min. interval starting at 4:45 p.m. on a Thursday, in Baton Rouge. Thus, in this case the 4:45 p.m. image represents the average traffic conditions between 4:45 p.m. and 5:00 p.m.

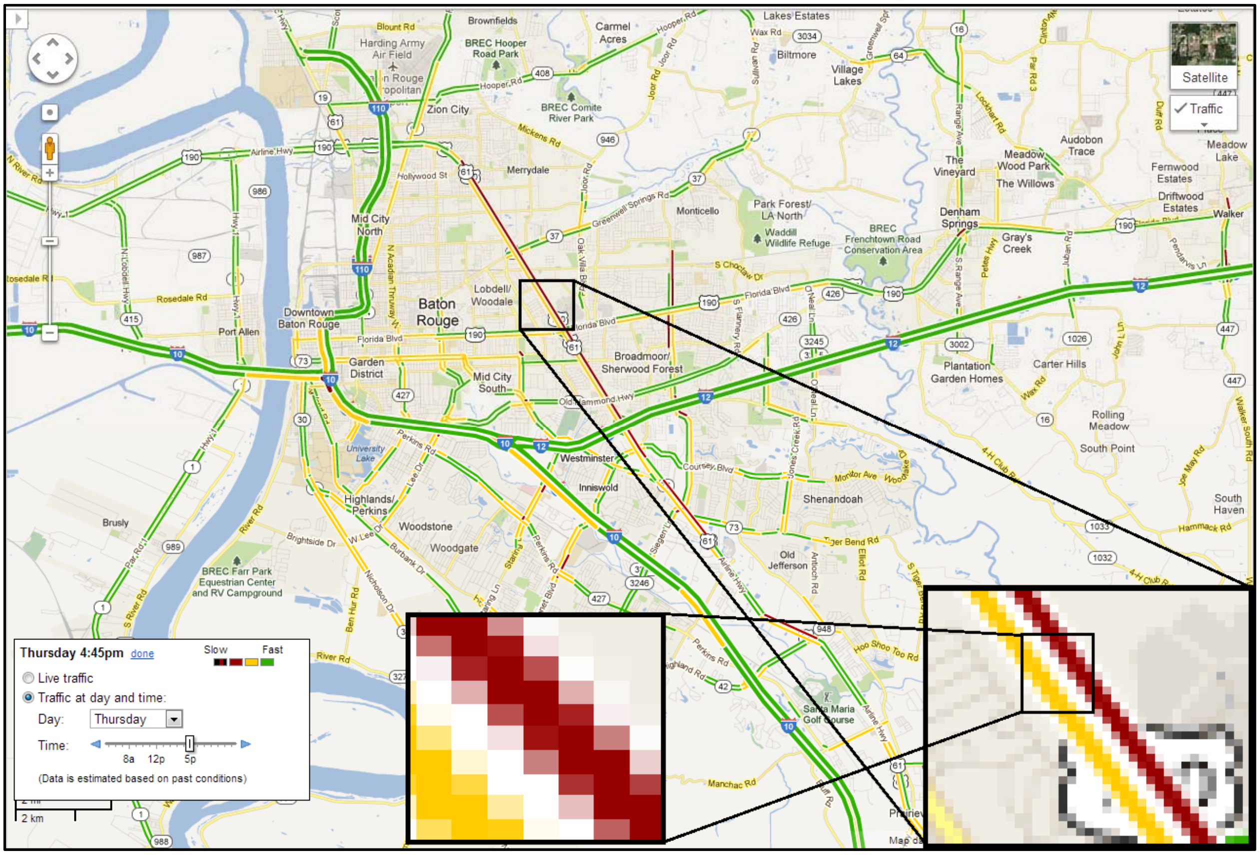


Figure 10
Image of area of interest in Baton Rouge, LA

All of the maps displaying historical traffic conditions graphically are freely available, but there is no direct way to access the traffic speed data used in producing the graphics. Thus, an alternative method of identifying traffic speed from the graphic image is needed. The images provided in Google Maps are made up of thousands of pixels as seen in Figure 10. The pixels which are red in color represent locations of slow speed and, therefore, high congestion. Thus, pixel data can be used to identify congested corridors by employing image analysis techniques that translates color information to digital data.

Amount of Data

To identify road sections on which congestion occurs frequently, historical maps from all days in the week and at all-time intervals are needed. This is because congestion varies by time of day and day of week and, therefore, incidence of congestion must be summed over an entire week to measure the frequency of congestion at a particular location. However, it was confirmed in a preliminary analysis that, in Baton Rouge, congestion generally does not occur before 7 a.m. or after 10 p.m. on any day. Thus, a decision was made to limit capturing of images to the 15-hour time frame between 7 a.m. and 10 p.m. each day. As mentioned earlier, this data is available at 15-min. intervals for every day of the week. Hence for one day, a total of 60 images (15 hours × 4 images/hour) were acquired for the city. Similarly, 60 images are acquired for each day of the week, making a total of 420 (7 days × 60) images for an entire week.

A two-month observation showed that Google's historical traffic maps are updated in a cycle of approximately a week to 10 days. To capture historical traffic conditions over a longer period, historical traffic maps were captured every 7-10 days over a period of a month (i.e., 3-4 sets of historical traffic maps were downloaded to identify recurrent congestion conditions over a month).

The geographical scope of a map changes with the resolution of a monitor and the zoom level chosen to display the map. When displaying live traffic conditions on Google Maps, it was observed that maps were consistent in displaying colors at different zoom levels. However, the choice of a zoom level impacted the way in which historic traffic speed data was represented in a map. At any particular 15-min. period in a day, Google Map's show, for the most part, the same color on road segments at different zoom levels on freeways. But in the case of arterials, colors were observed to change by varying zoom levels. However, this phenomenon was observed only at isolated locations. An effort was made to understand the rationale behind this phenomenon by contacting Google Map's technical team, but no reply was received from them. It was ultimately decided to collect images at a scale of 1: 178,816 because it covers the entire Baton Rouge Metropolitan area in one image with visible traffic color data present on all arterials and freeways.

Capturing Images

Before image analyses can be performed, all the images requiring processing must be downloaded from the Internet by taking screenshots using an Internet browser. However, it is a very tedious and error-prone task to take screenshots of historical traffic maps on a long-term basis, i.e., to take screenshots and store the 420 images manually in a systematic order every week or 10 days. Therefore, an automated procedure was devised that did not need human intervention to capture historical traffic map screenshots in a repetitive manner.

GhostMouse, in combination with FastStone Capture, is a software bundle in which repetitive mouse movements and key strokes can be recorded and coded to capture screenshots of Google Map images. The operating system of the computer, the location of icons, windows on the screen, and the size and relative position of an additional monitor should be set up before running the software to automate the process of capturing the images. The entire setup is explained in detail below and with the layout shown in Figure 11:

The setup requires two monitors:

- Monitor-1 on the left at a resolution of 1600 x 900
- Monitor-2 on the right at a resolution of 1280 x 1024

Monitor 1 must be set up with the following settings:

- The FastStone Capture software's window should be present in the right top corner.
- MS Excel sheet with path names to store the images in chronological order should be maximized.
- The GhostMouse window should be present in the yellow box over the excel sheet.
- The program icons of FastStone Capture and MS Excel should be pinned to the taskbar right next to the start menu.

Monitor 2 should be set up with the following settings:

- Google Maps should be opened by going to https://maps.google.com using a Google Chrome browser. The browser window should be maximized.
- In the search bar "Baton Rouge, LA" must be entered and the left information panel hidden by clicking on the hide panel button.
- Google Maps must be set to "Map" style, if it is not already set.
- The traffic layer must be switched on. This results in a small traffic options box popping up in the left bottom corner of the screen.
- The "traffic at day and time" must be selected from among the options. The time and day must be set to 7 a.m., Monday.

Note: Approximately half of the above-mentioned arrangements need to be made only the first time the program is set up on a computer; the other half need to be set each time a new sample is collected.

Monitor-1 (1600 x 900 resolution) **Monitor-2 (1280 x 1024 resolution)**

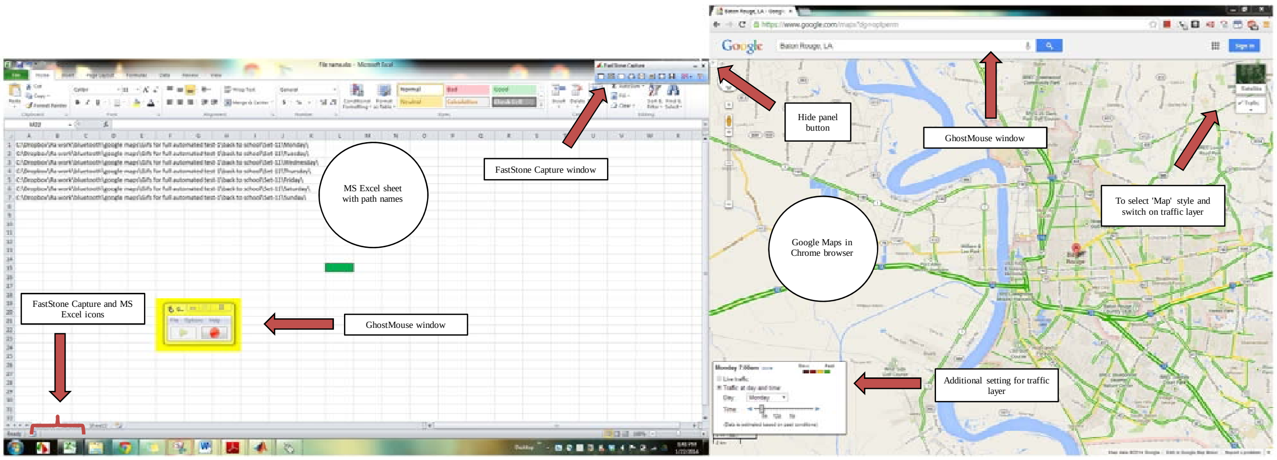


Figure 11
Layout of programs and icons before GhostMouse Software is run

Once the above-mentioned setup is performed, repetitive actions of the mouse and keyboard strokes performed by the user are captured onto a file by the GhostMouse software. This task needs to be performed only once. When the user requires a new set of data to be downloaded, he/she just needs to execute the coded GhostMouse file after setting up the computer as shown in Figure 11. Mouse movements in combination with the keyboard strokes interact with the windows, icons, and programs as recorded in the initial setup and the resulting captured image data is saved onto the hard drive. Stable internet connections typically load traffic data on maps within 1 sec. However, the pre-coded GhostMouse file was set to accommodate any internet lag (up to 3 sec) that could occur due to increased internet latency or decreased bandwidth.

Using the described set up, images required for analysis were downloaded and stored in seven different folders, one for each day. All the downloaded images were in a GIF (Graphics Interchange Format) format indexed with 256 colors and each image had a resolution of 1280×1024 pixels.

Hot Spots Identification

The rationale behind the image analysis technique lies in exploiting the pattern in which an image's digital representation is stored in a computer memory. There are different formats that can be used to store an image, but the GIF format was chosen in this case because image data is "indexed" rather than presented in "true color" as in the widely-used JPEG (Joint Photographic Experts Group) format. An image in the GIF format has an array that is the size of the image

(1024 × 1280, in this case), where each cell of the array has an index value that is between 0 and 255. Each of the indices refers to colors in a predefined palette of 256 colors to display the color in that cell. This makes the GIF format more flexible to use compared to a true color image that has color values for each pixel stored as red, green, blue (RGB) triplets.

There are several software packages that are commercially available and can be used to perform image analysis. However, MATLAB was chosen to perform image analysis because the basic data structure in MATLAB is the array, an ordered set of real or complex elements. Moreover, MATLAB stores most images (such as GIF) as two-dimensional arrays or matrices in which each element of the matrix corresponds to a single pixel in the displayed image. Furthermore, MATLAB provides several built-in functions that can be used to write custom scripts to perform image analysis. The following section describes the steps involved in performing image analysis.

In the first step, images are imported into MATLAB. MATLAB stores the image as a 1280-x-1024 matrix with each cell of the matrix storing information related to a single corresponding pixel on the image. This convention makes working with images in MATLAB similar to working with any other type of matrix data, and makes the full power of MATLAB's matrix manipulation capabilities available for image processing.

In the second step, MATLAB's matrix processing capabilities are used to identify cells corresponding to pixels of interest in identifying congestion hotspots. It was known a priori that Google Maps color code congestion on freeways and arterials with a red color. However, in the bottom inset in Figure 10, it can be seen that congested corridors are not represented by one red color but a range of red colors. Thus, it was required to separate the pixels that represent congestion from pixels that do not represent congestion.

In order to identify the entire range of congestion representing red colors, index values and RGB values should be used together. In addition to each color being represented by an index value as described before, they are also described in terms of the three base colors (RGB) each of whose values ranges from 0 to 1 (e.g., black has an RGB of [0,0,0,]; white has an RGB of [1,1,1]; and parrot green has an RGB around [0.16,0.68,0.01]). MATLAB's image processing tool called the "inspect pixel values" tool can be used to obtain more information related to the color of a pixel. The tool provides a means of inspecting each pixel and identifying whether it is of interest by observing (1) if the pixel is red, (2) the color of the pixel in visual form, (3) its associated index value, and (4) its associated RGB values as shown in the pair of windows in Figure 12.

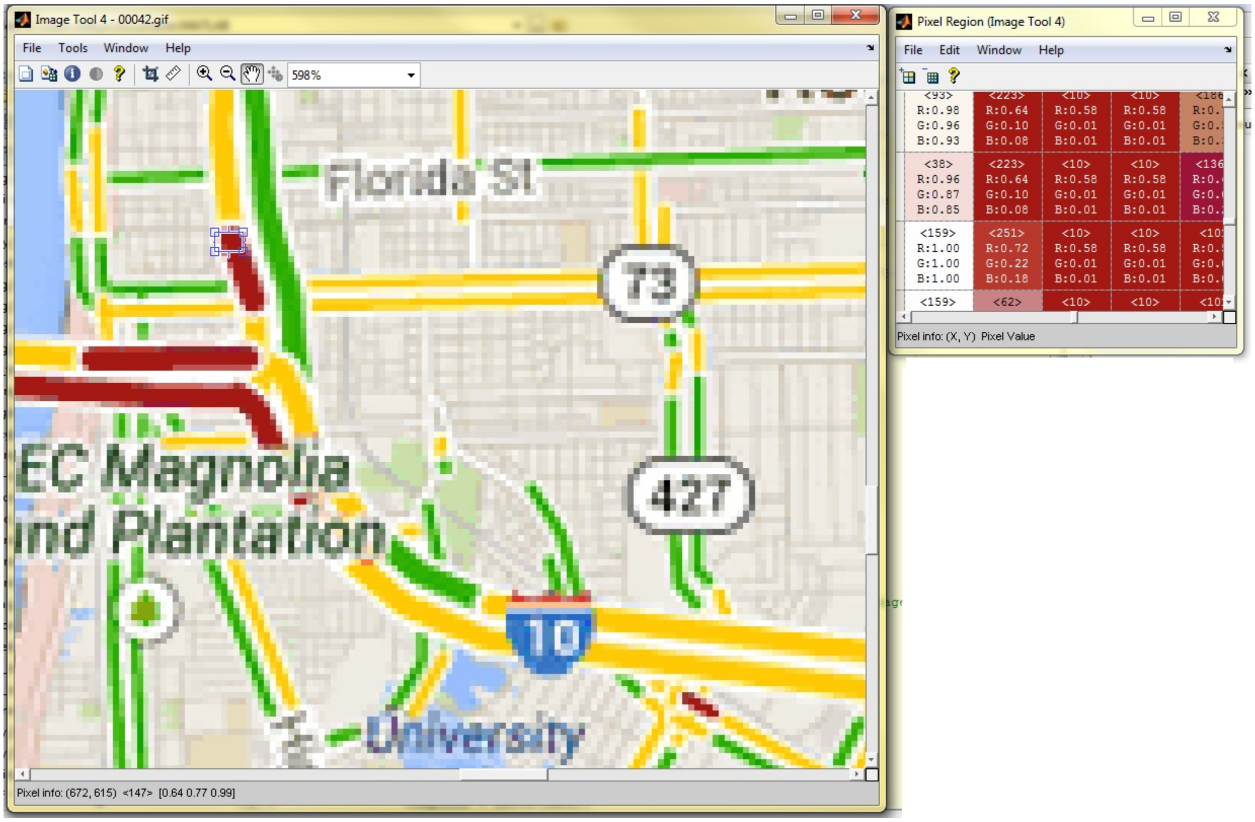
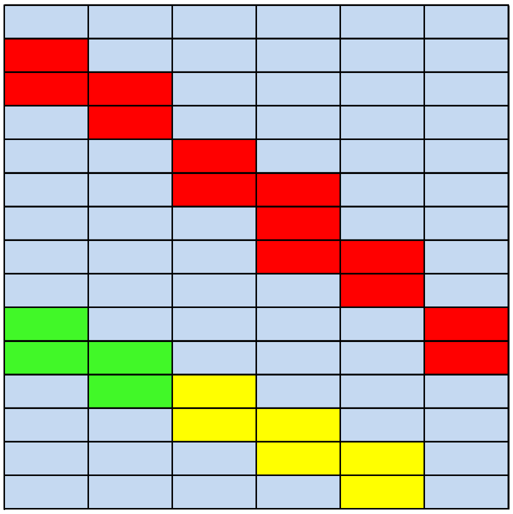


Figure 12
Image toolbox window (left) and Inspect pixel value window (right)

Using the “inspect pixel values” tool, several maps were inspected and the most suitable range for RGB values were identified as R > 0.45, G < 0.38, and B < 0.32.

In the third step of the image analysis, MATLAB’s programming interface was used to isolate index values of colors associated with the previously discussed RGB value ranges. Then, in the fourth and final step, matrix cells that contain congestion-representing index values were populated with a value of one and the rest of the cells with a zero. So if congestion is present on a road, a value of 1 is inserted into all the cells in the matrix that correspond to congested portions of the road as represented by individual pixels in the map. Figure 13 shows a pictorial representation of this concept with an initial image along with its analytical matrix.



0	0	0	0	0	0
1	0	0	0	0	0
1	**1**	0	0	0	0
0	**1**	0	0	0	0
0	0	**1**	0	0	0
0	0	**1**	**1**	0	0
0	0	0	**1**	0	0
0	0	0	**1**	**1**	0
0	0	0	0	**1**	0
0	0	0	0	0	**1**
0	0	0	0	0	**1**
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Figure 13
Example of Google Map image with corresponding matrix

It is important to note that the congestion-representing index values can change from image to image (i.e., from one 15-min. matrix to another). Therefore, the analysis to convert an image to numbers must be done for each matrix of observations.

Fifteen-Minute Interval Analysis

The process of populating matrix cells based on congestion needs to be repeated for each 15-min. time period, every day for a single week. If these matrices are summed over a seven-day period, 60 15-min. matrices will be produced. These represent aggregate traffic conditions over a week (between 7 a.m. to 10 p.m.). A road experiencing congestion throughout the week in a particular time interval would get a value of 7 in the matrix for that time interval. The process of summing up the matrices for each time interval is shown schematically in Table 2.

Table 2
Analysis of 15-min. interval matrices

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday		Final matrix for 15 min interval
7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	=	Matrix for 7:00 am
7:15 AM	7:15 AM	7:15 AM	7:15 AM	7:15 AM	7:15 AM	7:15 AM	=	Matrix for 7:15 am
7:30 AM	7:30 AM	7:30 AM	7:30 AM	7:30 AM	7:30 AM	7:30 AM	=	Matrix for 7:30 am
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.

The process of analyzing images to identify congestion becomes tedious if many images must be processed manually. Recognizing this, a script was written in MATLAB that automatically performs the four steps required to analyze images.

Analysis Beyond the 15-Min. Interval

The results obtained from the 15-min. interval analysis might not be enough to identify severely congested corridors because it only examines if corridors were congested for only 15 min. It would be useful to analyze if corridors were congested for 30-min., 45-min., or for 1-hr. periods since duration of congestion is one of the dimensions on which congestion is characterized. The results from such an analysis might give a totally different perspective of congestion in a city from that of a 15-min. interval analysis.

In identifying congestion in 30-min., 45-min., and 60-min. periods, the presence of congestion in consecutive 15-min. intervals first needs to be identified. For instance, in the case of a 30-min. interval period, the analysis would begin by analyzing the two 15-min. consecutive data intervals for the time period between 7:00 a.m. and 7:30 a.m. on Monday for each cell of the matrix. The pixels which have congestion in both the images are then mapped into a new matrix named "7:00 to 7:30 a.m. matrix"; with the corresponding cell getting a value of 1. This procedure was repeated for all contiguous pairs of 30-min. interval matrices for all 7 days of the week. The resulting matrices were then summed over the entire week to produce a new set of 59, 30-min. matrices. The resultant set of 59 matrices represented aggregate 30 min. congestion over the entire week. The 59 matrices result from the fact that there are 59 consecutive overlapping 30 min. intervals between 7 a.m. and 10 p.m. A schematic representation of 30-min. interval analysis is shown in

Table 3 for a sample pixel where a red highlighted cell indicates congestion in the matrix cell represented by the pixel for the 15-min. time period shown.

Table 3
Analysis of 30 min. interval matrices

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday		Final matrix for 30 min interval			
7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	7:00 AM	=	Matrix for 7:00 AM to 7:15 AM	Freq. of congestion=2		
7:15 AM	7:15 AM	7:15 AM	7:15 AM	7:15 AM	7:15 AM	7:15 AM	=			Matrix for 7:15 AM to 7:30 AM	Freq. of congestion=3
7:30 AM	7:30 AM	7:30 AM	7:30 AM	7:30 AM	7:30 AM	7:30 AM	=				
.	.	.	.	.	.	.	=				

A similar procedure was repeated for the 45-min. and 1-hr. intervals to obtain their respective final matrices (58 and 57 in number, respectively). The range of values in the final matrices ranged from a minimum of 0 to a maximum of 7 in all four cases.

Congestion Index (CI) Computation

Duration of congestion is one of the factors that characterizes the level of congestion experienced. For instance, if a road is congested for 15 min., that road is not experiencing the same level of congestion as one that is continuously congested for 30-min. or longer. Thus, the notion is proposed that smaller intervals have a smaller effect on congestion than longer intervals of congestion. Accordingly, weights of 1/10, 2/10, 3/10, and 4/10 were assigned to the 15-min., 30-min., 45-min., and 1-hr. time interval values, respectively. These weights imply a linear relationship between congestion and duration, and they add up to 1 so they apportion out total effect.

Secondly, it is also suggested that the frequency with which congestion occurs also characterizes the severity of the congestion problem. That is, a site that experiences congestion regularly is perceived as experiencing more congestion than one where it rarely occurs. To quantify this, two parameters are required in each of the four time intervals. The first is the total number of matrices in each time interval (denominator) and the second is the weekly average daily congestion frequency in each time interval of each pixel (numerator).

Using the two congestion characteristics mentioned above, a CI can be calculated for each pixel on roads using the following equation:

$$\text{Congestion Index for pixel [X, Y]} = {}^{1}\!/_{10}\left(\frac{A1}{A2}\right) + {}^{2}\!/_{10}\left(\frac{B1}{B2}\right) + {}^{3}\!/_{10}\left(\frac{C1}{C2}\right) + {}^{4}\!/_{10}\left(\frac{D1}{D2}\right) \quad (1)$$

Where,

A1 = Weekly average daily 15 min. congestion frequency $= \frac{\sum_{T=7\,am}^{T=10\,pm} \sum_{D=Monday}^{D=Sunday} T15_D}{7}$

A2 = Total no. of final 15 min. interval matrices in a week.

B1 = Weekly average daily 30 min. congestion frequency $= \frac{\sum_{T=7\,am}^{T=10\,pm} \sum_{D=Monday}^{D=Sunday} T30_D}{7}$

B2 = Total no. of final 30 min. interval matrices in a week.

C1 = Weekly average daily 45 min. congestion frequency $= \frac{\sum_{T=7\,am}^{T=10\,pm} \sum_{D=Monday}^{D=Sunday} T45_D}{7}$

C2 = Total no. of final 45 min. interval matrices in a week.

D1= Weekly average daily 60 min. congestion frequency $= \frac{\sum_{T=7\,am}^{T=10\,pm} \sum_{D=Monday}^{D=Sunday} T60_D}{7}$

D2 = Total no. of final 1hr. interval matrices in a week.
[X, Y] = The coordinates of the pixel.
$T15_D$ = 15 min. matrix
$T30_D$ = 30 min. matrix
… and so on.

Since the time between 7 a.m. to 10 p.m. is considered for analysis, the denominators are fixed at A2 = 60, B2 = 59, C2 = 58, and D2 = 57. The ratios (A1/A2, B1/B2, C1/C2, and D1/D2) vary between zero when congestion does not occur at a particular pixel location in any time interval during the analysis period (7 a.m. to 10 p.m.) during a week of observations, to 1 when congestion occurs continuously at that location from 7 a.m. to 10 p.m. for a week. Thus, the four ratios A1/A2, B1/B2, C1/C2, and D1/D2 represent the frequency characteristic of the congestion index, and the $\frac{\text{Number of 15 min. in the duration interval}}{10}$ represents the duration characteristic of the congestion index.

A CI is computed for every pixel, resulting in a value between 0 and 1 that is assigned to each pixel with the overall level of congestion being signified by its magnitude. Pixels with CI values of zero imply no congestion while for the congestion index of a cell to attain the value of 1, the road must remain congested during all time periods between 7 a.m. and 10 p.m. for a week. Obviously, no road would experience such high level of congestion, so CI values are always less than 1. As formulated previously, the CI formula represents a general level of congestion experienced over a week. However, the time period considered could be reduced to shorter periods such as a day, morning peak, evening peak, or special event time, etc.

Based on CI values obtained in the study area, the CI ranges shown in the Table 4 are recommended for categorization as congestion hotspots. The categorization was developed based on observed empirical relationship between CI and recurrent congestion over a month. Clearly, different CI ranges could be used to reflect greater or less sensitivity to congestion conditions.

Table 4
Congestion index ranges for hotspots

Time period of analysis	Congestion Index of Hotspots
Morning peak period/Evening peak period – 2hr.	0.26 to 1
Entire day (7 a.m. to 10 p.m.) -15 hr.	0.039 to 1

Congestion Index Mapping

In the previous section, a numerical congestion index was proposed and computed for individual pixels or locations on a road section. To visually represent the numerical information, one method adopted was to draw solid red circles on the map proportional in size to the congestion index values. This was achieved by populating the cells around a pixel to a radius proportional to the congestion index of that pixel. That is, a red circle proportional to the level of congestion experienced was drawn on the map. This is shown schematically in Figure14 and Figure 15 where eastbound traffic on road A experiences congestion over its entire length but with the most prevalent congestion occurring in advance of the intersection with road B.

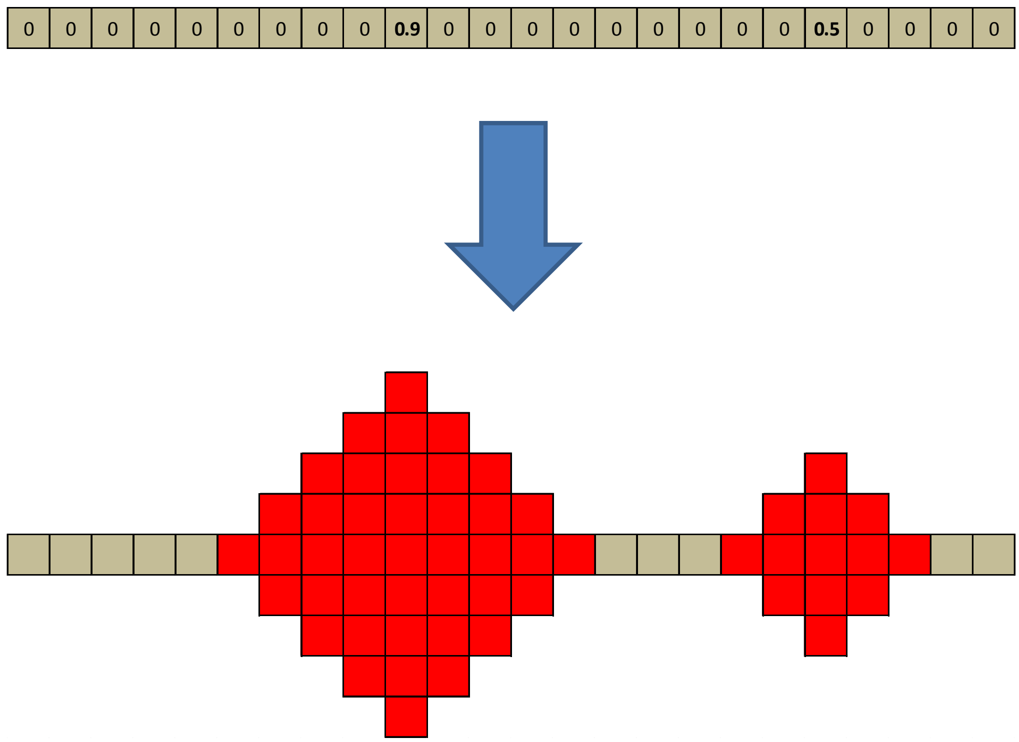


Figure 14
Graphical representation of level of congestion

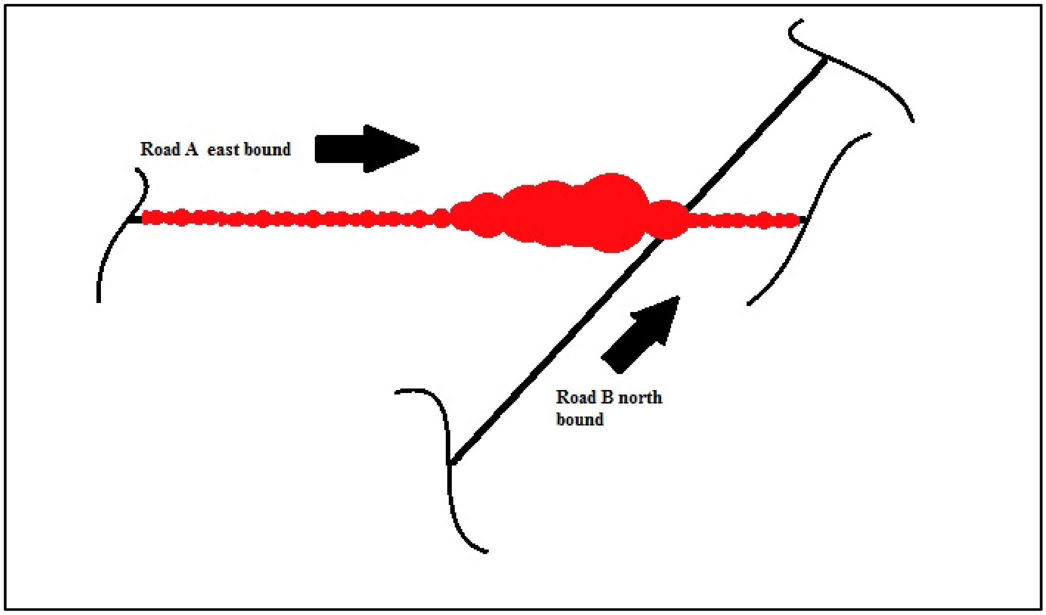


Figure 15
Level of congestion represented by size of red dots

In this case two aspects can be varied manually when representing data, namely:

1. Resolution factor: CI values for pixels are usually very small numbers and typically occupy a large number of decimal places. If the resolution factor is too coarse, only large values of CI will be recognized and it will be difficult to distinguish between CI values which are very similar, being only different in the second or third decimal place (e.g., 0.239 and 0.234). This will render the buffer analysis to provide imprecise and very aggregate results. If a fine resolution value (e.g., by considering six decimal places of CI values) is used, the differences between congested areas are more clearly distinguished. However, trials showed the computing time to increase exponentially with an increase in each decimal place and the computer could run out of memory as well. Therefore, the person who runs the program should be prudent when selecting the resolution value to represent data. A resolution factor of $4x10^n$ is recommended where n is the number of decimal places that one prefers to use.
2. Scaling factor: A scaling factor can be employed to increase or decrease the size of the solid red circles that represent the CI values of the pixels. The user can specify the value they find most appropriate for their purpose.

Recommended values for resolution and scaling are shown in Table 5.

Table 5
Recommended resolution and scaling factors

Time period of analysis	Resolution	Scaling
Entire day (7 a.m. to 10 p.m.) – 15 hr.	4000	40
Morning peak period/Evening peak period – 2hr.	400	30

Mapping Frequency of Congestion

Another method of portraying congestion in graphic form is to use colors to depict different levels of congestion. For example, if frequency of congestion is used as a measure of congestion, then the 15-min. matrices populated with 1's and zeros from the earlier analysis could be added together to produce a matrix showing the frequency of congestion at each pixel. In this study, MATLAB's built-in color maps were used to color roadways to portray the level of congestion present. For example, low levels of congestion were illustrated with a green color and high levels of congestion in red, with a transition in color in between as shown in Figure 16.

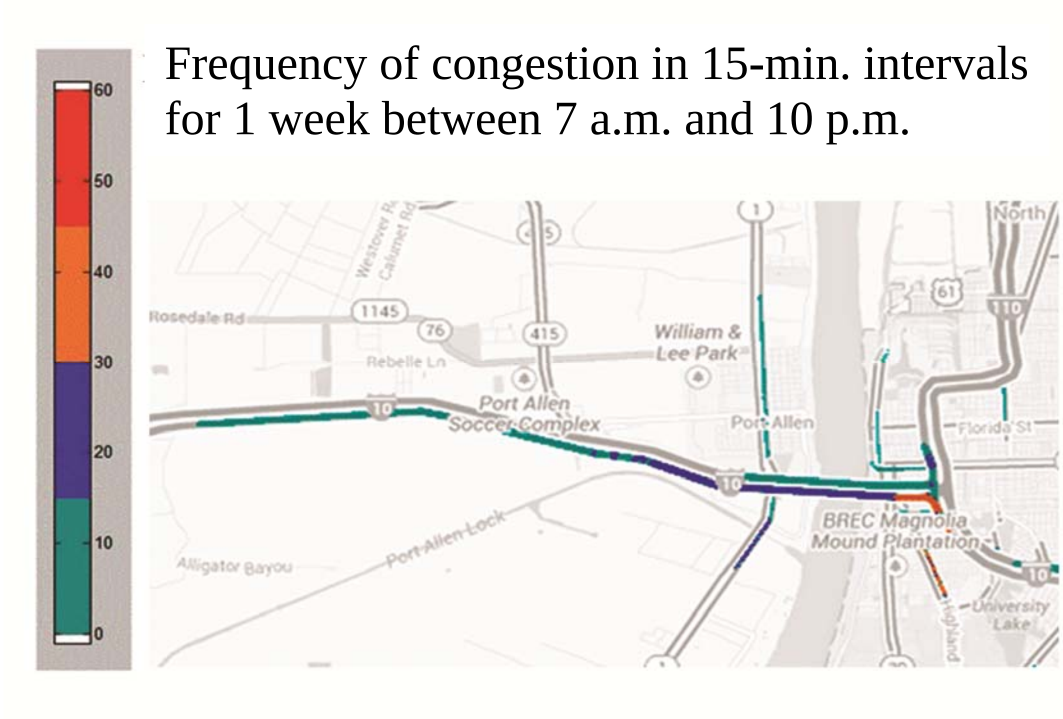


Figure 16
Frequency analysis for 15-min. congestion for entire day

Application

Analysis on One Week Data. The data for conducting analysis in this section was collected from Google Maps on 09/03/13 covering a period of one week between 7 a.m. and 10 p.m. each day. After downloading images, invalid red pixel data in the images that did not represent congestion was removed by applying screening procedures and visual inspection. These red pixels were from features in the image such as: the legend, browser extension icons, Google's logo, the top part of the interstate sign present on interstates, the red balloon in the center of the image and other isolated pixels from letters of labels on roads and places. Then a 15-min. frequency analysis and Congestion Index analyses were performed. (Note: The background in all the maps was only used as a base map; the colors in the maps except red have no congestion/traffic significance.)

The congestion map shown in Figure 16 was obtained by applying the technique developed to represent frequency of congestion. The four ranges of frequencies of 15-min. congestion are shown using a custom color map of four colors. This map gives a perspective of congestion in the city as a function of frequency of congestion. From the map it is clear that I-10 eastbound direction is more congested than other roads, especially at its intersection with the I-110. This map gives a perspective of 15-min. congestion in the city. However, it does not provide any information on congestion duration and moreover it is difficult to detect and decipher congestion frequency of isolated pixels at intersections.

The first method/technique used to represent congestion described above provides more information about congestion since it takes into account both frequency and duration of congestion into account. Here the diameter of the solid red circle of the pixels is in proportion to its congestion index as seen in Figure 17. Figure 18 is a result of the same analysis. However, the figure shows congestion over roads near downtown and Louisiana State University in greater detail.

From the congestion index analysis, it can be observed that the I-10 over the Mississippi River, arterials next to the I-10 before the I-10/I-12 split (Perkins Road, College Dr.), two intersections (Old Hammond Highway – Jefferson and Brightside Dr. – Nicholson Dr.) and a major arterial (Airline Highway) crossing the I-12 on the right-hand side of the diagram, experienced heavy congestion with CI values in the range of 0.0393 to 0.2331. Hence they are considered hotspots based on the ranges established in Table 4. These observations are consistent with common opinion among motorists of sites in Baton Rouge with high levels of congestion.

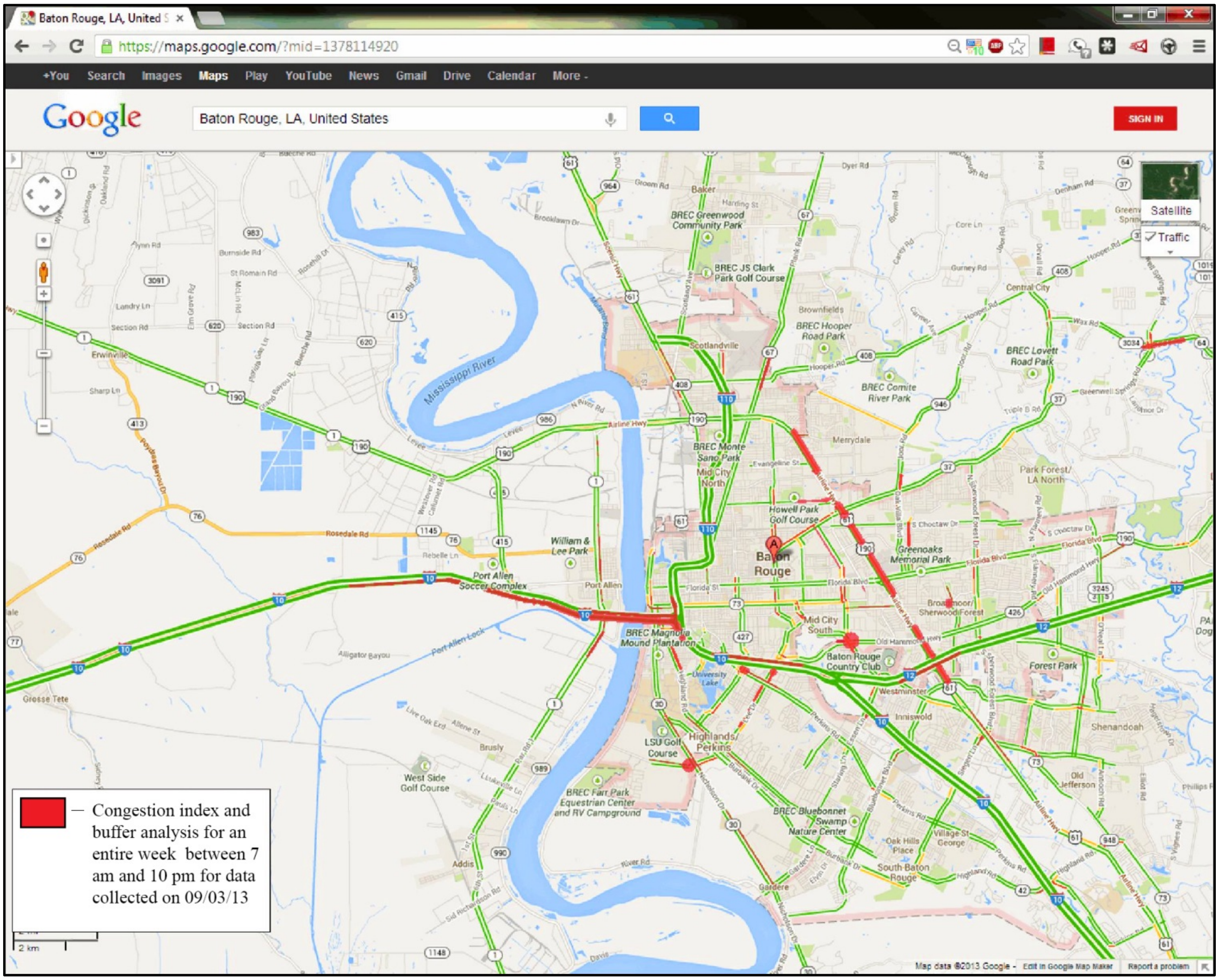


Figure 17
Congestion analysis for entire day (7 a.m. to 10 p.m.)

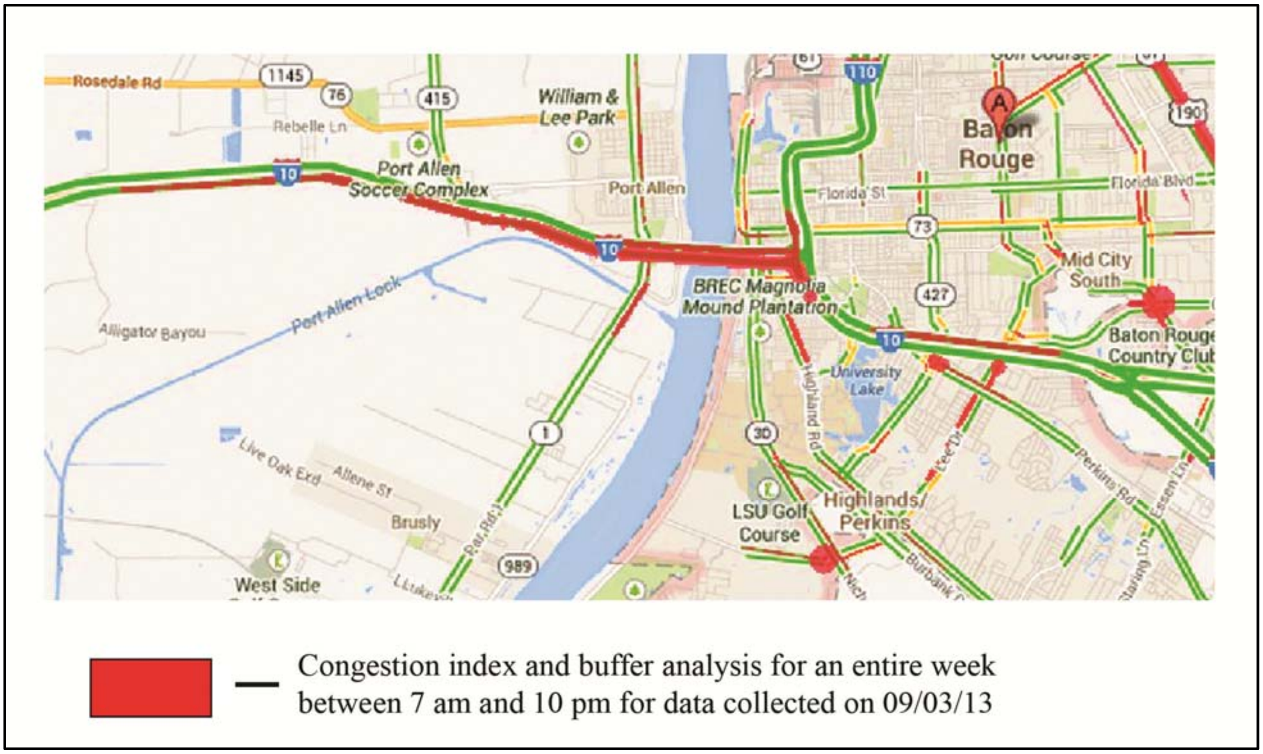


Figure 18
Congestion analysis for entire day (7 a.m. to 10 p.m.) for downtown area

Analysis for Peak Period. It was observed that in Baton Rouge, the morning peak occurs between 7 a.m. and 9 a.m. and evening peak between 4 p.m. and 6 p.m. for major arterials. Accordingly, the CI was computed for both morning and evening peaks and to further enhance our understanding of congestion buffer analysis was performed. The resultant maps are shown in Figure 19 and Figure 20.

From the images, it can be observed that for the 1 week data collected on 9/03/13, the morning peak period is significantly less congested than evening peak period. During the evening peak period, Airline Highway., I-10, I-110, Perkins Rd., and College Dr., Siegen Lane and two intersections (Old Hammond Highway – Jefferson and Brightside Dr. – Nicholson Dr.) are severely congested. These were observed to have CI values in the range of 0.261 to 0.665. Hence, they are considered hotspots based on the definition established in Table 4.

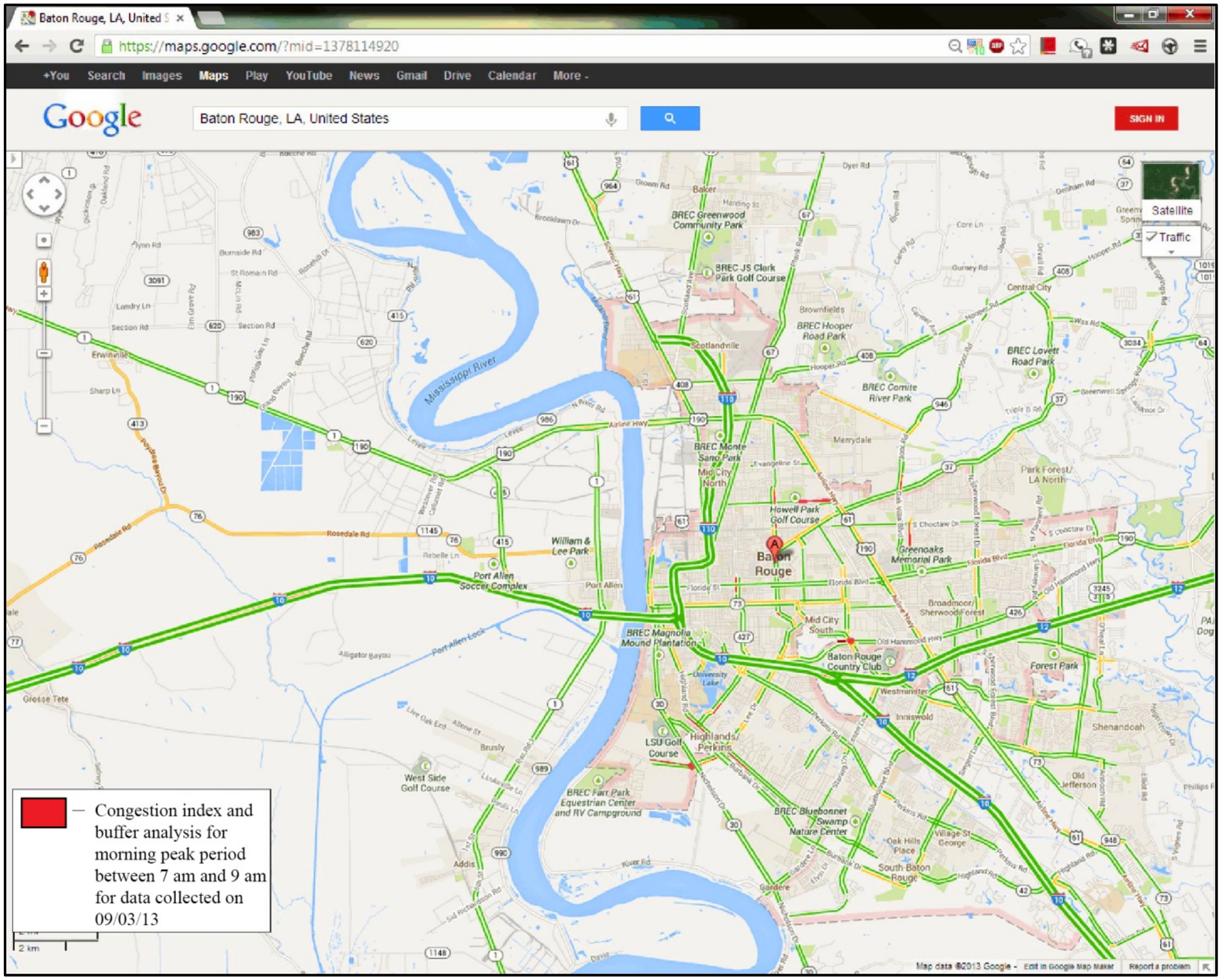


Figure 19
Congestion analysis for morning peak period (7 a.m. to 9 a.m.)

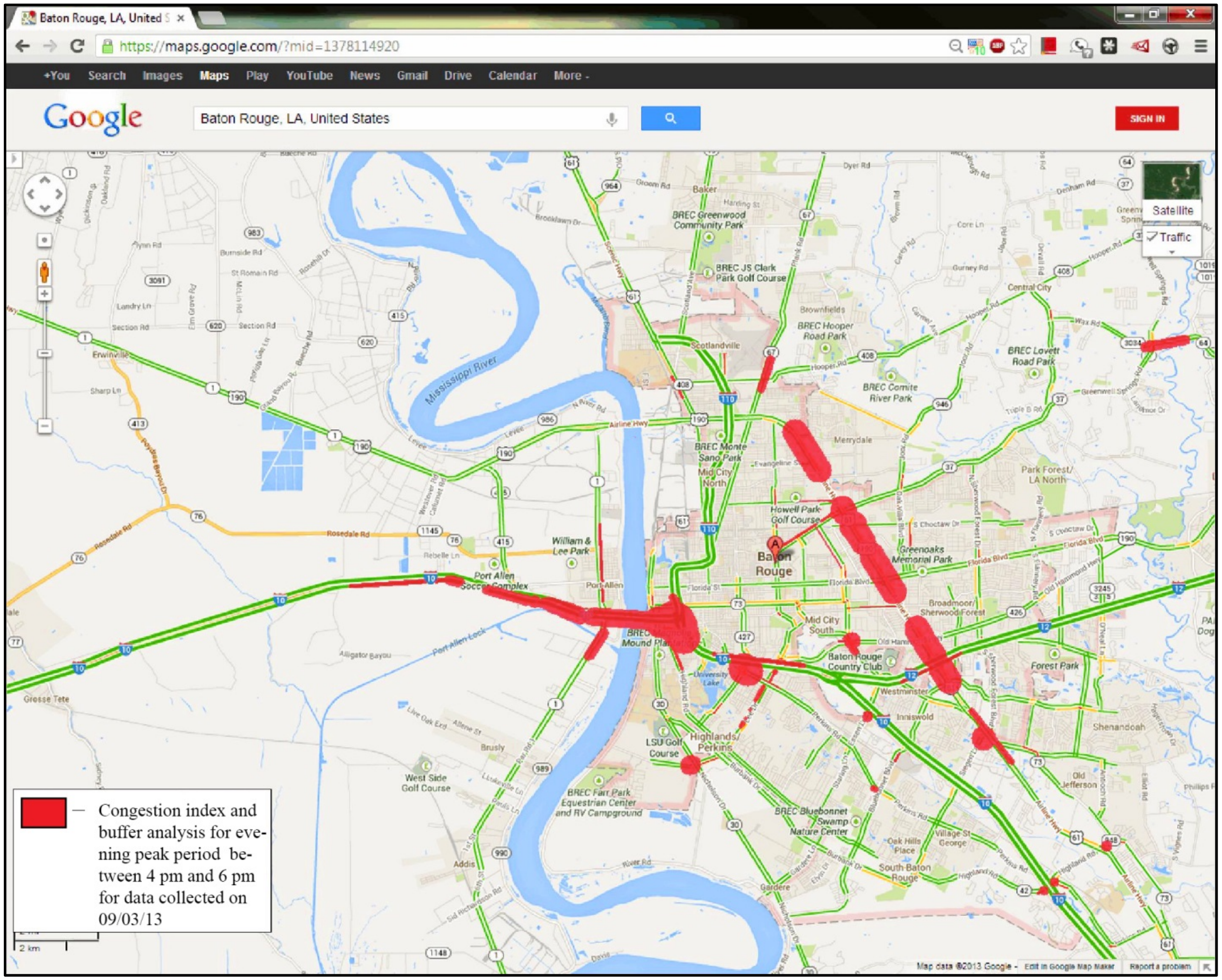


Figure 20
Congestion analysis for evening peak period (4 p.m. to 6 p.m.)

Analysis on One Month Data. The analysis described in the previous section was repeated using historic traffic maps representing conditions over a month. Google updated traffic data only three times for the month in which the analysis was conducted. These three unique data sets were collected on 8/12/13, 8/19/13, and 9/03/13 (8/26/13 data was not included since it was the same as was collected on 8/19/13) and arithmetically averaged using the following formula:

$$Average\ matrix_{(i,j)} = \frac{Sample\ one_{(i,j,1)} + Sample\ two_{(i,j,2)} + Sample\ three_{(i,j,3)} + \cdots + Sample\ k_{(i,j,k)}}{k} \quad (2)$$

where,
i = time of the day
j = day in the week
k = samples that represent a month's traffic

This equation produced a set of 420 average matrices, representative of the entire month, which was used in the rest of congestion analysis for the month. CIs were calculated for all pixels and buffer analysis was conducted to generate the results shown in Figure 21.

From the congestion index analysis, it can be observed that the I-10 to the east of the Mississippi River, arterials next to the I-10 before the I-10/I-12 split (Perkins Road and College Dr.), Siegen Lane, two intersections (Old Hammond Highway – Jefferson and Brightside Dr. – Nicholson Dr.), Airline Highway between Greenwell Springs Road and Bluebonnet experienced heavy congestion with CI values in the range of 0.0393 to 0.1207. Hence, they are considered to be congestion hotspots based on the ranges established in Table 4.

For the purpose of congestion measurement using Bluetooth technology, Airline Highway was chosen as the candidate route out of all the available candidates because it showed persistent congestion throughout the analysis period.

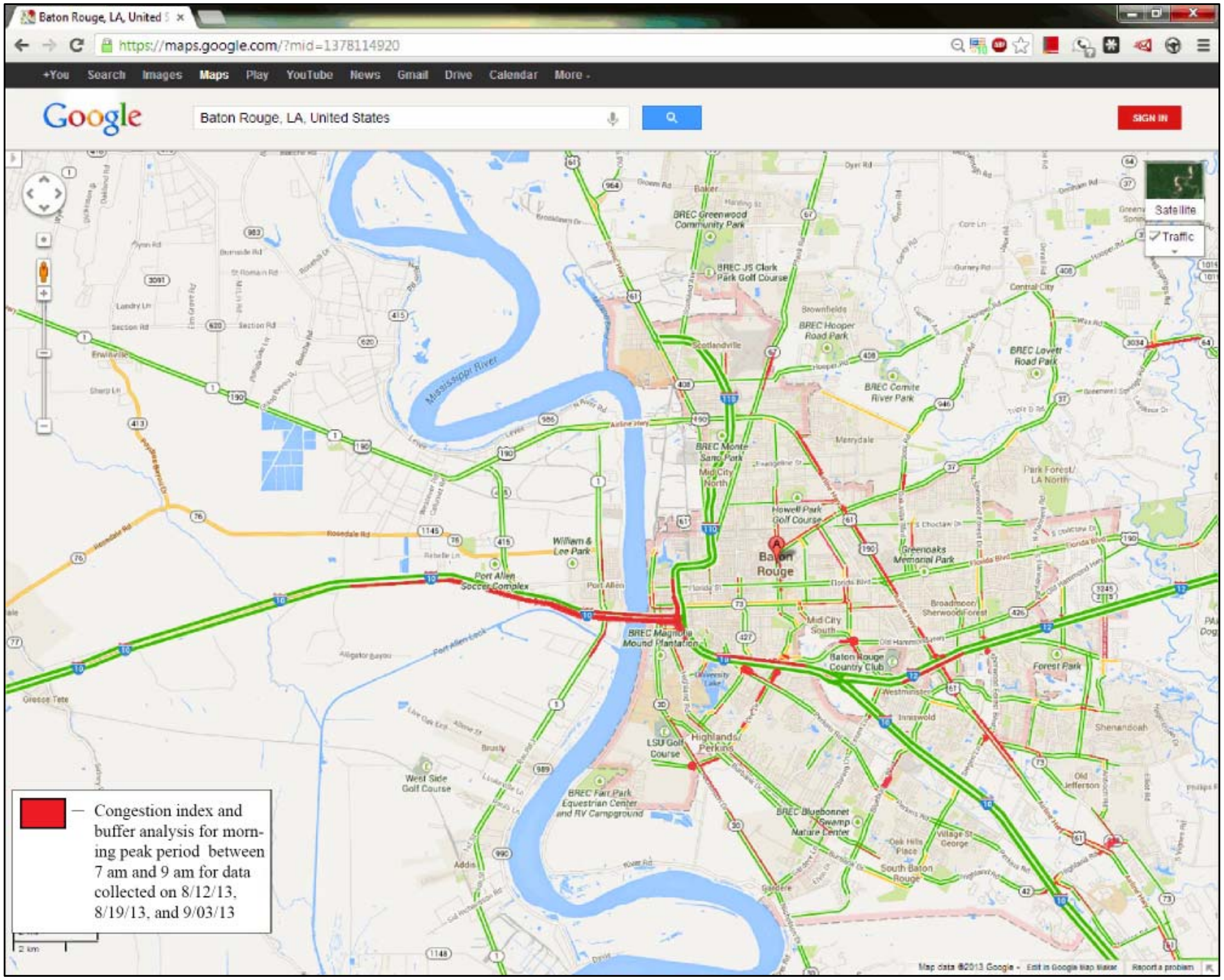


Figure 21
Congestion analysis for entire month (7 a.m. to 10 p.m.)

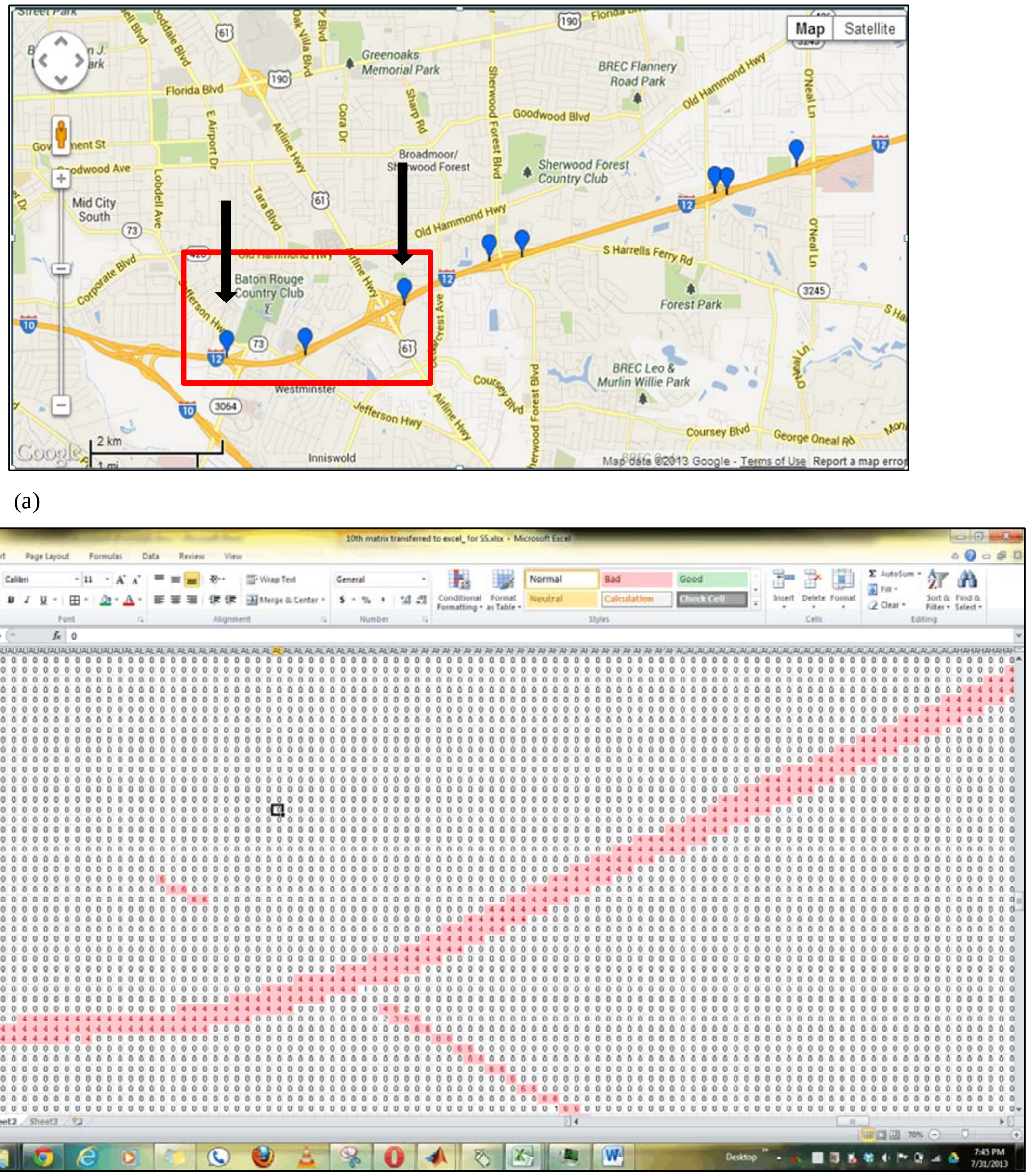
Validation

To validate the methodology described in previous sections, an image analysis was first conducted using historic traffic images downloaded from Google Maps of the I-12 corridor between Essen Ln. and Airline Hwy in Baton Rouge. After performing the image analysis, travel time and average travel speed data were gathered from a network of Bluetooth devices installed along the I-12 corridor by DOTD in relation to a different project. The frequency of congestion computed through image analysis for a specific time period was then compared with the average travel speed for the same time period for observations gathered from the Bluetooth devices. The procedure used to perform the analysis is described in the following paragraphs.

For the I-12 corridor, images were captured from Google Maps on 7/31/13 in GIF format with 256 colors at a resolution of 1280 × 1024 pixels. It was assumed that the images captured on 7/31/13 represented traffic conditions for the preceding week. Figure 22 (a) shows the part of corridor that was the subject of this analysis. These images were captured for all 7 days of the week between 3 p.m. and 7 p.m.The time period between 3 p.m. and 7 p.m. was chosen because in the preliminary analysis it was observed that the I-12 experienced congestion only between the noted timeframe. Sixteen images (4 images/hour × 4 hours) were captured per day which resulted in a total of 16 × 7 = 112 images for the entire week.

The MATLAB script developed in the previous section was then used to analyze the captured images. However, instead of using only the red color as an indication of the presence of congestion both red and yellow colors were used in the analysis. As was discussed in the preceding sections, the presence of both colors in historical traffic speed maps represent a fall in speeds below 50 mph.

The 15-min. interval matrices were then generated by processing historical traffic map images, which were populated with either zeros or ones based on the presence or absence of red/yellow pixels. The resulting matrices were then added across all days of the week. This yielded one matrix for each of the 15-min. intervals. Therefore, a total of 16 matrices 16 time intervals of 15-min. each between 3 p.m. and 7 p.m.) were generated, which represented the weekly traffic conditions existing between 3 p.m. and 7 p.m. The number in each cell represented how often congestion conditions (speeds < 50 mph) occurred at the locations represented by the pixel in a 7-day period, at a specific 15-min. time period. Figure 22 (b) shows the resulting matrix after adding matrices representing traffic conditions at 5:00 p.m. for 7 days. The cells that contain value of 4 indicate the presence of congestion on four days and the cells coincided with the pixel location on the I-12 corridor shown in Figure 22 (a). Similarly, the same congestion frequency of 4 was observed for the remaining 15-min. time intervals until 6 p.m.



(a)

(b)

Figure 22

(a) I-12 Corridor in Baton Rouge showing location of Bluetooth detectors (b) Frequency matrix with frequencies of 4 highlighted

To validate the image analysis technique developed in this research, it is important to compare the results of image analysis with the actual traffic conditions that occurred for the same time period. In order to achieve that, the travel-time data was retrieved from Bluetooth devices deployed over the road sections where image analyses were conducted.

To capture travel time, 11 BlueToad Bluetooth monitoring devices deployed over I-12 by DOTD between Essen Lane and Walker were utilized. These devices capture and display speeds and travel time in real time and all captured data are archived as well. Two devices that were installed at the Essen Lane and the Airline Highway interchanges were used to retrieve the required data for validation. The device locations are shown in Figure 22 (a) with arrows and blue balloons.

Speed data collected between 7/23/13 and 7/28/13 aggregated at 15 min. was downloaded from the Bluetooth devices. Figure 23 displays the speeds obtained from the Bluetooth devices over the week.

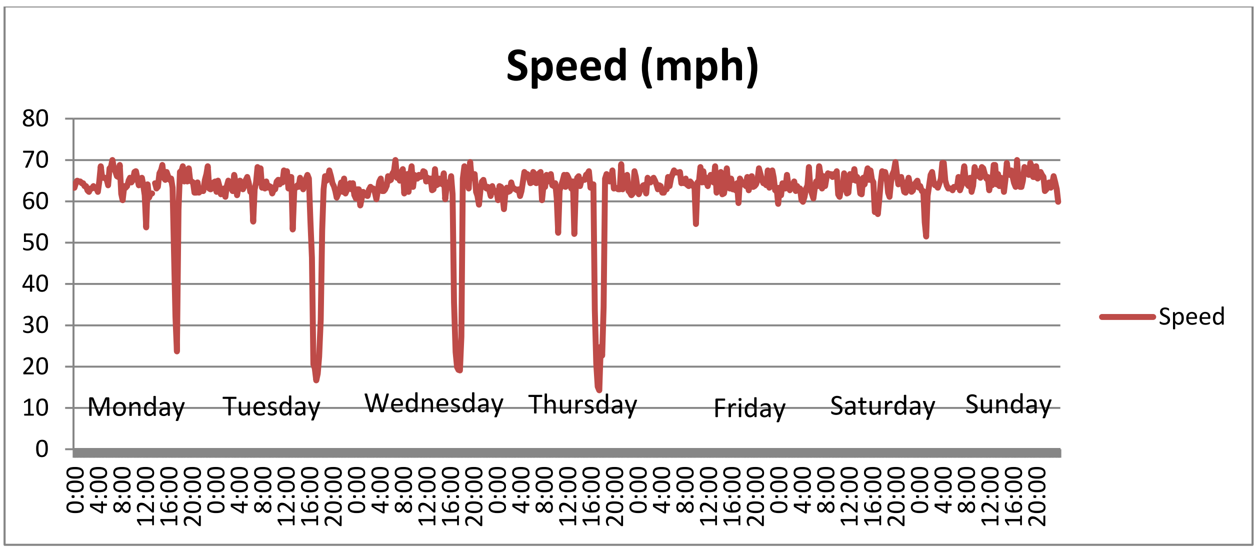


Figure 23
Bluetooth speeds over I-12 between Essen Ln. and Airline Hwy. between 7/22/13-7/28/13

From the graph in Figure 23, it is clear that between 5 and 6 p.m. on Monday through Thursday there was a fall in speed to less than 50 mph, which implies congestion. This did not occur Friday through Sunday. Returning to the image analysis conducted using Google Maps, this section of the corridor for the same time period shows a congestion frequency of 4, as represented by cell values in the matrix shown in Figure 22 (b). This implies congestion occurred 4 out of 7 possible times in a week on this corridor between 5 p.m. and 6 p.m. Thus, the consistency between observed traffic conditions and derived conditions from image analysis conducted on Google Map data validates the image analysis technique.

Deployment of BPDS

Once the locations of maximum congestion are identified (as described in the previous section), there is a need to measure the degree of congestion experienced at these locations. For this, the research team used Bluetooth devices to measure travel time. They were installed on Airline Highway, an arterial experiencing a high level of congestion as identified by its Congestion Index in the previous section. The research team made two field trips to Airline Highway to identify potential infrastructure installation points for the BPDS devices. Eight poles, either on light poles or traffic light poles, were identified to host the BPDS devices.

Even though it is desirable and recommended by other researchers to install Bluetooth devices one mile apart, the research team had to take real-time constraints into consideration while identifying the locations. For example, the research team ruled out the possibility of erecting its own poles and other infrastructure for the purpose of installing Bluetooth devices as it was out of scope of the project and beyond the budget limit allocated to the project. Thus, the team considered using existing infrastructure such as traffic signal and electric light poles that could be accessed by obtaining permission from relevant authorities. Figure 24 shows the locations along Airline Highway that were identified as the final installation locations. As can be seen from the figure, the study corridor consisted of a total of seven segments between Industrial Avenue and Pecue Lane. The total length of the study corridor is approximately 7.1 miles. The majority of the installation points were located at intersections.

Installation of Bluetooth devices to the identified traffic light poles and electric poles required getting permission from the city parish chief traffic engineer, Entergy (local gas and electricity company), and the DOTD District 61 traffic operations engineer. A brief summary of the project along with the map of identified locations were submitted to relevant people to obtain permission. The entire process of obtaining permission from the city parish itself took about four months because it required the city parish to contact other related agencies, such as Entergy.

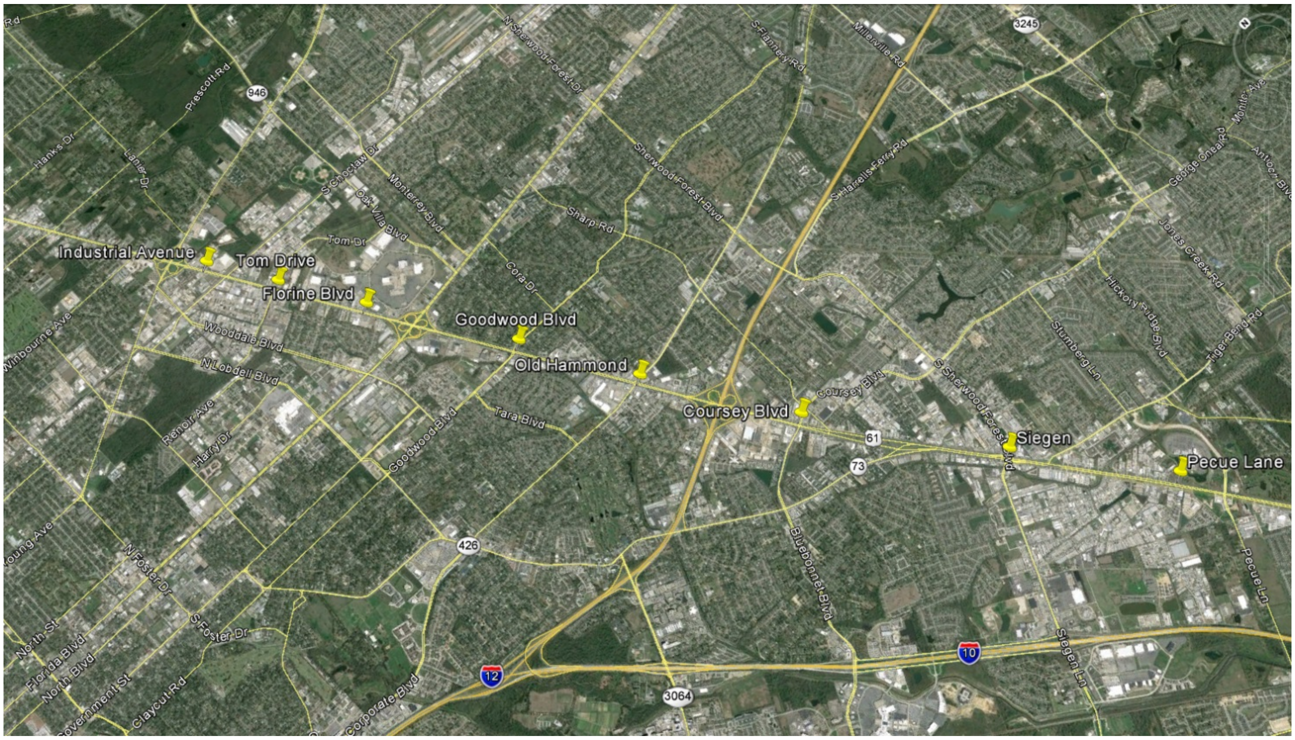


Figure 24
Identified installation locations along Airline Highway

Installation and Activation of Devices

For installation of devices at the identified locations, there was an expectation on the part of research team to receive assistance in the form of equipment and personnel from the District 61 Traffic Operations division. To fulfill the expectation, the research team organized a series of meetings with the District 61 traffic operations engineer and other maintenance personnel to discuss the needs and request assistance in the form of a bucket truck and operating personnel. Once an agreement was reached, a schedule was established to install BPDS at the identified locations. The BPDS were installed at identified locations in the second week of May 2014. Figure 25 shows the installation of BPDS at the intersection of Airline Highway and Tom Drive. The entire process of installing a single device took approximately about 30 to 45 min. per location. The Bluetooth Probe Detection System devices at each individual location were then activated and immediately started transmitting raw data to a central server using the cellular modem installed on each device.

Figure 25
Installation of Bluetooth probe detection system

The vendor who supplied the BPDS also provided the services for processing the raw individual vehicle speed data to provide average speed data in 5-min. intervals for each segment of the entire study section on Airline Highway. The vendor, Trafficast/Bluetoad, set up a web interface in advance of the installation and trained the research team members using a webinar on how to use the web interface to monitor and download travel-time data. The web interface along with tools to download archived data also provided some additional query tools that let users compare different route’s performance over time.

Acquisition of Travel Time Data and ADT. The raw data provides the average travel speed data of each vehicle traversing the study section. It is first sent to the central server of the vendor and checked for errors or outliers. For example, data collected from a vehicle that is parked close to a Bluetooth detector or data from a vehicle stopped for refueling would be filtered out before calculating speed between two Bluetooth locations. The filtered out data is then processed using a two stage mean algorithm developed by Trafficast to produce smoothed speed and travel time for each individual segment for every five min. The data, once processed and archived, can be averaged over 15-min., 30-min., 45-min. and 1-hr. intervals as required for further analysis.

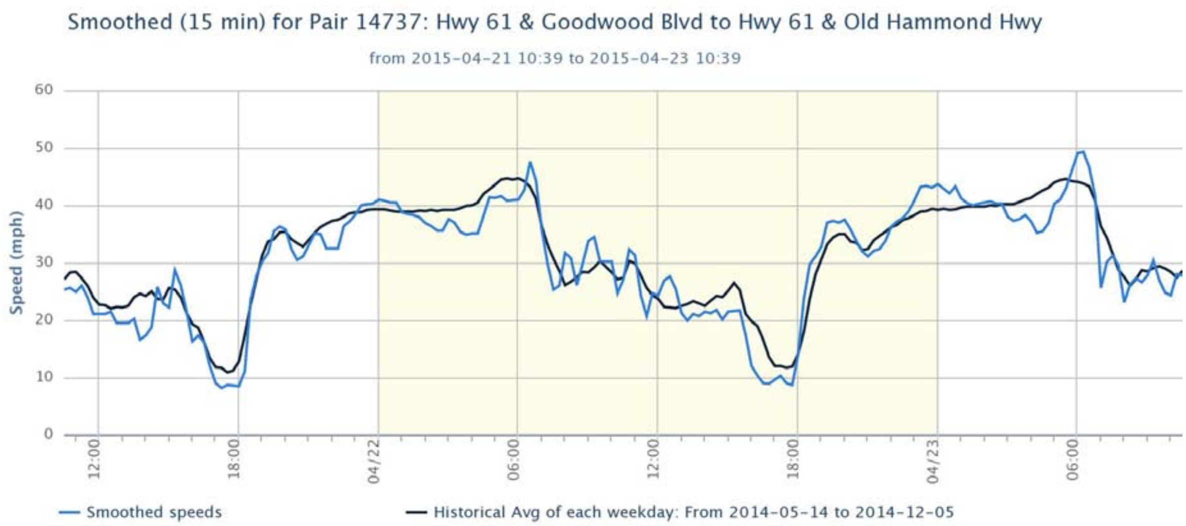


Figure 26
Smoothed speed for segment between Goodwood Blvd and Old Hammond

One of the objectives of the study was to compute congestion indices such as travel delay and travel time index. To compute such indices along with travel-time data, it was also necessary to collect traffic volume data for the study corridor. Traffic volume data collection as originally planned by the research team using magnetic counters had to be altered because of difficulties identified by District 61 operations in installation and retention of such devices on the highly travelled Airline Highway corridor. As an alternative, the research team contacted the DOTD's data collection team and acquired Average Daily Traffic count data at nine locations on the study corridor. The ADT was collected by DOTD between June and September 2014, at various locations to comply with FHWA highway performance monitoring program. The table below shows the ADT values for seven different sections along the study corridor.

Table 6
Average daily traffic

Section	ADT (Average Daily Traffic in Vehicles Per Day)
E. Industrial Avenue to Tom Drive	47040
Tom Drive to Florline Blvd	40773
Florline Blvd to Goodwood Blvd	51842

Section	ADT (Average Daily Traffic in Vehicles Per Day)
Goodwood Blvd to Old Hammond	61950
Old Hammond to Coursey Blvd	63223
Coursey Blvd to Siegen	48510
Siegen to Pecue	39012

Purchase of Travel Time Data

The alternative to deploying a BPDS is to purchase travel-time data from commercial vendors such as NAVTEQ or INRIX. The research team bought data from INRIX after receiving quotes from INRIX and NAVTEQ. The travel-time data is sold on a per mile basis and the cost varies based on the type of road (freeway or arterial) and whether data are historical or real time. To be consistent with the travel-time data estimated by BPDS, the data was bought for the same section of Airline Highway as was identified as most congested in the previous section. The data bought in this study was historical travel-time data for a stretch of 7.1 miles for a time period between January and September 2014, for a total cost of $800. The data thus obtained was in 1-min. intervals and for a total of seven segments in both directions. In contrast, real-time data would have cost $400 per mile/year for a major arterial and $800 per mile/year for a freeway. One of the requirements of INRIX before delivering data was to sign a contractual agreement to abide with terms and conditions of data usage, which included not making direct comparison of measurements from INRIX data with that from other sources.

DISCUSSION OF RESULTS

There are many congestion indices available in the literature that could be used to measure or monitor a roadway's congestion level and intensity over time. However, indices such as travel time, travel delay, travel time index, and planning time index are often used to identify recurrent congestion on a roadway. The methods used to acquire input data and compute travel delay, the travel time index, and the planning-time index are discussed and demonstrated in the following sections.

Congestion Indices Computation

The Urban Mobility Report (UMR) produced by Texas Transportation Institute provides estimates of performance measures of mobility such as congested travel (% of peak VMT), annual delay (in person hours) and congestion cost at the area wide level. Along with mobility estimates, the UMR also reports on the trends in estimated mobility measures. To avoid duplication, this study estimated mobility measures at individual road level and limited the estimation to the study corridor chosen as the most congested in the Baton Rouge area (Airline Highway). The methodology used draws upon the definitions and procedures established by TTI for estimation of congestion indices. It should be noted that the congestion index developed earlier to measure congestion from image analysis data, cannot be used here since it operates on pixel data unique to that observational method.

Mobility/congestion indices were calculated using average travel speed data collected using the BPDS on the study corridor between May 15 and November 30, 2014. This study period was chosen based on continuous availability of data from all the devices during that time. Continuous BPDS travel speed data was available in 15-min. intervals for each segment of the study corridor for each day for a total of 196 days or 28 weeks. The 15-min. travel speed data was averaged over one hour for each segment and in both directions. Availability of continuous speed data improved the arterial street congestion measure estimation by providing peak hour measured speeds rather than estimated speeds. Speeds measured at night time between 10 p.m. and 6 a.m. were used as free flow speeds required for measuring travel delay on the study corridor. Finally, the hourly distribution of traffic volume was derived from ADT by using Bluetooth signal match counts for each segment of the study corridor.

Congestion Measure Calculation

The congestion indices for each segment of the study corridor were computed by following a series of steps for each segment of the study corridor. For demonstration purposes, the travel delay and the indices such as Planning Time Index (PTI) and Travel Time Index (TTI) are only shown for a selected segment. The steps comprised of the following activities or tasks.

1. Acquire Traffic Volume Data

The ADT data collected by DOTD's data section provided the source for traffic volume data needed for computing congestion indices. Although the geographical locations at which ADT was measured did not coincide with the middle point of each segment of the study corridor it was assumed that the ADT was uniform across each segment of the study corridor.

2. Estimate Traffic Volume for Hourly Time Intervals

The paired match count is the number of times a BPDS processes a MAC address at two locations on a given segment. Typical paired match counts for the segment between Siegen and Pecue Lanes are shown in the following graph. To divide the daily traffic volume into hourly volumes for calculation of congestion indices, the hourly traffic volumes for each segment were assumed to be distributed the same as the Bluetooth signal paired match counts. That is, the distribution of paired match counts available for each segment from BPDS in both directions was used to distribute the ADT to hourly volumes on each section.

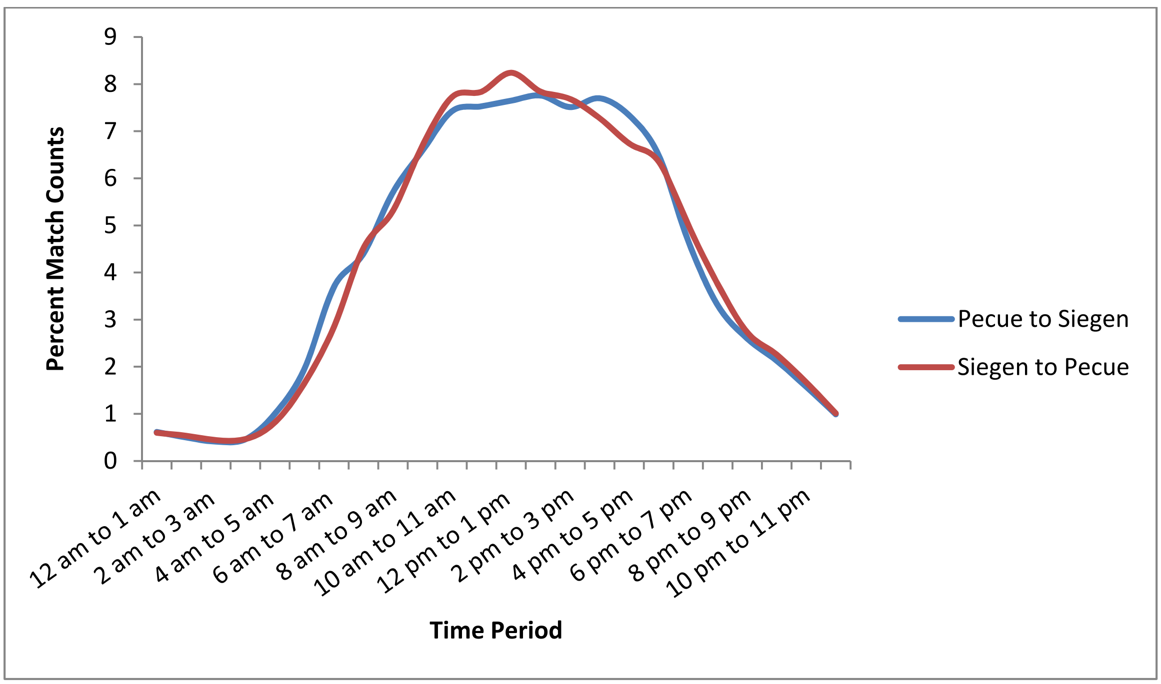


Figure 27
Percent match count variation

Hourly volume estimates for each day of the week were created from the ADT using the percent match counts measured for each segment. The match count values available in 15-min. intervals were averaged over an hour and then the ratio of hourly counts to total counts per day were estimated to get a percent match count. In calculating the percent match counts, data from the month of November 2014 were used as representative data for the period between May 18, 2014, and November 30, 2014. Once the percent match count per hour per direction was determined, it was multiplied by the ADT to get estimates of hourly volumes by direction.

To validate the use of paired match count as a surrogate for hourly volume distribution, analysis was conducted to test the premise. The analysis consisted of measuring the correlation between ADT values and paired match counts in five sections of the study corridor. To conduct the analysis, paired match counts for both north-bound and south-bound traffic for one month were retrieved from the website for the five sections. The paired match counts for each section were summed by direction to get the total paired match counts by direction. The average total paired match counts were then compared with the ADT values as shown in Table 7. As can be seen from the table, a correlation coefficient of 0.93 indicates a high correlation between ADT and the paired match counts thus providing a justification for the use of paired match counts as a surrogate to hourly volume distribution. It is important to note that for correlation analysis only five sections were used out of seven because for two of the segments, the ADT collected did not accurately reflect the traffic that was diverted from the study segment. For instance, for the segment between Industrial Avenue and Tom Drive, Choctaw Drive acted as a major diversion of traffic off the facility before it could be observed by both Bluetooth receivers. Similarly, for the segment between Old Hammond Highway and Coursey Blvd, traffic diverting on to I-12 was not picked up as a match on the Bluetooth devices but did feature in the estimation of ADT from traffic counts.

Table 7
Correlation analysis

Section	ADT	Average Paired Match Counts
E. Industrial Avenue	47040	2372
Florline to Goodwood	51842	2275
Goodwood to Coursey	61950	3172
Coursey to Siegen	48510	2186
Siegen to Pecue	39012	1957
Correlation Coefficient	0.93	

3. Tabulate Hourly Traffic Volume and Speed for Road Segments

The next step was to tabulate hourly volume and speed data for each road segment in both directions. The tabulation of the traffic volume and traffic speed for each road segment was accomplished using Microsoft Excel as the total number of road segments was very small. The speed data that was averaged over an hour for each day for a total of 196 days was combined with hourly volume data for the same time period. The tabulated data was then used for calculation of congestion indices in the subsequent steps.

4. Establish Free Flow Speed and Peak Period Speed for All Road Segments

Congestion indices computations require free-flow speed and peak-period speeds. A free-flow speed during the light traffic hours (10 p.m. to 6 a.m.) was computed for each road segment and used in the congestion indices calculations. To establish peak-period speeds, a simple average peak period speed was computed by adding up the peak-period speeds in each hour during the peak period and dividing by the length of the peak period in hours. It was observed that for most of the road segments, the peak period started at around 10 a.m. and lasted until 6 p.m. for a total of 8 hours, in contrast to typical peak periods caused by commuter traffic. On Airline Highway, the regular morning and the afternoon peak traffic is supplemented by shopping trips to adjoining businesses in the midday period.

The graph in Figure 28 shows the typical speed variation that is averaged over a week for the hours between 7 a.m. and 7 p.m. on Airline Highway. As can be seen from the graph, there is a significant drop in the speed in the afternoon period before it increases again in the evening.

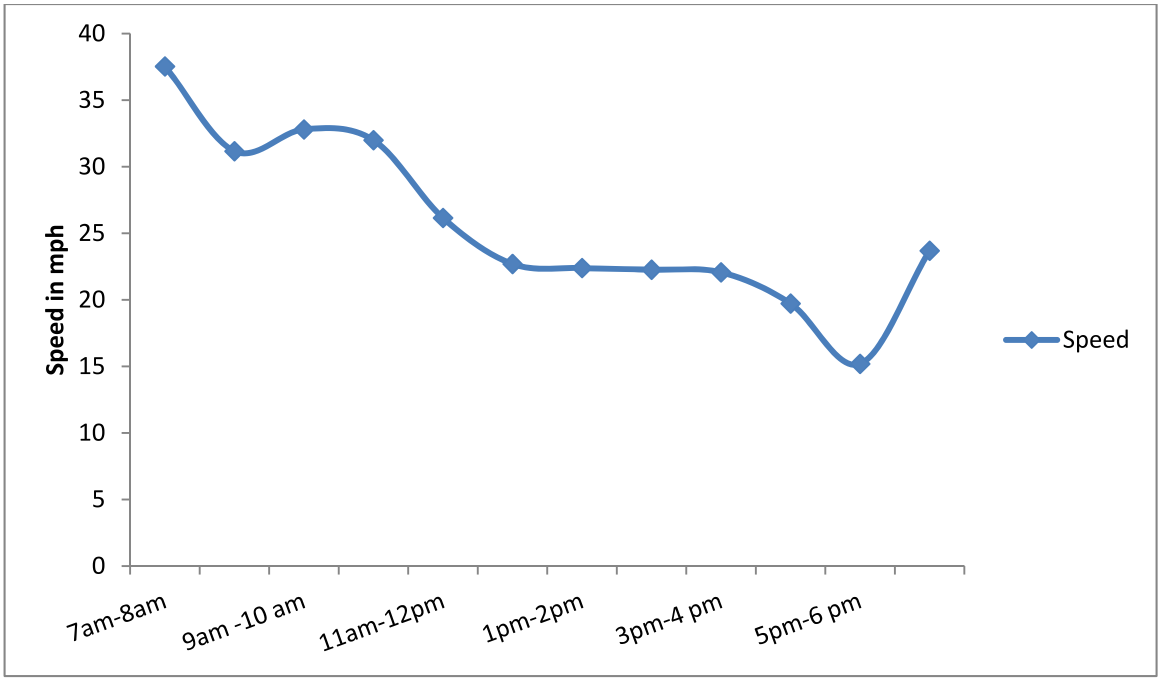


Figure 28
Speed variation between Goodwood Blvd. and Old Hammond Highway

The calculation of congestion indices such as travel delay requires establishing a congestion threshold such that delay is accumulated for any time period once the speeds fall below the congestion threshold. There is no consensus in the literature about the appropriate level of the threshold, but for the purposes of calculation in this research the free-flow speed estimated from measured speed at low volume conditions was used.

5. Compute Congestion Indices

(a) Travel speed
The peak period average travel speeds for four weeks are shown in Figure 29 for the road segment between Goodwood Blvd to Old Hammond Hwy. The speeds are computed by averaging speeds over an hour for a given segment and then by averaging for a week for a given time period.

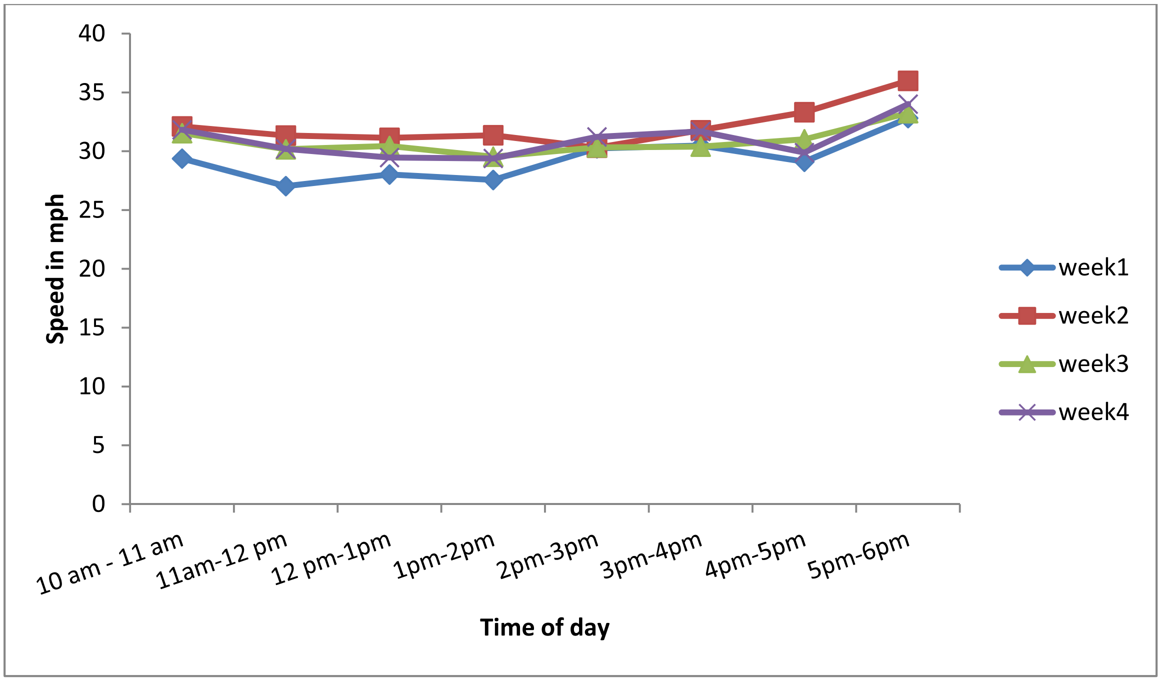


Figure 29
Weekly average speed variation for the segment between Goodwood and Old Hammond Highway

(b) Travel delay

The amount of extra time spent travelling due to congestion can be estimated from the observed increase in travel time. Travel delay calculations were performed for each individual road section and for each hour of the week. The direction that displayed the lowest peak-period speed was used in the final computation of peak-period speed and free-flow speed. The speed data used in this study reflects the effects of both recurring delay and incident delay and because the information about incidents were not collected it is not possible to segregate recurring and incident delay. Depending on the need, delay can be estimated for different time periods such as a one week peak-period, weekend, morning peak period, afternoon off-peak period, and so on. In this study the researchers estimated delay for a week of peak periods from 10 a.m. to 6 p.m. each day. Travel delay is defined and computed using the following equation:

$$Daily\ Vehicle - Hours\ of\ Delay\ = \frac{Daily\ Vehicle{-}Miles\ of\ Travel}{Speed\ in\ mph} - \frac{Daily\ Vehicle{-}Miles\ of\ Travel}{Free{-}Flow\ Speed\ in\ mph} \quad (3)$$

Where, vehicle miles of travel are computed by multiplying the length of a road segment with number of vehicles in a unit period of time

The delay calculations were performed at the individual roadway segment level and for each hour of a week before averaging them by week for 28 weeks. The trend in delay for a span of 12 hours for a weekday and weekend is shown in Figure 30. The delay is high in the evening period compared to the morning and is high on a weekday compared to weekend.

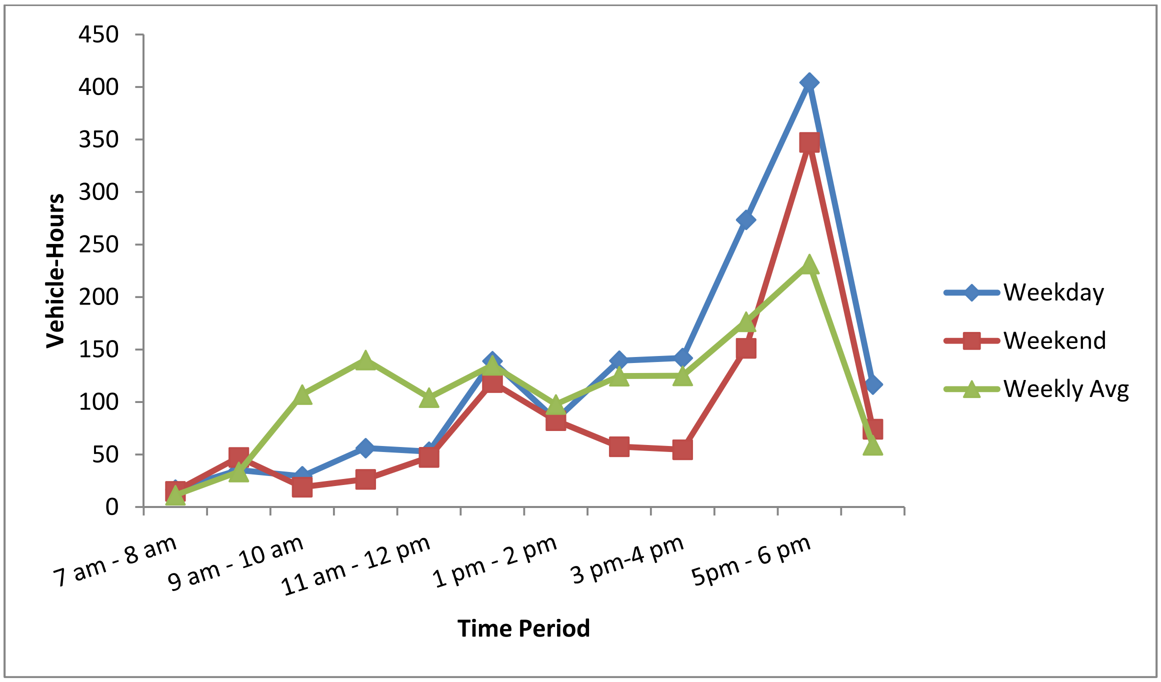


Figure 30
Trend in delay for the segment between Goodwood Blvd and Old Hammond Hwy

Table 8 shows weekly average total delay for peak period for all the segments. The delay was computed for the direction that had lowest peak-period speed. As can be seen from the table, the segment between Goodwood Blvd and Old Hammond recorded the highest delay in vehicle-hours.

Table 8
Weekly average delay for segments on the study corridor

Segment	Direction(North Bound/South Bound)	Average Weekly Delay Vehicle-Hours	Rank(Worst to Best)
Industrial Ave and Tom Dr	South Bound	381.3	3
Tom Dr and Florline	South Bound	193.4	7
Florline and Goodwood Blvd	South Bound	304.46	5
Goodwood and Old Hammond	South Bound	1009.3	1
Old Hammond and Coursey	South Bound	234.63	6
Coursey and Siegen	South Bound	315.48	4
Siegen and Pecue	North Bound	479.94	2

(c) Travel Time Index (TTI)

The TTI is defined as the ratio of peak travel time to free-flow travel time and as such it is an index that is unitless. It is normally used to measure congestion intensity and is measured as the ratio of time spent in traffic during peak hours compared to the time spent in traffic under free-flow conditions. A TTI value of 1.4 indicates that for a 15-min. trip in light traffic, the average travel time for the trip is 21 min. (15 x 1.4 = 21 min.), which is 40% longer than light traffic travel time. The TTI includes both recurring and incident conditions and is therefore considered to be an estimate of the daily conditions experienced by urban commuters. The index also allows comparing trips of different lengths to estimate the travel time in excess of that experienced in free-flow conditions. The TTI is defined as:

$$Travel\ Time\ Index = \frac{Peak\ Travel\ Time\ (minutes)}{Free\text{-}Flow\ Travel\ Time\ (minutes)} \tag{4}$$

Figure 35 shows the TTI trend for the road segment between Industrial Avenue and Tom Drive. As can be seen from the figure, the TTI is low in the morning but increases significantly in the afternoon before dropping back to pre-congestion levels.

Figure 32 shows weekly average TTI for all road segments. The segment between Goodwood and Old Hammond showed the highest weekly average TTI. The highest recorded TTI was 3.95.

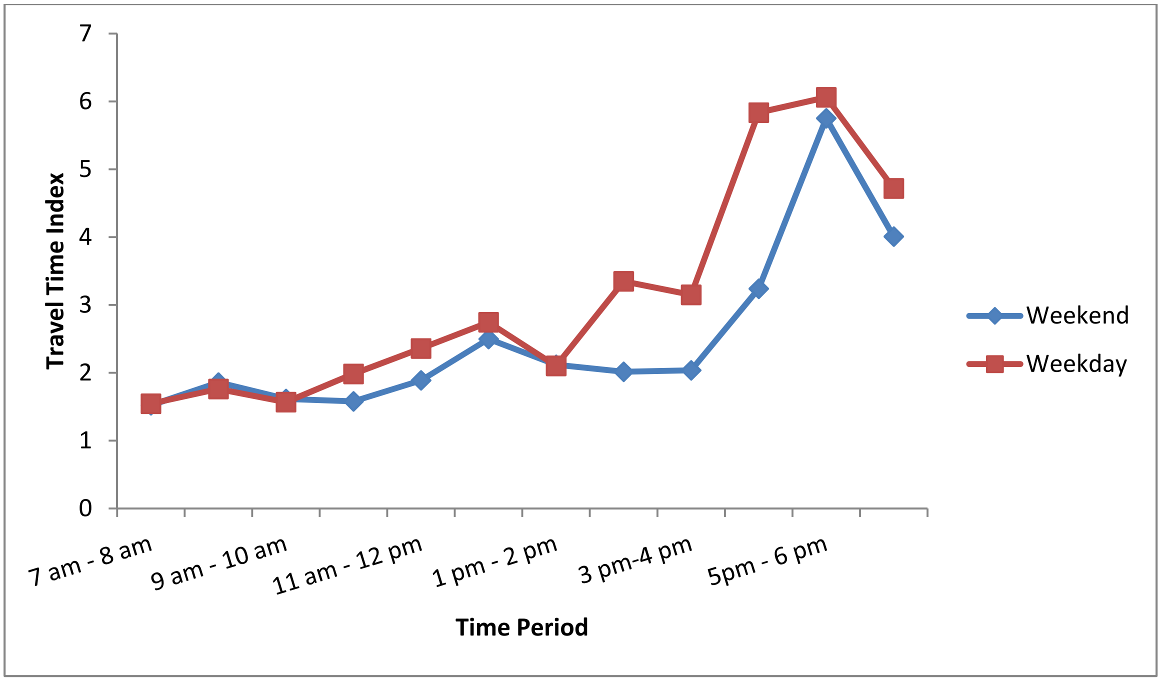


Figure 31
Trend of TTI between Goodwood Blvd and Old Hammond Hwy

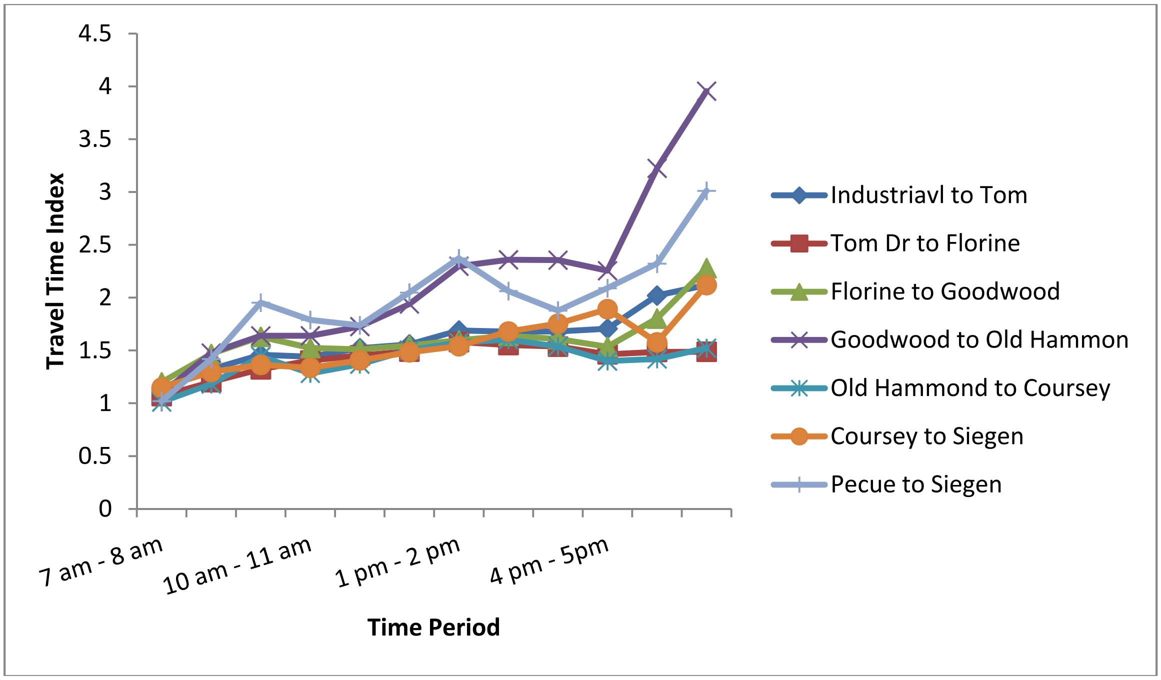


Figure 32
Weekly average TTI for all road segments

(d) Planning Time Index (PTI)

While the TTI is used to measure congestion intensity, the PTI is used to measure congestion reliability. That is, it expresses the increase in travel time that a motorist must plan for to reliably reach their destination in time. The planning time index is defined as the ratio of the 80th percentile travel time in minutes to the reference travel time, which is normally free flow travel time in minutes. Thus, the planning time index is a ratio of the maximum travel time that will occur 80% of the time to free flow travel time.

$$Planning\ Time\ Index = \frac{80th\ percentile\ Travel\ Time\ (minutes)}{Free{-}Flow\ Travel\ Time\ (minutes)} \tag{5}$$

Similar to TTI, as shown in Figure 33, PTI values increase during the afternoon period before dropping to pre peak period levels at night.

Figure 34 shows weekly average PTI for all road segments. As was observed previously the segment between Goodwood and Old Hammond recorded the highest weekly average PTI.

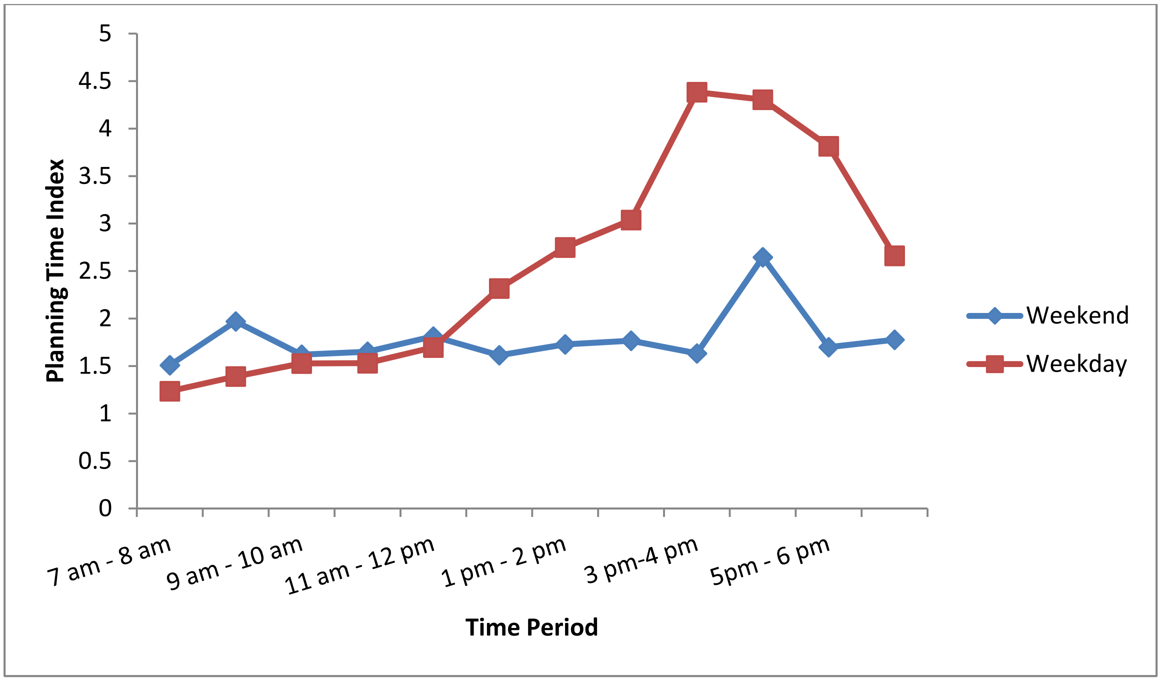


Figure 33
PTI trend between Goodwood Blvd and Old Hammond Hwy

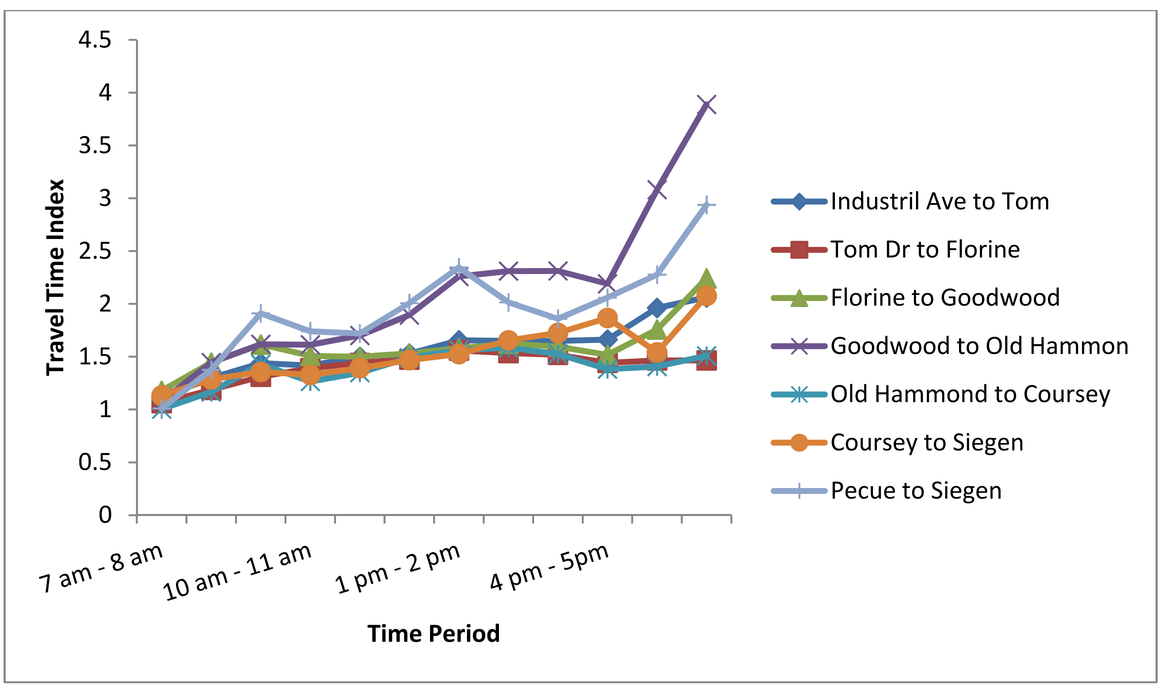


Figure 34
Weekly average PTI for all road segments

The analysis conducted by using speed and travel time measured by a BPDS demonstrated that it is feasible and fairly quick to compute congestion indices that give an indication of congestion and its intensity on a continuous basis. Thus, a BPDS should be considered for deployment when there is a need to obtain information about congestion intensity and frequency over long periods of time and on a continuous basis.

CONCLUSIONS

This study sought to investigate the possibility of using a Bluetooth Probe Detection System (BPDS) for measuring congestion and the trend in congestion over time. The research conducted in this study led to the following conclusions:

1. A BPDS appears to be the best way to measure the level of congestion at a location. Other methods such as probe vehicles or license plate matching appear to be more expensive and time-consuming than the use of a BPDS.

2. A BPDS is easy to use and can be deployed quickly if there is infrastructure to which the BPDS can be attached. BPDS systems can start measuring travel-time and transmitting data to a central server without delay thus providing access to travel-time data very quickly.

3. Obtaining permission to attach Bluetooth devices to structures or light poles that do not belong to the fixing agency can be a time-consuming and frustrating task. However, agencies that own such facilities can install BPDS quickly and easily.

4. Purchase of historical travel-time data involves less administrative work and requires fewer resources than obtaining travel-time data from BPDS. However, it comes with certain caveats such as abiding by the contractual terms and policies established by a commercial vendor in using the data. Moreover, historical travel times obtained from the commercial vendor may not always be between a desired starting and ending point on a route but between points that are defined and identified by the commercial vendor. Thus, a compromise might have to be reached between accuracy and ease of access.

5. Real-time travel-time data is expensive and is time and distance sensitive. Thus, for real-time data over long distances for a reasonable period of time, the acquisition of BPDS equipment appears to be preferable to purchasing data from a vendor.

6. Maintenance of a BPDS might be problematic if an agency wants to handle all the maintenance of BPDS by itself. This is especially true for BPDS during winter season that is dual powered by both battery and solar power. When there is no sunlight for considerable amount of time, then there is a potential for a BPDS unit to run out of battery power.

RECOMMENDATIONS

The research team makes following recommendations based on the research and analysis conducted in this study:

1. It is recommended that travel times be measured by Bluetooth Probe Detection Systems at individual locations or in short corridors where the number of instruments needed is not too large, and real-time data is needed over a period of time. The travel-time measurements that are produced by the BPDS can be used to compute congestion indices such as travel delay, travel time index, and planning time index. This recommendation is made based on the finding that historic data can be purchased relatively inexpensively from commercial vendors, while real-time data is expensive and is charged by the mile.

2. It is recommended that hourly paired match counts recorded by Bluetooth devices be used as a surrogate for deriving hourly traffic volume distribution when such data is available. This recommendation is based on the high correlation observed between ADT and paired match counts. It is also motivated by the difficulty of installing traffic counters on the road when a facility experiences a high volume of traffic.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ATMS	Advanced Traffic Management System
BPDS	Bluetooth Probe Detection System
CI	Congestion Index(
cm	centimeter(s)
DOTD	Department of Transportation and Development
FHWA	Federal Highway Administration
ft.	foot (ft.)
GIF	Graphics Interchange Format
JPEG	Joint Photo graphics Expert Group
in.	inch(es)
LTRC	Louisiana Transportation Research Center
LSU	Louisiana State University
lb.	pound(s)
m	meter(s)
MATLAB	Matrix Laboratory, Software Used to conduct high-level technical Computing
min.	Minutes
PDA	personal digital assistants
PTI	Planning Time Index
RFID	Radio Frequency Identification
RTMS	Remote Traffic Microwave Sensor
TRID	Transportation Information Research Database
TTI	Travel Time Index
UMR	Urban Mobility Report

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