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# TrafficTurk Evaluation

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## EXECUTIVE SUMMARY

This report summarizes a project undertaken by the University of Illinois on behalf of the Illinois Department of Transportation to evaluate a smartphone application called TrafficTurk for traffic safety and traffic monitoring applications. TrafficTurk is a smartphone-based turning movement counter that was developed at the University of Illinois to allow large-scale traffic data collection during large events. The data can be used to quantify congestion during events, which has historically been difficult to measure because of the high cost of deploying sensing infrastructure on surface streets. TrafficTurk data can be used for real-time decision-making or to assist in future event traffic management plans. Because TrafficTurk is implemented on a smartphone, it is able to stream the data collected through the device to a central place where it can be used for real-time decision-making or offline analysis.

Prior to this project, TrafficTurk was deployed at more than 100 intersections simultaneously around Urbana-Champaign to monitor traffic at a football game in 2012. It was also deployed in New York City shortly after Hurricane Sandy in 2012.

This document reports on the deployment and evaluation of the technology at the 2013 Farm Progress Show. The application was evaluated on the 2013 Farm Progress Show, to collect data and to analyze the data to determine whether queues on the freeway can be eliminated during the event. The Farm Progress Show is the largest outdoor farm show in the United States and is held in Decatur every two years. Apart from the large amount of delay caused by the traffic congestion during this time, there are also specific safety concerns that have been raised by the Macon County Highway Department. In particular, vehicles tend to queue on I-72 just upstream of exit ramp at IL 48. In general, the exit ramp from I-72 EB was of more concern because part of the show-bound traffic on I-72 WB was diverted at an earlier exit ramp. Because I-72 is a high-speed roadway, stopped vehicles are susceptible to high-speed rear-end collisions.

With the assistance of the Macon County Highway Department, TrafficTurk was used to collect traffic data on the first two days of the show, August 27 and 28, 2013. On the first two days of the show, 31 data collection associates used TrafficTurk for three hours on each day between 7:00 a.m. and 10:00 a.m. to collect traffic data. The data was sent to TrafficTurk servers via the Internet and saved in a database to be used for post-event analysis.

One objective of this study was to analyze the traffic patterns quantitatively and to check the feasibility of re-routing traffic in such a way that queues are less likely to form on I-72. The collected traffic data was specifically used to analyze the arrival rates of traffic at each of the counting locations and the possibility of re-routing traffic from the eastern, northern, and western approaches to the show. The application also collected information on the data latency and energy efficiency of the application in order to provide insights on the feasibility, scalability, and scope of future deployments.

The analysis of data focused on estimating the traffic density across the road network surrounding the show. An algorithm was developed to quantify traffic congestion on each road segment, which was then used to analyze traffic re-routing.

It was found that re-routing traffic from I-72 EB at the interchange with IL 121 is possible through Mound Road, provided that certain conditions hold. In particular, the reroute will be possible if traffic controllers (e.g. police officers to direct traffic) can be placed and operated on IL 121 at the intersections of I-72 EB exit ramp and Mound Road, and if

Mound Road can be used to store show-bound vehicles. This provides greater capacity for queuing on a low-speed roadway instead of a high-speed roadway, and thus reduces the chance of high-speed rear-end collisions. In addition, it was found that 65% of show-bound vehicles approaching from the east followed the recommended route. The recommended route was conveyed to road users in the form of road signs that directed show-bound traffic from all directions, and was also posted on the main show website. However, the capacity of the route was found to be sufficient for 90% of the show-bound traffic to take the recommended route.

The energy efficiency and data latency of the TrafficTurk application was found to be satisfactory. The latency of data between collection and saving in the TrafficTurk database was found to be low and the energy efficiency of the application was found to be good relative to previous versions of the application. Scalability is an issue that needs to be addressed in terms of recruitment, training, and compensation of users to collect the data; however, this can be addressed through the creation of straightforward tools and software. In addition, geographical scalability of the application can also be improved by upgrading the back-end system to support smooth future deployments with minimal event-specific software engineering.

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## CHAPTER 1 INTRODUCTION

In the United States, the Federal Highway Administration estimates that special events are responsible for 93–187 million hours of traffic delay annually, with direct costs ranging between \$1.7 and \$3.4 billion (Jonathan, Chami, and Walker 2008). Key features of extreme congestion events include customized traffic management plans, which often involve human traffic controllers to direct traffic, enforce special turning restrictions, and ensure pedestrian safety. Despite the existence of more than 24,000 large events drawing an estimated 600 million attendees annually (Jonathan, Chami, and Walker 2008), understanding and managing traffic during these events is an open area of research.

With special event-based congestion in mind, the University of Illinois at Urbana-Champaign developed a new application to assist with data collection during these events. TrafficTurk ([www.trafficturk.com](http://www.trafficturk.com)) is a turning movement counter application for Android smartphones. It uses temporary traffic sensors (smartphones carried by humans) to provide a high-resolution view of traffic conditions that can be used for real-time traffic monitoring. It has been deployed at more than 100 intersections around Urbana-Champaign, Illinois, to monitor traffic throughout the campus area during the 2012 Homecoming football game and in New York following Hurricane Sandy in 2012.

This report describes the deployment of TrafficTurk at the Farm Progress Show 2013. The Farm Progress Show is the nation's largest outdoor agricultural equipment exhibition and is held biennially in Decatur, Illinois. The event creates significant congestion in the area during the mornings of the show, including a queue on I-72.

In 2013, the event was held August 27–29, and the University of Illinois at Urbana-Champaign used TrafficTurk to collect traffic data on the first two days of the event, which have the highest traffic. The data collected by the application was used to assist in the analysis of the current traffic management plan for the show. This is critical as any improvements would reduce the delay experienced by visitors to the show, the queues on the interstate highway, and the opportunities for high-speed rear-end collisions.

The three major research tasks for this project consisted of:

- Data collection during the Farm Progress Show 2013.
- Data analysis for improvements to future traffic management plans.
- Evaluation of the technology and its potential for more widespread use.

This report is structured as follows. First, the TrafficTurk technology is introduced and an overview of how it works is provided. Then, each research task is detailed along with its execution, results, and potential improvements for future deployments. Finally, future directions and possible deployment applications for TrafficTurk are provided.

## CHAPTER 2 OVERVIEW OF THE TRAFFICTURK TECHNOLOGY

The TrafficTurk application is an Android operating system-based turning movement counter (Figure 1). The development of the application is inspired by traditional turning movement counter boards, shown in Figure 2. Traditionally, these devices have 12 or 16 counting buttons, one for each possible maneuver at a four-way intersection, and possibly one pedestrian button at each corner of the intersection. Users take the board to an intersection, input data, and offload the data later when it is connected to a PC. Then, it can be processed by software, for example, to improve signal timings.



Figure 1. TrafficTurk smartphone turning movement counter. User swipes (indicated by dashed arrows) are recorded as left, right, and through movements.

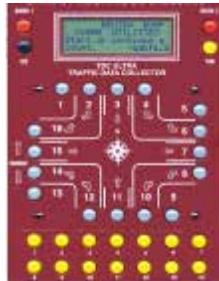


Figure 2. Conventional turning movement counter (Jamar Technologies).

Unfortunately, traditional turning movement counters have several constraints that prevent them from being used for monitoring extreme congestion events such as sporting and cultural events, extreme weather, and natural disasters that cause extreme traffic congestion. First, most counting boards lack wireless communication capabilities, which limits their applicability to real-time monitoring applications. Second, the boards can be expensive; a single board can cost over \$300, which means it is very costly to deploy them at multiple intersections simultaneously, and this limits the amount of data that can be collected.

The TrafficTurk application was designed to tackle the above-mentioned issues, by enabling turning movement counts to be collected in real-time and over larger portions of the transportation network simultaneously. The development of a smartphone application is a natural direction caused by the ever-growing ubiquity of smartphones and their inherent

connectivity to the Internet. The embedded communication capabilities allow for real-time data transfer to a centralized database. Moreover, excellent software development kits enable fast application development and debugging. The easy availability of existing hardware that can run the application (e.g., any Android 2.2 or greater device) eliminates the need for expensive and rigid hardware solutions. Finally, the user interface is adaptable, which enables custom counting screens for three-way intersections, one-way streets, etc., and leads to improved counting accuracy at these intersections.

The long term goal of the TrafficTurk project is to develop a traffic monitoring platform to enhance traffic information during extreme congestion events, such as sporting events, political events, natural disasters, and events such as the Farm Progress Show.

# CHAPTER 3 DATA COLLECTION

## 3.1 TASK DESCRIPTION

Traffic generated by the Farm Progress Show created significant congestion between 7:00 a.m. and 10:00 a.m. on August 27 and August 28, the first two days of the show. Using TrafficTurk, the University of Illinois at Urbana-Champaign measured the traffic levels during the peak hours at 31 critical locations in the surrounding area on both days. The locations of the traffic measurements are shown in Figure 3. Data was collected at all 31 intersections simultaneously to provide a detailed picture of the network-wide traffic conditions on the main routes into the show. The locations for data collection were selected in collaboration with the Macon County Highway Department.

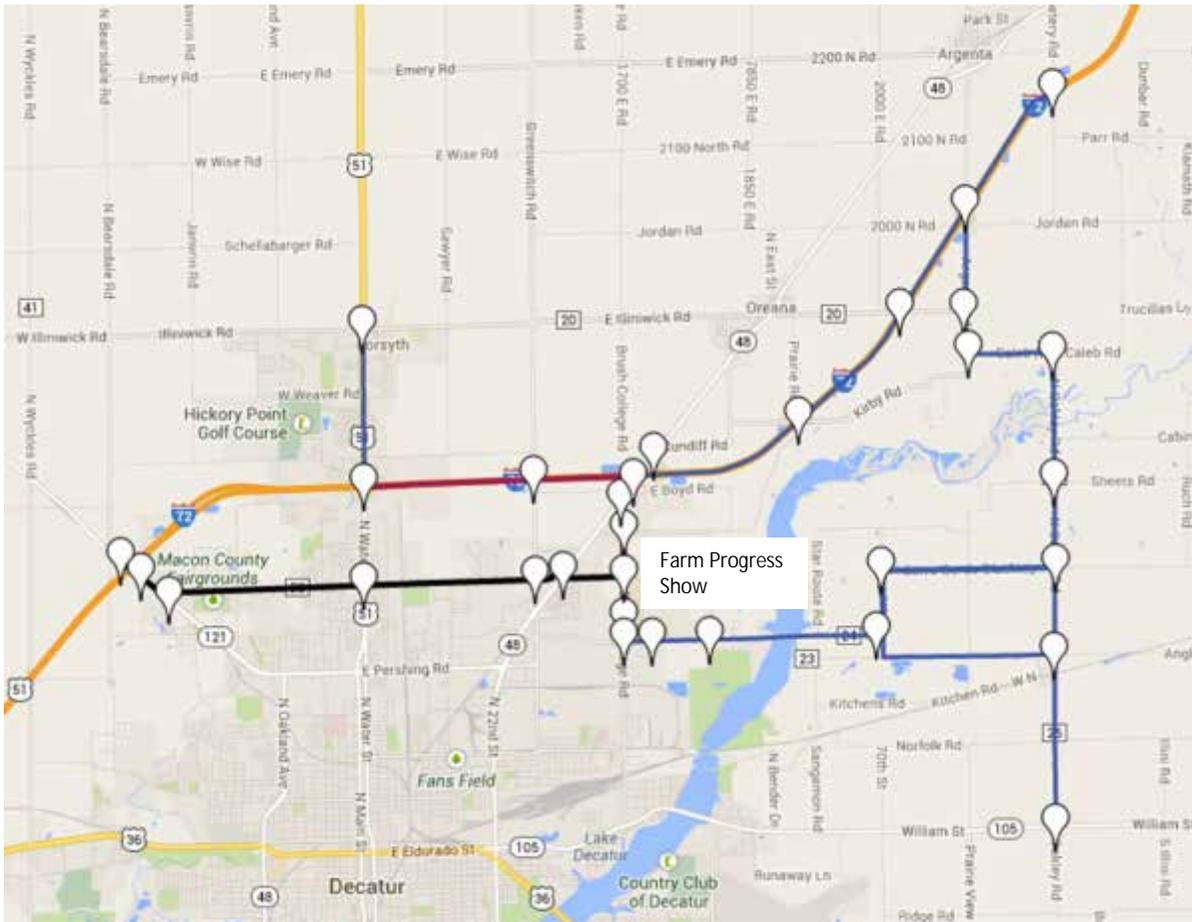


Figure 3. Data collection locations and typically congested routes (along colored lines on the map) during the Farm Progress Show 2013.

## 3.2 TASK OBJECTIVES

The specific objectives of the task were:

- Collect turning movement counts at 31 counting locations between 7:00 a.m. and 10:00 a.m. on August 27 and 28, 2013.
- Ensure that the data sets from each counting location are complete and were stored in a reliable and easy-to-access database to facilitate data analysis.

- Publish the collected data so that it is accessible to collaborators and other researchers.

## 3.1 DETAILED SUMMARY OF THE DEPLOYMENT

### 3.1.1 Deployment Plan

#### 3.1.1.1 Testing TrafficTurk

The collection of data with TrafficTurk requires an underlying map over which counting locations are overlaid. In order to run the application in Decatur, Illinois, a map of the road network was downloaded from *OpenStreetMap* and deployed on the back-end TrafficTurk servers to uniquely identify each counting location as a location on the physical road network. Moreover, each counting location has specific road geometry and the collection of turning movement counts requires knowledge of these geometries. For example, collecting turning movement counts at a three-way intersection (T-intersection) is different from collecting turning movement counts on a highway (which are simply the through movement counts in both directions).

In order to ensure that the application is able to correctly display the road geometry and location on the road network, the application was thoroughly tested at each counting location. This is important because the map may have errors, and it is important to correct the errors before the data collection begins. During the test of each intersection, critical information such as feasible and safe locations for individual collection of data, the quality of the cell phone network at each location, and any errors in the application related to display of street names or road geometry were collected.

Note this information is important for several reasons. The counting locations need good network coverage if the data is to be collected in real-time. Similarly, safe counting locations are important. In general it may not always be possible to find a safe counting location, especially after a natural disaster, which may prevent counting at key locations. The accuracy of the street names is important to reduce counter confusion.

The results of the test indicated that most intersections had a parking spot nearby, a safe place from which to perform the count, and fair cell phone network connectivity. A few counting locations did not display correctly on the TrafficTurk application because of errors in the underlying *OpenStreetMap* data. Appendix A, Table A.1. shows the results of conducting these tests at each counting location.

The *OpenStreetMap* data was edited to correct erroneous road geometry, the incorrect street names were changed to match the street signs on the physical road network and any relevant modifications to the application were made. This ensured that collecting data at every intersection would be possible and reliable and that the user experience would be smooth and intuitive. The intersections where cell phone network quality was seen to be low were also flagged for use by the event management team, described later in this section.

Further, the entire system was tested for accuracy and completeness of data. In other words, the system was developed and tested thoroughly to ensure that every single vehicle that was recorded on the application was accounted for in the database and that each data point was accurately stored. This involved creating different data collection scenarios, entering a known sequence of movements into the application, and checking whether it was reflected exactly in our database. Different scenarios include combinations of various data connection qualities and various counting location types. An example scenario is as follows: "A user starts collecting data at the intersection of two two-way streets and

loses the data connection shortly after, but continues to collect data. The data connection is re-gained later on.”

These tests were crucial because several significant enhancements were made to the TrafficTurk application prior to the Farm Progress Show deployment. For example, a more reliable and energy efficient communication protocol between the application and the server was built, and the system was modified to use the free and widely used OpenStreetMap map data. These changes were developed in order to improve the application’s functionality and scalability, but needed extensive testing before the Farm Progress Show experiment. Even though the application has been in development for over a year, improvements are being constantly made and tested. These tests ensured that the new parts of the system worked well and that the application would work as expected during the deployment.

The outcome of the tests was that the application functioned well and all data was being collected accurately and completely.

### *3.1.1.2 Recruitment of Data Collection Associates*

One of the main objectives of Task 1 was to collect a complete data set for each counting location. In order to ensure that this is possible, a team of data collection associates was recruited from the Decatur community. These volunteers agreed to run TrafficTurk on their own cell phones for three hours on each day of the show and to attend a one-hour training session to cover safety issues that could be encountered during the show.

Based on previous tests that relied on student volunteers, the fact that several people might not complete their assigned tasks because of a number of reasons (not able to travel to counting location, cell phone not working, illness, change of plans, not prepared for the weather, forgetting about the tasks, not waking up on time, etc.) was considered. In a previous test, 150 people were recruited to fill the 110 data collection associate positions, for a completion rate of 73%. Similarly, recruitment was planned for many more data collection associates for the Farm Progress Show deployment compared with the number of counting locations to make sure all intersections were covered during the event.

The process of being recruited as a data collection associate for the Farm Progress Show deployment started at TrafficTurk’s website ([www.trafficturk.com](http://www.trafficturk.com)). The website was modified just before the recruitment period started in order to quickly direct people to the registration page. The website’s structure was such that one would first enter a page with detailed information about the responsibilities of being a data collection associate. The information displayed on this webpage is available in Appendix B.

Then, if a person decided to sign up for the opportunity, they were directed to an online form that they were required to complete. A screenshot of the sign-up form and link to a live version of the form are available Appendix B (Figure B.1). The responses to the form were directed to a spreadsheet in Google Drive from which the potential recruits could be filtered. The questions on the form were designed to obtain information that is critical in determining whether a person would be able to carry out his/her duties successfully as a data collection associate. For example, Question 3 asked about the type of phone the user owns. Because TrafficTurk is only available for smartphones that run the Android operating system, any response that indicated otherwise disqualified that person from being a data collection associate. Note that despite providing information about the requirement that their cell phone must run on Android, several responses that indicated otherwise were received. Similar questions were asked to roughly gauge the ability of the person to collect traffic data.

The strategy to direct web traffic to the TrafficTurk website was to raise awareness about the opportunity on local media including television and newspaper. A number of local groups were also contacted to promote the opportunity within the group.

In total, 75 responses were received through the website. Emails were sent to 70 individuals asking for a confirmation. Confirmations from 51 people were received. Eight people canceled their participation between signing-up and attending a training session. Two people did not show up to their assigned training session. Overall, 41 people were recruited and trained as data collection associates with 31 people assigned to specific counting locations and the rest assigned to be backup data collection associates.

### *3.1.1.3 Training of Data Collection Associates*

Each data collection associate was required to attend a training session that covered important logistics and safety information in order to participate. There was a choice of four training sessions that the volunteers could attend. Each volunteer indicated the training sessions that they could attend on the sign-up form and was assigned to a training session. Overall, 41 people attended a training session. The backups were asked to report to the control center during the experiment and were deployed to an intersection as needed.

The need could occur if a data collection associate's phone lost charge, or a data collection associate failed to report to the experiment location on time. The backup data collection associates were compensated if they were available to act as a backup for the entire duration of data collection. Previous deployments of the technology suggested that the application could run on the phone for approximately 3 hours before completely exhausting the battery; therefore, this precaution of hiring backup data collection associates was necessary. However, a new version of the application that is significantly more energy efficient was developed for this deployment; therefore, hiring backup data collection associates to cover for insufficient battery life may not be needed in the future. Backups may still be needed to cover counters who do not report on time, however.

Training sessions covered essential experiment information including safety, how to use the application to collect traffic data, the importance of being on time, and how to get paid. The training session consisted of a presentation, installation of the application, and practice counting with TrafficTurk.

As data collection associate trainees arrived at the training session, they were encouraged to install the TrafficTurk application on their phone if they had not already done so. Although the application is now available on Google Play, during this experiment the data collection associates were required to install the application directly from the TrafficTurk website. They were also given help if needed by the training session staff (Figure 4).



Figure 4. A data collection associate being trained at a training session for the Farm Progress Show deployment.

The trainees were also required to sign-in to the training session with training session staff. As part of the registration, the data collection associates were given a statement of informed consent to participate in the research, as well as a talent release form. Prior to the start of this project, the University of Illinois at Urbana-Champaign's Institutional Review Board (IRB) reviewed the proposed research (Protocol Number 14065) and confirmed that it did not meet the definition of research on human subjects. Regardless, the statement of informed consent was used to provide the data collection associates with a better understanding of the requirements and expectations of participating in the experiment. The talent release form allowed a photographer to document the experiment. These forms, *StatementofInformedConsent.pdf* and *TalentReleaseForm.pdf*, can be found in a Dropbox folder titled *Farm Progress Show Report Files* (see Gowrishankar and Work 2013 in the reference section of this report).

The slides from the presentation used in the training session, *TrainingSession Presentation.pdf*, can also be found in the Dropbox folder (Gowrishankar and Work 2013). The trainees also practiced collecting data with TrafficTurk by watching a pre-recorded video of four-way and three-way intersections.

Prior to the training sessions, the Macon County Highway Department marked each counting location with spray paint. This indicated where trainees could park their vehicle safely and collect data with TrafficTurk. This information was given to the trainees in the form of a picture of the counting and parking location. An example, *ParkingspotPhoto.jpg*, can be found in the Dropbox folder, *Farm Progress Show Report Files* (Gowrishankar and Work 2013).

Each trainee was also given a bright T-shirt and a placard that identified them as part of a research study to the general public and authorities. Each trainee was also given an information packet that consisted of three main documents. The first was a "the-day-of" handout, which had information about the study; the times, locations, phone support phone number, tips to make the counting experience more comfortable; and troubleshooting for common issues that might arise. A copy of this handout, *ExperimentHandout-BlueTeam.pdf*, is in the Dropbox folder (Gowrishankar and Work 2013). The second document was a list of safety considerations that reiterated the safety instructions presented in the training session; this handout is in the Dropbox folder and is named *BasicRoadsideSafety.jpg* (Gowrishankar and Work 2013). Finally, a map of the 31 counting locations with each data collection

associate's specific location highlighted was also included. This map, in the Dropbox folder, is titled *MapOfIntersections.jpg* (Gowrishankar and Work 2013). Backup data collection associates were given the same materials except their map did not include a specific counting location.

#### 3.1.1.4 Event Managers

The role of event managers during the data collection period was to ensure that data was being collected at all 31 intersections and to provide the data collection associates with the assistance needed (Figure 5). Because there were different tasks that had to be completed to successfully manage the event, the event managers performed three distinct roles – data monitor, phone operator, and field support.



Figure 5. Event managers monitoring the incoming data from the event control center at the Macon County Highway Department.

##### 3.1.1.4.1 Data Monitor

The role of the data monitor was to ensure that all counting locations had active data collection associates collecting data. In order to do this, data monitors used a tool known as the *Monitoring Tool*. This tool ran in an Internet browser and is able to display the current status of each counting location. The tool displayed various attributes of the data collected at each counting location as well as attributes of the user and his/her phone. This was helpful because it was a quick way of identifying and predicting future issues. For example, one could easily identify the case where data was not being collected at a counting location and one could estimate whether a phone will run out of battery life before the end of the counting period. The data monitor used this information and makes decisions regarding issues. They might, for example, decide that someone needs to be checked on in the field, that someone needs to be called, or that a backup data collection associate needs to be sent to replace someone. For this particular deployment, the team consisted of two data monitors.

The data monitors also constantly updated a Google spreadsheet that was accessible in real-time by everyone at the event control center. This helped everyone stay current on the ongoing issues and allowed others to assist in complex issues as needed. An

anonymized copy of this spreadsheet is in the Dropbox folder and is named *IssueTracker(Anonymized).gsheet* (Gowrishankar and Work 2013).

#### 3.1.1.4.2 Phone Operator

Phone operators complemented data monitors by helping in resolving issues over the phone. They are equipped with a Google Voice (<http://voice.google.com>) account from which they could call or text any data collection associate. They also received messages from data collection associates and field support. These messages were used to keep track of data collection associates' issues and the location and status of field support. An anonymized copy tool used to keep track of data collection associates is named *CounterManagement (Anonymized).gsheet*, and the tool used to keep track of field support vehicles is named *DriverManagement.gsheet*; both files are in the Dropbox folder (Gowrishankar and Work 2013).

The phone operators were also responsible for delivering phone support to data collection associates and communicating with field support. For example, a phone operator might call a data collection associate who had a problem with the application, and guide them through the procedure to fix the issue. If the issue was not possible to resolve over the phone, field support could be dispatched to help the data collection associate in person.

For this deployment, two phone operators were used. Each phone operator used a different Google Voice account and a different phone number. Half of the data collection associates were given one Google Voice phone number and the other half were given another. This way, each phone operator and each data monitor only had a subset of the counting locations to monitor and to provide support.

#### 3.1.1.4.3 Field Support

Because of the size of the area covered by the 31 counting locations, all field support personnel were equipped with a car and backup phones. Backup phones were available in case a phone stopped working because of an exhausted battery or any other issue. Field support personnel were instructed to send a text message to the phone operators each time they moved their location in order to help the data monitors and phone operators make decisions on field support.

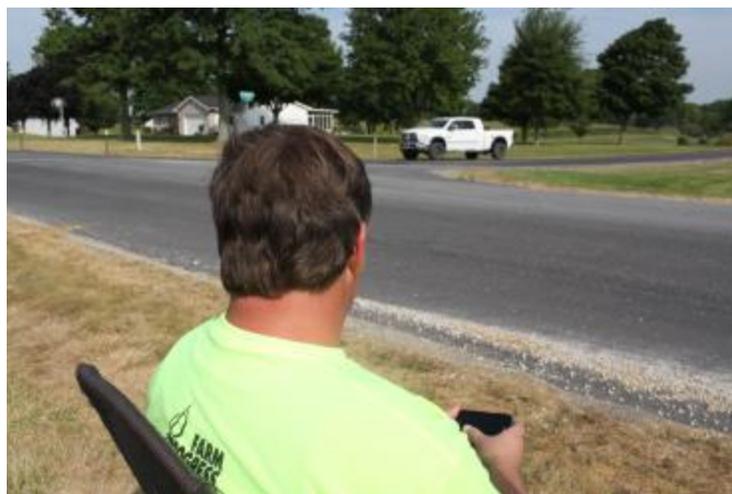


Figure 6. A data collection associate collecting data with TrafficTurk on August 28, 2013.

In this deployment, there were three field support personnel, each with their own area of operation. This division of the covered area was necessary so that each car could quickly get to any counting location in their designated area. To facilitate this further, all field support personnel were given maps of their area with the counting locations and congested routes highlighted. They were instructed to avoid congestion to be able to provide quick field support to the data collection associates (Figure 6). The field support personnel had to be very well acquainted with their area of operation, so they were encouraged to explore the area before the data collection period.

### *3.1.1.5 Event Control Center*

The event control center housed the data monitors, phone operators, and backup data collection associates. This was the hub for communication and decision-making. It also served as the place where data collection associates could come to pick up their compensation. For this deployment, the event control center was the Macon County Highway Department office in Decatur, Illinois. This location was sufficiently far away from the Farm Progress Show so that there was no congestion in and around it, yet sufficiently central so that one could go to most counting locations quite quickly.

The most important pieces of equipment at the event control center were the computers used to monitor the incoming data and make phone calls through Google Voice and a fast, reliable Internet connection. Another important feature of the event control center was the real-time sharing of tools. Google Drive and Google Docs allows multiple users to access and edit documents while they are being edited in real-time and therefore it is a great way to keep the entire event control center updated with the latest information in real-time. The issue tracker tool and field support tracker were both used by all event managers at the event control center. Everyone at the event control center also used the monitoring tool because multiple instances of it could be opened in an Internet browser.

Compensation was also paid to the data collection associates at the event control center at the end of the second day of data collection. Before paying each data collection associate, the event managers made sure that the database contained all the data from them for both days of data collection. There was a feature in the monitoring tool that showed whether a complete data set had been received from each data collection associate. In case some data was missing in the database because of any reason (no Internet connection at their counting location, something wrong with the phone, etc.), the event managers restarted the application and connected the phone to the Wi-Fi Internet at the event control center. This ensured that any collected data that was locally stored on the phone, but not yet sent to the TrafficTurk database, was sent. Once all the data was seen in the database, the data collection associate was paid and thanked for their time and effort.

## **3.1.2 Data Collection**

### *3.1.2.1 Day 1 – August 27, 2013*

The first day of data collection started early for the TrafficTurk team. The event management team departed Champaign, Illinois, to the event control center in Decatur, Illinois, at 4:45 a.m. One team member remained in the server room in Champaign, IL to monitor TrafficTurk's back-end systems (servers, database, monitoring tool, map, etc.). The team reached the event control center and started setting up for the day's data collection 50 minutes later. This included setting up computers, screens, a waiting area for backup data collection associates, etc. The systems and tools at the event control center were also tested thoroughly.

In the meantime, field support personnel directly went to their areas of operation and explored the area. This exploration was required in order for them to be familiar with their area before the start of data collection. It was also a chance for them to find a central location in their area where they could wait to receive field support tasks from the event control center. One of the field support personnel described this exercise as, “absolutely necessary because some roads were closed and others had street names that were different from the printed maps.”

At 6:45 a.m., 15 minutes before the start of data collection, the phone operators sent a mass text message to all data collection associates. This text was as follows:

*Good morning! The TrafficTurk test will begin in 15 minutes. Please go directly to your counting location, and have a great morning!*

This text was meant to remind anyone who had either forgotten about the day of data collection or was running late. This also gave data collection associates who changed their minds at the last minute a chance to let us know that they could not make it so that the events managers could arrange for a backup data collection associate to take their place. Then, at 6:55 a.m., another text message was sent to everyone who had not been seen on the monitoring tool at the assigned counting location. This text read:

*We do not see you at your counting location yet. Please let us know if you are on your way.*

Then, at 7:00 a.m., a final text message was sent to anyone who had not started collecting data or had not replied to earlier text messages confirming that they were on their way:

*We do not see you at your counting location, please reply: I am on my way, or I am already here. Thank you, TrafficTurk.*

After this text message, most people had either shown up at their counting location or had confirmed that they were on their way. A few data collection associates had not replied or shown up at their counting location. At this time, field support personnel were sent to these locations to confirm whether they had indeed not shown up or whether their phone had no network connectivity and as a result did not receive text messages or send any data to the TrafficTurk servers. It turned out that on this day, two data collection associates did not show up, so backup data collection associates replaced them promptly.

It is important to note that during the safety briefings before the event, each data collection associate was warned about the text messages they would receive. They were also given explicit instructions to ignore the messages while driving and to respond only when safe and legal to do so.

After this busy initial period, field support personnel made their way to each counting location and verified that every data collection associate was wearing their bright T-shirt, had a placard displayed, and that they were experiencing no problems. The field support personnel resolved any issues that came up. While there were no reported issues with the visibility of the data collection associates, high visibility vests could be used to further improve safety.

Soon after, all counting locations were covered and the data was continuously monitored. There were a relatively very small number of issues on Day 1 compared with previous deployments. These issues are described in a file named *IssueTracker.gsheets* in the Dropbox folder (Gowrishanker and Work 2013).

At the end of the data collection period, another mass text message was sent to all data collection associates in order to inform them that the data collection was completed for the day, to thank them for their effort, and to ensure that they had safely departed their counting location.

*Thank you very much for your participation. You have done a great job in helping us out. Please send us a text to confirm that everything went well and you have left the counting location.*

In total, 87,778 vehicles were recorded between 7:00 a.m. and 10:00 a.m. on Day 1. One data collection associate collected data at the wrong counting location; he/she collected data at the intersection of IL 48 and Boyd Road instead of at the I-72 eastbound ramp onto IL 48. The highest number of vehicles recorded at any counting location was 8105 vehicles on I-72 at Greenswitch Road, and the smallest number of vehicles recorded at any counting location was 575 at the intersection of Brush College Road and College Park Road. A total of 5447 minutes of active data collection occurred on Day 1, which is 94.6% of the total counting time that could have been covered. The counting location with the lowest flow rate was the intersection of Brush College Road and College Park Road (192.6 veh/hr), and the counting location with the highest flow rate was I-72 at Greenswitch Road (2702.3 veh/hr).

### 3.1.2.1 Day 2 – August 28, 2013

Day 2 of data collection started off similarly to Day 1 except that the equipment at the event control center was already setup. The field support personnel were also already familiar with their area, and the data collection associates were familiar with their counting location and their duties. The same text messages were sent as Day 1 and all counting locations had a data collection associate collecting data.

After the end of data collection on Day 1, a quick debrief helped the event management team look for any issues and correct them early on Day 2. One of the field support personnel coordinated with the police department to move a data collection associate to another counting location. This was done because the counting location was not ideal to record data during heavy traffic. As congestion built up, the queue blocked the view of part of the intersection and therefore the data collection associate had to be moved to another location. Three data collection associates reported that they were indeed at their counting location collecting data; however, because of poor network quality at their locations, the monitoring tool did not show any of their collected data. It was also revealed later that several data collection associates turned off their data connection in order to save on data transmission costs. Field support personnel were sent to confirm their locations and a note was made to connect their phones to an Internet connection at the end of the day's data collection. The data collection associate that counted at the wrong counting location on Day 1 was briefed on the location of the correct counting location. Because the associate incorrectly counted at a nearby intersection located only a few hundred yards away, it was difficult to detect the problem in real-time.

Additionally, the Macon County Highway Department suggested that an additional turning movement count be collected at the interchange between I-72 WB and US 51. Therefore, shortly after counting started on Day 2, a backup data collection associate was sent to that location and started collecting data, so a total of 32 intersections received counts.

On Day 2, a total of 90,384 vehicles were recorded. Again, the counting location with the least recorded vehicles and smallest flow rate was the intersection of Brush College Road and College Park Road (660 vehicles at 221.8 veh/hr). Interestingly, the counting

location with the highest number of vehicles recorded was the intersection of Mound Road and US 51 (6850). This intersection also had the highest flow rate out of all the counting locations (2289.1 veh/hr). The data collection associates actively collected data for 5483 minutes, which is 95.2% of the total possible data collection time between 7:00 a.m. and 10:00 a.m.

### **3.1.3 Data Storage and Access**

All the collected data was stored in two databases. One database was located on a server at the University of Illinois at Urbana-Champaign and the other was a backup server located on an Amazon EC2 cloud server. This ensured that if for any reason, one of the servers stopped, the collected data could still be accessed.

The data is available for download from a Dropbox folder in comma-separated value format files named *rawData\_Day1.csv* and *rawData\_Day2.csv* (Gowrishankar and Work 2013). The data format is explained further in Appendix H.

### **3.1.4 Potential Improvements for Future Deployments**

Overall, the data collection was a success. Some potential improvements for future deployments are:

- The number of counting locations can be increased significantly to get a more complete picture of the traffic movement. This would definitely involve a more aggressive and prolonged recruitment process because many more data collection associates would be required. However, having more counting locations would provide some redundancy in the collected data and this could be used to estimate the state of traffic with more certainty and also help in the evaluation of the technology (compare differences in collected data between two or more data collection associates, etc.).
- An automatic counting error detection algorithm could be developed to check in real-time whether data collection associates are counting at the right location and whether they are counting the correct streams and amounts of traffic. This would allow the event managers to better predict potential issues with the collected data and correct for it.
- An automated system to send mass text messages could be incorporated into the monitoring tool. This way, event managers would not have to check each counting location individually and would be able to send text messages appropriately. This would enable much larger deployments.
- A GPS enabled tracking system for field support personnel would eliminate the need to continually use the field support management tool to keep a track of the location of field support personnel. This would reduce the workload of the event management staff and as a result facilitate decision-making and better monitoring of incoming data.
- An online payment system for data collection associates would eliminate the need for the organization and execution of an in-person compensation session. This would reduce the workload on all participants and would also facilitate much larger deployments of the technology.

## CHAPTER 4 DATA ANALYSIS

### 4.1 TASK DESCRIPTION

The data collected with TrafficTurk was analyzed in a number of ways in order to provide insights into improvements to future traffic management plans.

### 4.2 TASK OBJECTIVES

The specific objectives of the task were:

- To determine the arrival rates at each counting location in order to identify the peak arrival rates on each of the entrance routes to the show.
- To analyze the counting locations measuring vehicles entering from the west on I-72 and from the north on US 51 in order to identify vehicles that could be rerouted in the future to avoid congestion on I-72.
- To determine the amount of traffic exiting the freeway at Argenta Road, which is a recommended alternate route to the show.

### 4.3 ARRIVAL RATES

TrafficTurk collects data that is a direct measure of flow across a point in the road network in units of vehicles per hour, by maneuver. (A maneuver is the specific movement of a vehicle at an intersection. For example, at a standard four-way intersection, some maneuvers that vehicles can execute include NBL (northbound left), NBT (northbound through), SBR (southbound right), etc.) Moreover, the flow rate at one counting location along a route is approximately equal to the arrival rate at the next counting location along the route (and equal if no vehicles enter or exit the route). Therefore, the flow rates from different directions over 10 minute periods are a good way to measure how many vehicles are coming into the show from different directions at different times.

Figures C.1 through C.5 in Appendix C show the flow rates in 10-minute intervals during the entire duration of data collection (from 7:00 a.m. to 10:00 a.m.) at critical counting locations around the show. These figures show a comparison between the first day and the second day of data collection and they are useful in comparing the vehicular arrivals from different directions on different days and at different times.

For example, there was more flow on the recommended route through Oakley Road on the second day of the show compared with the first day of the show. Additionally, the demand for the I-72 roadway was approximately the same on both the first and second days of the show. The arrival rates of the remainder of the counting locations are available in a *comma-separated value (csv)* files named *FPS2013\_10minArrivals\_Day1.csv* and *FPS2013\_10minArrivals\_Day2.csv*. These files are in the Dropbox folder (Gowrishankar and Work 2013).

The flow also was computed over the entire network of TrafficTurk sensors, as shown in Figure 7, which indicates that the peak demand for the road network exists approximately between 7:45 a.m. and 8:15 a.m. After this, the flow rate across the network decreases with a small increase towards the end of the data collection period. The pattern of flow on both days over the entire network follows a similar trend for each individual intersection where data was collected.

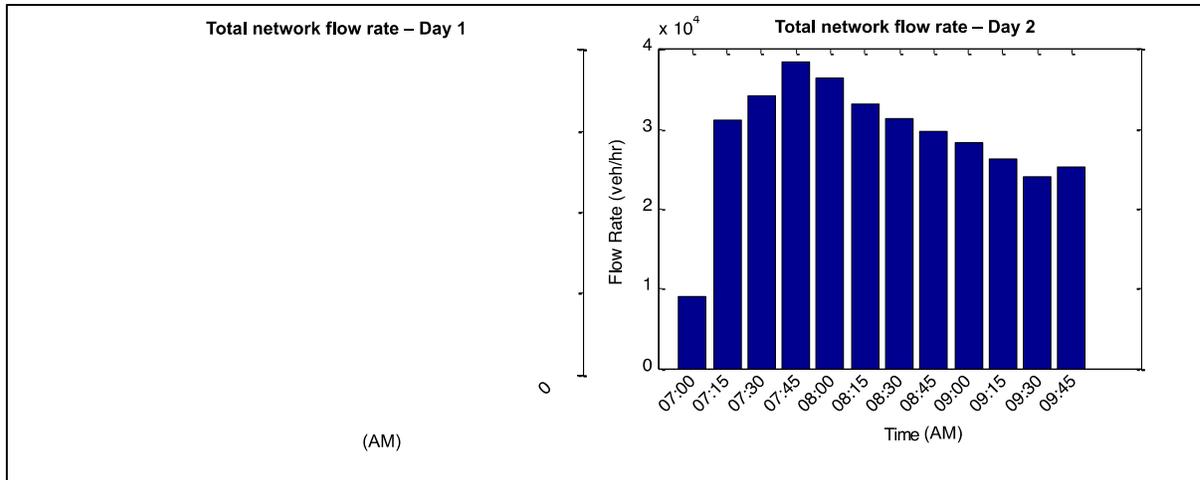


Figure 7. The total flow over all sensors in the network on both days of data collection.

#### 4.4 NORMALIZATION OF DATA

Considering that TrafficTurk data is collected by humans, it is susceptible to the introduction of biases because of human error. The user interface of the application is designed to minimize this error; however, it does not completely eliminate it (Schneider 2011). Therefore, some sort of data normalization is required to correct for counting errors.

A new method was developed to normalize the data. It relies on the fact that vehicles are conserved on a stretch of roadway, and the roadway has a finite amount of storage capacity. Then, an optimization problem is solved across the network to minimally adjust the flow recorded at each counter to make the data consistent. To our knowledge, this is a new but straightforward technique to correct for network flows, and it could easily be extended for other flow sensors, such as inductive loop detectors.

The normalization ensures that the collected dataset is physically feasible under the premise of mass conservation and the geometry of the road network. An example of a problem that could arise when data is not normalized is as follows: if one of two data collection associates on either end of a road segment misses vehicles in their data collection, it is possible that over a period of time, a negative queue length may develop on the road connecting the two counting locations. Of course, this is not possible. The same road might also have a queue that far exceeds its capacity in the opposite direction of traffic flow. A detailed description of the normalization procedure and the resulting optimization algorithm is described in Appendix D.

The normalization was carried out for all links (road segments) in the network that had a data collection associate at each end. However, some links had very high rates of vehicles exiting the link in between the two data collection locations and therefore the mass conservation did not hold for these links. This occurred, for example, at the parking entrance to the show off of N. Brush College Rd.

The results of the normalization include correction factors for each data collection associate, and a description of the number of vehicles on each link over time. The results of the normalization for both days have been visualized similar to Google Maps traffic in videos that can be found in the Dropbox folder (Gowrishankar and Work 2013). It visualizes the estimated traffic congestion on each route to the show over time. A more detailed description of the visualization can be found in Appendix D.

#### 4.5 TRAFFIC FROM THE WEST AND NORTH

The data analysis in this report separates the incoming routes to the show into two parts. The first considers traffic coming in from the west on I-72 EB and from the north on US 51. The second part of the analysis considers traffic coming in from the east on I-72 WB and from the south on Oakley Road. Figure 8 shows the different routes to the show from the west and north. The main entrance routes to the show from the west include:

1. I-72 EB until the interchange at IL 48. Then south on Brush College Road;
2. Exit I-72 EB at IL 121. Turn onto Mound Road and go east to Brush College Road;
3. Exit I-72 EB at the interchange at US 51 and go to Mound Road. Then go east on Mound Road to Brush College Road;
4. Exit US 51 onto I-72 EB. Exit at IL 48 and go south on Brush College Road; and
5. Turn from US 51 onto Mound Road and go east on Mount Road to Brush College Road.

The routes as numbered above are illustrated in Figure 18.



Figure 8. The approaches to the show from the west and north.

The most important route to consider for these approaches is the series of roads between IL 48 at the I-72 EB ramp and the intersection of Brush College Road and Mound Road. This particular flow determines whether there will be a queue on the I-72 EB exit ramp at IL 48. A queue on this ramp gives rise to a dangerous situation where a high-speed road has a long queue of slow moving vehicles. This increases the risk of a high-speed rear-end collision and should be avoided if at all possible. Therefore, the road segments were analyzed along this route in 10 minute time periods between 7:00 a.m. and 10:00 a.m. and predictions were made whether alternative re-routing strategies could mitigate queues on I-72 EB.

For the route between the I-72 EB ramp on IL 48 and the intersection of Brush College Road and Mound Road, the estimated average state of traffic between 7:10 a.m. and 7:20 a.m. is shown in Figure 9, using the data normalization process described in Appendix D.

The road segments marked in green have an estimated average density ( $\rho$ ) of vehicles that is less than one-fifth of the jam density (maximum density) of the road segment ( $\rho_j$ ). Road segments marked in yellow have average density values between one-fifth and two-fifths of the jam density. Orange indicates that the average density of the road segment is between two-fifths and three-fifths of jam density and red indicates that the average density is above three-fifths of jam density.

Figure 9 shows a very high density of vehicles on Brush College Rd. just before the entrance to the show also has a high vehicle storage value. It can also be noticed that there is low density on the road segment between the WB and EB ramps on Day 2, which indicates that there is relatively less traffic coming in from the east onto I-72 WB ramp than from the west onto I-72 EB ramp. Note that one of the data collection associates counted at the wrong location on Day 1 and therefore the data for the intersection of IL 48 and I-72 WB ramp is not available for Day 1. On Day 2, heavy congestion is observed on IL 48 towards the show.

There is also a low density on Mound Road between US 51 and Greenswitch Road on Day 2. However, these road segments have a higher density on Day 1. It can be clearly seen that because the intersection of Mound Road and Brush College Road has to serve two streams of incoming vehicles, there is high density just upstream of the intersection on both Brush College Road and Mound Road on Day 1. However, on Day 2, the density on Mound Road just upstream of the intersection with Brush College is lower than on Day 1.

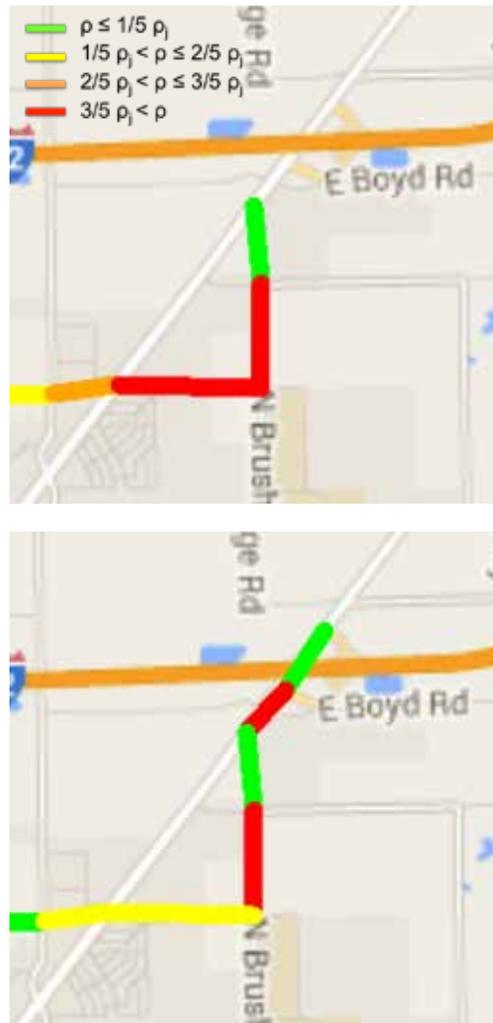


Figure 9. A visualization of densities  $\rho$  relative to the jam density  $\rho_j$  on L 48 and Brush College Road on August 27 (top) and August 28 (bottom), 2013, between 7:10 a.m. and 7:20 a.m.

Figure 10 shows the densities on IL 48 and Brush College Road between 7:40 a.m. and 7:50 a.m. A reduction in densities is apparent on IL 48 on Day 2 between Brush College Road and the I-72 WB ramp compared with the densities between 7:10 a.m. and 7:20 a.m. The density on Brush College Road decreased on Day 1, but there is a high density on Day 2 similar to the one observed between 7:10 a.m. and 7:20 a.m. Interestingly, the density on Mound Road between Brush College Road and Greenswitch Road (the colored east/west route) has decreased on Day 2, but is higher on Day 1.

From 8:00 a.m. onward, the densities on all these road segments reduce for the remainder of the data collection time period. The average densities between 8:10 a.m. and 8:20 a.m. are shown in Figure 11.

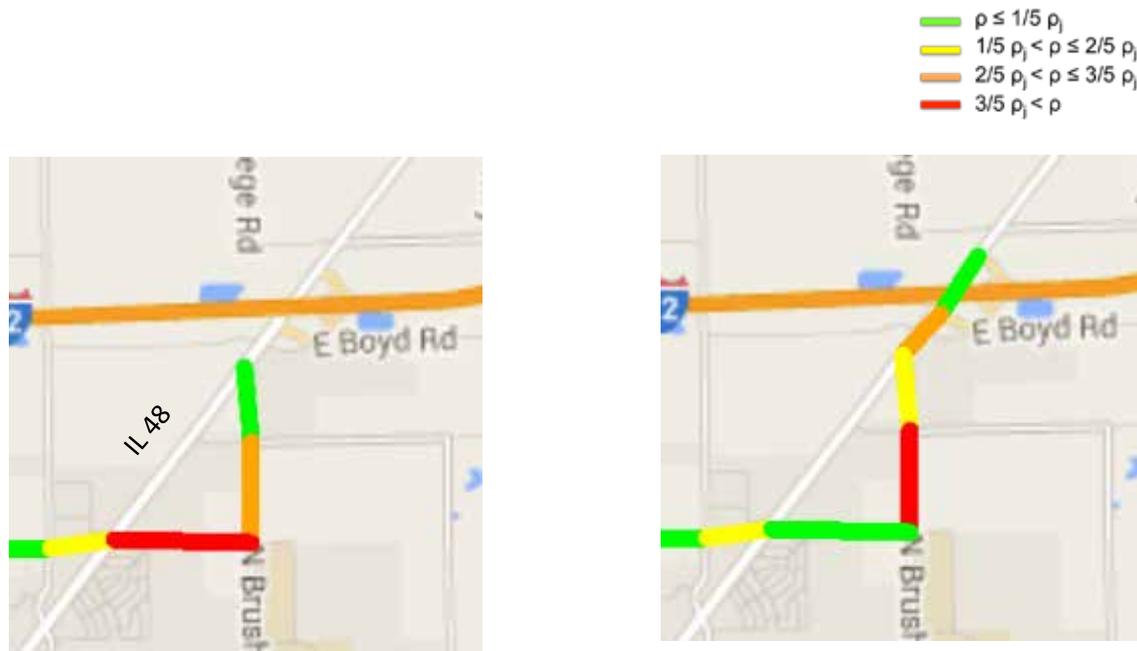


Figure 10. A visualization of densities  $\rho$  relative to the jam density  $\rho_j$  on IL 48 and Brush College Road on August 27 (left) and August 28 (right), 2013, between 7:40 a.m. and 7:50 a.m.

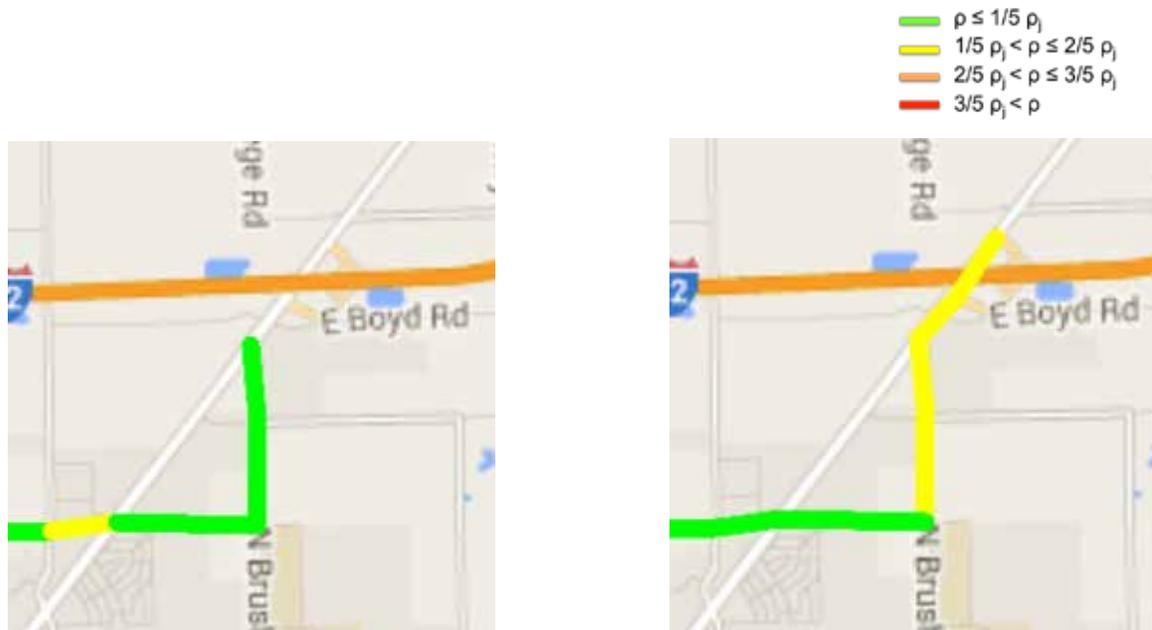


Figure 11. A visualization of densities  $\rho$  relative to the jam density  $\rho_j$  on IL 48 and Brush College Road on August 27 (left) and August 28 (right), 2013, between 8:10 a.m. and 8:20 a.m.

The western approach from Mound Road does not get highly congested for the duration of the data collection on both days. Specifically, the road segment between US 51 and Greenswitch Road maintains a density that is less than one-fifth the jam density throughout the three hours of data collection on Day 2 and for the majority of the three hours on Day 1.

This suggests that there is available capacity that can be filled with vehicles. If a portion of eastbound vehicles on I-72 are rerouted to enter Brush College Road from Mound Road, it may reduce the queue on the I-72 EB ramp at IL 48.

#### 4.5.1 Reroute of Traffic on I-72 EB at the Interchange with IL 121

In order to enforce this reroute, vehicles need to exit I-72 EB at the interchange of IL 121 instead of taking the exit at IL 48. Then, vehicles can make their way onto Mound Road and eventually to the show. One concern with this reroute is that there may be insufficient capacity at the intersections of Mound Road and IL 48 and Mound Road and Brush College. This may induce spillback onto the intersections of Mound Road with IL 48 and Greenswitch Road. However, the negative effects of this spillback can be reduced if cross traffic on IL 48 and Greenswitch Road is temporarily stopped.

Another consideration for this reroute is the fraction of vehicles that are going to show and can be taken off at the IL 121 interchange. This needs to be known to estimate whether this particular reroute will indeed reduce the queues at IL 48. Moreover, the reroute should also ensure that a queue on I-72 EB does not form at the interchange with IL 121. First, the densities on the road segments were analyzed around the IL 121 interchange and then the number of vehicles that can be rerouted at this location were estimated.

It can be seen from Figure 12 and Figure 13 that the densities on the road segments just downstream of the I-72 exit ramps at the IL 121 interchange stayed in the range

between one-fifth and two-fifths of jam density at the beginning of the day's data collection. From 7:30 a.m. onward, the densities on these road segments did not increase. By 7:40 a.m. on Day 1, the road segment of IL 121 between I-72 WB ramp and Mound Road had decreased to a level that is less than one-fifth of the jam density, and this did not change for the remainder of the day's data collection period. On Day 2, however, this road segment stayed at average density values between one-fifth and two-fifths of jam density for the majority of the data collection time period. This suggests that there was still some vehicular storage space available on these road segments.

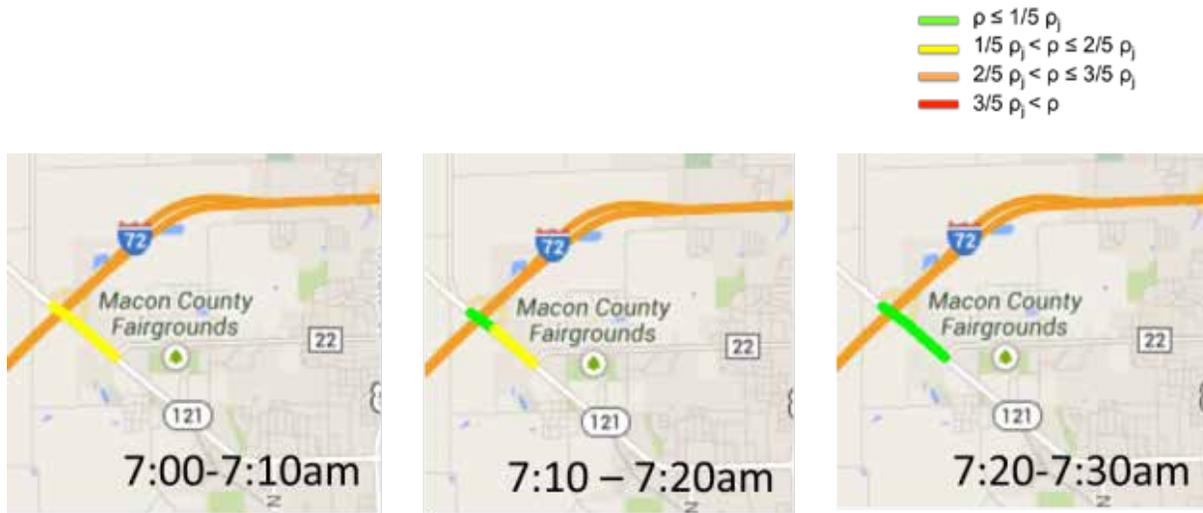


Figure 12. Evolution of densities  $\rho$  relative to the jam density  $\rho_j$  on August 27, 2013, on L 121 around the interchange with I-72.

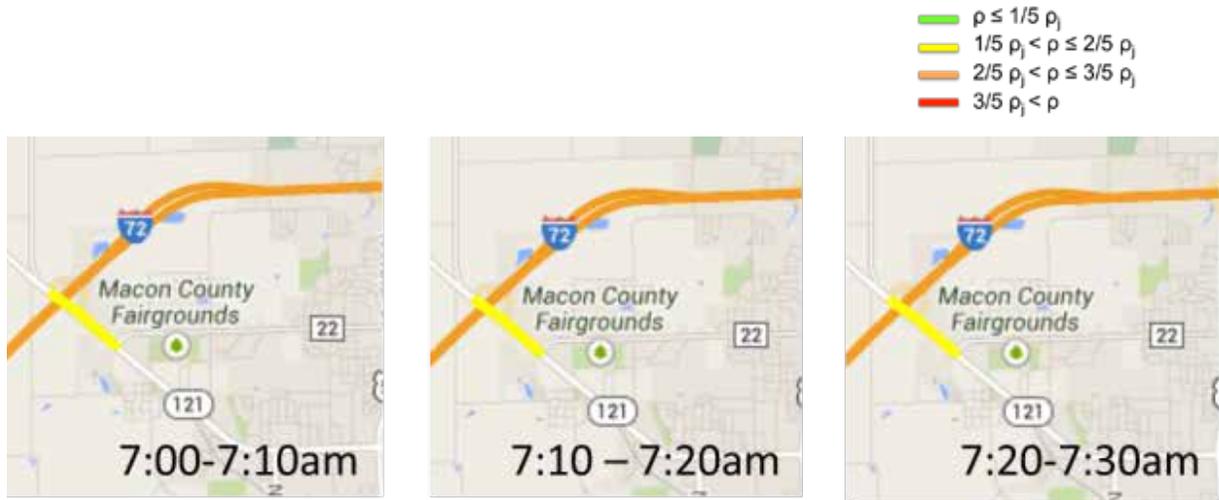


Figure 13. Evolution of densities  $\rho$  relative to the jam density  $\rho_j$  on August 28, 2013, on IL 121 around the interchange with I-72.

Now, in order to check how much traffic can potentially be pulled off I-72 EB at the interchange with IL 121, the total turning movement counts and the arrival rates at the counting locations located at I-72 WB and I-72 EB ramps and the intersection of IL 121 and Mound Road were analyzed. Figure 14 and Figure 15 define the flows, and the following equation estimates the amount of traffic that can be taken off at this interchange.

$$q_1 = q_3 + q_{1R} - (q_{2EL} + q_{2WR})$$

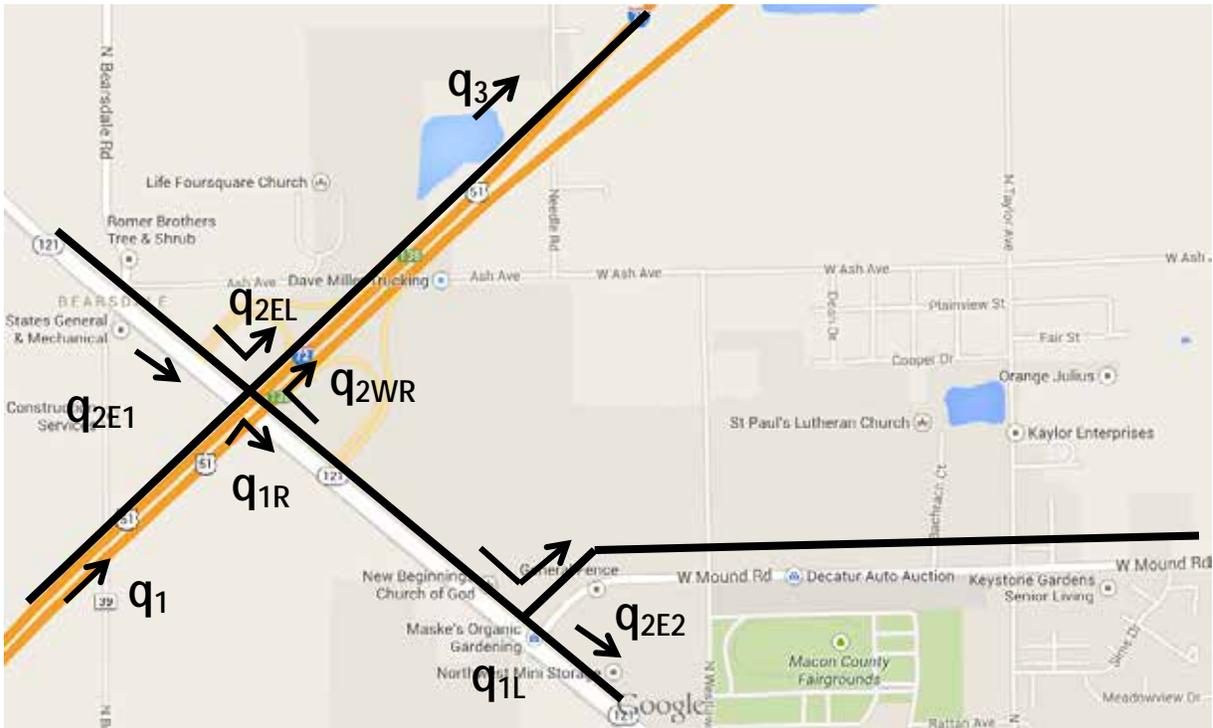


Figure 14. Definitions of flows of traffic from the west.

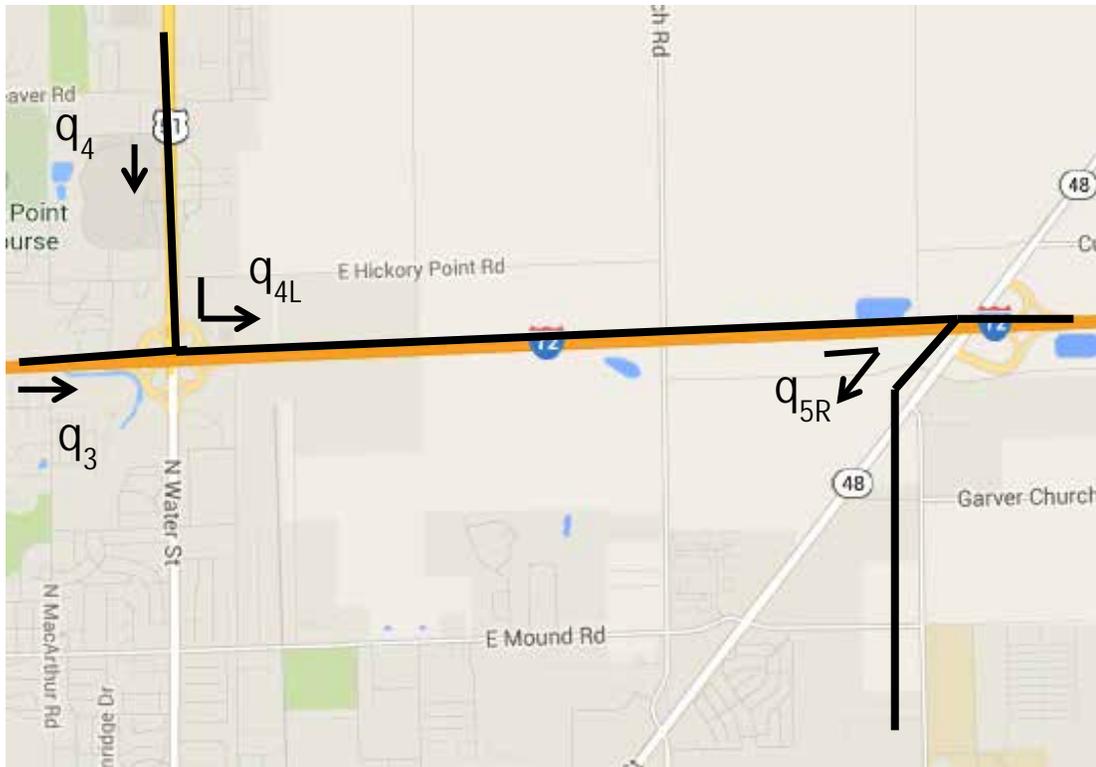


Figure 15. Definition of flows from the west and north.

In the analysis, flows mean the total number of vehicles that were counted as part of a stream of traffic.

It was found that  $q_1 = 3515$  vehicles on Day 1 and  $q_1 = 3515$  vehicles on Day 2. Out of these vehicles, we must estimate the fraction that is going to the show,  $q_{1,show}$ . In order to do so, the following relationship can be set up:

$$q_{1,show} = q_{5R} - q_{4L} + q_{1R}$$

Note that the quantity  $q_{4L}$  was not available because of human error in the data. One data collection associate collected data on the wrong stream of traffic at that location.

The assumption made to calculate  $q_{1,show}$  is that most vehicles from the stream  $q_{1R}$  are heading to the show. This is a reasonable assumption because it was observed that  $q_{2E1}$  and  $q_{2E2}$  are similar and  $q_{1L}$  and  $q_{1R}$  are similar.

Because the exact value of  $q_{4L}$  is not known, the upper and lower bounds of the value and an upper and lower bound on  $q_{1,show}$  were calculated. Suppose,  $q_{4L}$  is negligibly small, then most vehicles that exited I-72 EB at IL 48 would have passed through the IL 121 interchange. In order to calculate the highest value of  $q_{4L}$ , it is assumed that the saturation flow rate of the entrance ramp onto I-72 EB from US 51 is equal to the saturation flow rate of a single lane road, which is, in ideal situations, assumed to be 1900 veh/hr. The bounds on the number of vehicles going to the show on I-72 EB just upstream of the IL 121 interchange are given by:

$$950 \leq q_{1,show} \leq 2850$$

A reasonable assumption that can be made about  $q_{1,Show}$  is that it follows the same distribution as  $q_3$ . Figure 16 and Figure 17 show the estimated arrivals of the vehicles going to the show if a complete reroute is instantiated.

Now, one may check whether this reroute will create a queue on I-72 EB at the IL 121 interchange because this is an undesirable situation. In order to do this, the peak flow with the reroute in effect just downstream of the I-72 EB exit at IL 121 can be checked and also whether this number breaches the capacity of the roads involved in the reroute.

The peak flow rate of eastbound vehicles on IL 121 just downstream of the I-72 EB exit is approximately 1200 veh/hr. Now, it may be checked whether the ramp has a flow rate capacity high enough to support the inflow of vehicles. Because the ramp exits onto IL 121 and show-bound vehicles must take a left turn from the ramp onto IL 121, the calculation of the flow rate capacity of this movement must be done with a left turn adjustment factor.

Equation 10.5 in Garber and Hoel (2002) is used to calculate the capacity. This equation holds for signalized intersections and is used because a major reroute would require some type of control (possibly manual control) in order to ensure that show-bound vehicles can safely take left turns onto IL 121 from the I-72 EB ramp. The capacity is calculated under the condition of a shared left turn lane with protected left turns. The estimated capacity of the intersection is calculated to be 1277 veh/hr. The detailed calculation of this value is provided in Appendix E.

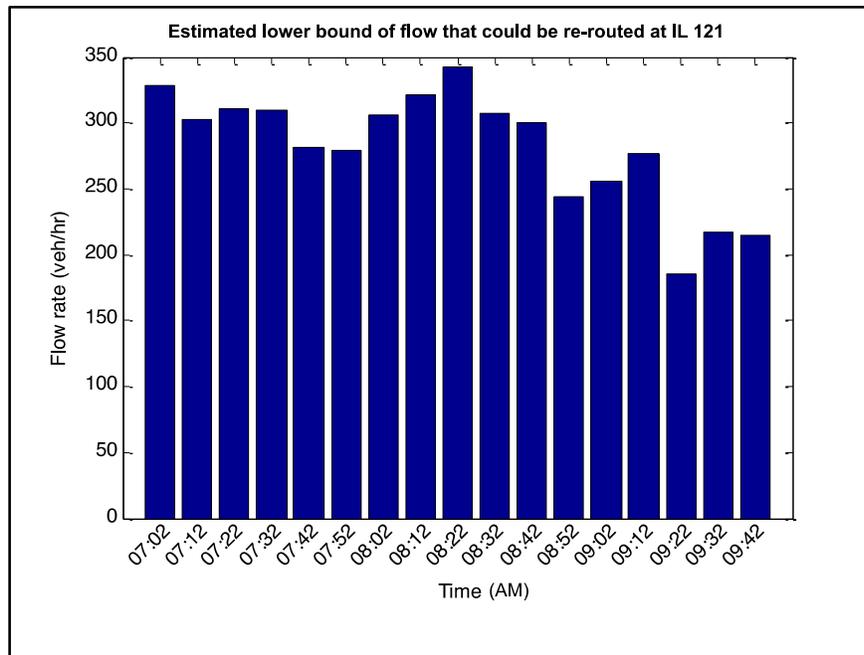


Figure 16. Estimated lower bound of flow that could be rerouted at the IL 121 interchange on August 28, 2013.

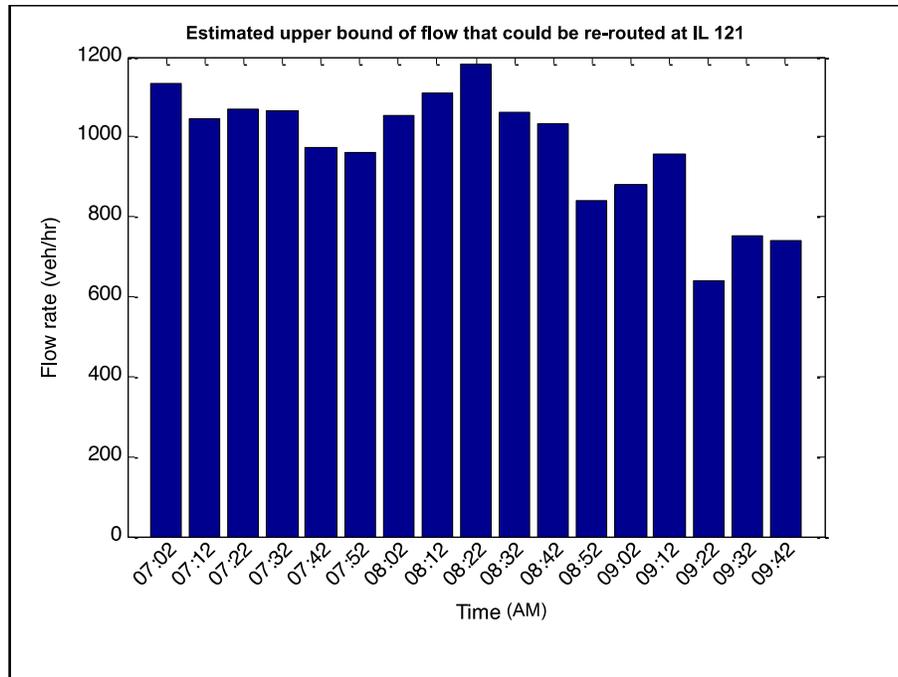


Figure 17. The estimated upper bound of flow that could be rerouted at the IL 121 interchange on August 28, 2013.

Other calculations of capacity are also required here because it must be ensured that the entire route has a capacity high enough to support the inflow of vehicles from both I-72 EB and IL 121 EB.

The capacity of the intersection at IL 121 and Mound Road is calculated using Equation 10.5 from Garber and Hoel (2002). This quantity is calculated with the assumption of a one-lane road because all show-bound vehicles must take a left at Mound Road and therefore it would be unreasonable to assume that more than one lane can be used for vehicles taking a left turn. Again, it is assumed that the intersection would need to be controlled to manage the large number of left turns onto Mound Road from IL 121. The saturation flow of left turns at this intersection is estimated to be at most 1805 veh/hr. The detailed calculation is provided in Appendix E. The green time (the amount of time for which a particular maneuver receives a green signal during a traffic signal cycle) will depend on the control strategy being used, but it can be assumed that the fraction of green time at the intersection given to this maneuver will be proportional to the number of left turn maneuvers. Therefore, assuming that the non-show-bound traffic remains the same, the fraction of show-bound vehicles  $f$  has the bounds  $0.49 \leq f \leq 0.74$ . Thus, the capacity is at least 900 veh/hr and up to a maximum of 1336 veh/hr.

The calculations show that the capacity of the intersections on IL 121 under ideal conditions is not reached at the EB exit ramp of I-72 at IL 121.

However, these calculations assumed that all rerouted vehicles take the recommended route, which is not realistic. If it is assumed that the same fraction of vehicles that took the recommended route at the Argenta Road exit of I-72 WB takes this particular reroute (approximately 65%), then, we expect the route to easily have a flow capacity high enough for show-going vehicles. Thus, a queue is not likely to build if the reroute is

instantiated, provided that there is some form of traffic control implemented at these two major turns in the route that does not reduce the estimated capacities.

The next intersection to consider along this route is the intersection of US 51 and Mound Road because it was in high demand throughout the two days of data collection. A significant amount of traffic passed the intersection on US 51 in the north-south directions and a reroute will increase the demand on the intersection even further. The intersection was operating close to its capacity during the data collection duration and therefore we estimate its capacity to be the maximum flow rate observed at the intersection during data collection.

This value is approximately 3000 veh/hr over all directions of traffic. The highest flow rate in one direction of traffic flow was from the north and the value was 1350 veh/hr and this is estimated to be the maximum possible flow of traffic through the intersection for any given direction. However, the intersection also must serve the demand of north-south traffic on US 51, which is significant. This will most likely reduce the maximum possible flow rate of traffic on Mound Road. One way to estimate the maximum possible flow rate of rerouted show-bound traffic at this intersection is to subtract the maximum flow rate observed in the north-south directions from the capacity of the intersection. This value is approximately 990 veh/hr.

Because the flow rate of show-going vehicles upstream of this intersection is anywhere between 900 veh/hr and 1277 veh/hr, a queue could form on Mound Road just upstream of the intersection with US 51.

Assuming that this queue can be allowed to form and that the flow rate of rerouted vehicles on Mound Road through the intersection with US 51 is approximately 990 veh/hr, the length of the queue can be estimated by calculating the vehicle storage capacity of the road segment between I-72 WB exit at IL 121 and the intersection of US 51 and Mound Road. The vehicle storage capacity of this road segment is approximately 930 veh/hr. This value is calculated in Appendix F.

Thus, with the highest possible flow of show-bound traffic on Mound Road, the length of the queue is predicted to reach the I-72 WB ramp at IL 121 in slightly over two and a half hours. This has a low likelihood of happening because the peak arrival rates of show-bound vehicles only exist for a short period of time.

#### **4.5.2 Mitigating the Queue on I-72 EB Upstream of the Exit at IL 48**

Another important aspect of this project is to study the queue formation on I-72 EB just upstream of the exit ramp onto IL 48, because this situation causes a major safety concern. Therefore, it is now checked whether the formation of the queue can be mitigated by using a reroute of traffic on I-72 EB at IL 121.

As shown previously, the upper and lower bounds of show-bound traffic on I-72 EB upstream of IL 121 are 2850 vehicles and 950 vehicles, respectively. We also know that a total of 2520 vehicles exited I-72 EB at IL 48 and were all likely going to the show. The capacity for left turns from I-72 EB ramp onto IL 48 is estimated to be 1092 veh/hr, because this was the highest flow rate observed at this intersection over the two days of data collection. It was observed that this intersection was being controlled in such a way that the intersection operated at maximum capacity for long periods of time; therefore, this is a good estimate.

In the current scenario, the maximum arrival rate of vehicles is 1250 veh/hr. This value is measured at the Greenswitch Road overpass on I-72 EB. Because, this is higher than the capacity of the intersection, a queue is formed.

The best-case scenario for the reroute at IL 121 is that there are 2850 show-bound vehicles that can be potentially rerouted and approximately 65% that can follow the reroute, assuming that there are a negligible amount of vehicles turning onto I-72 EB from US 51 and going to the show. In this case, it is estimated that 997 vehicles will take the exit at Route 48 and the maximum flow will be 495 veh/hr. This can be serviced comfortably by the intersection of I-72 EB ramp and IL 48.

In the worst-case scenario, a significant amount of traffic turns left from US 51 onto I-72 EB and goes to the show. In this case, there will be an estimated 950 vehicles available to be rerouted at IL 121, out of which 65% would follow the recommended reroute. This implies that with the reroute instantiated, 2232 vehicles would take the IL 48 exit from I-72 EB with a maximum arrival rate flow of approximately 1100 veh/hr. This is close to the capacity of the intersection and a queue is likely to form, but it is the worst-case scenario.

Therefore, a reroute at IL 121 of show-bound traffic on I-72 EB would reduce the likelihood of a queue forming at the IL 48 exit.

#### **4.3 TRAFFIC FROM THE EAST AND SOUTH**

The main routes into the show from the east are shown in Figure 18. They include:

1. Follow I-72 WB and exit at Argenta Road. Then, turn onto Oakley Road southbound till Cerro Gordo Blacktop. Then, turn onto Reas Bridge Road westbound;
2. I-72 WB and exit at IL 48. Turn onto Brush College Road southbound; and
3. Oakley Road northbound towards Angle Crossing Road. Turn onto Reas Bridge Road westbound.

The routes as numbered above are illustrated in Figure 18.

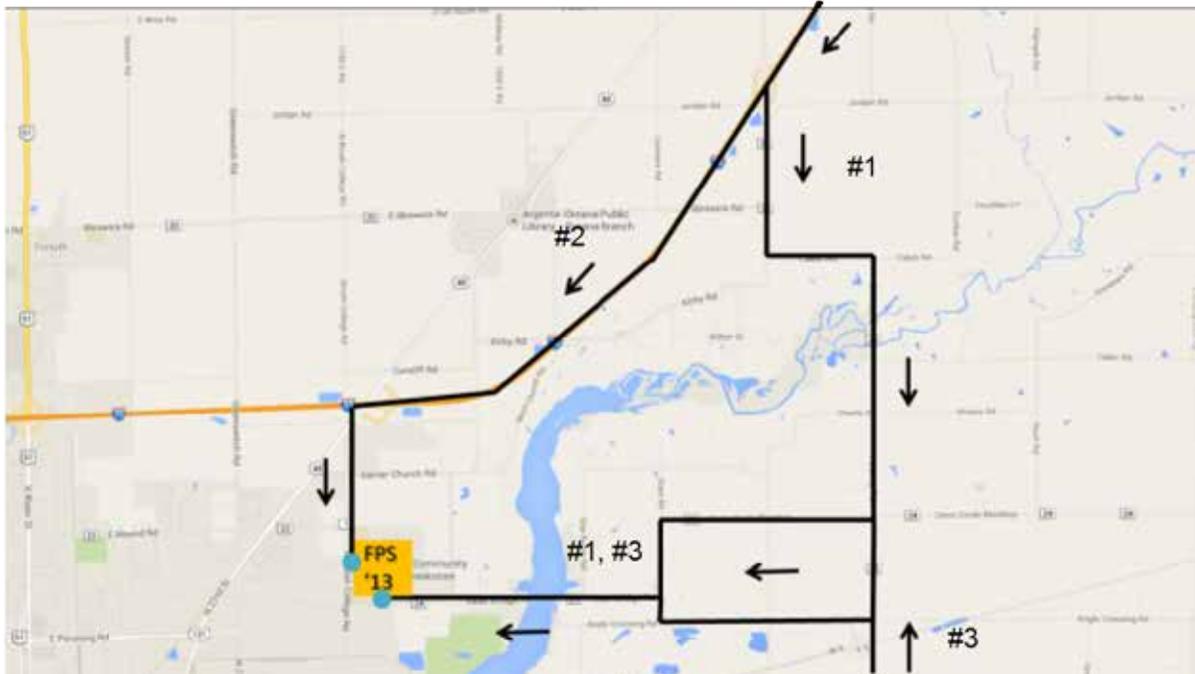


Figure 18. The eastern and southern approaches to the show.

Most of the traffic on the eastern and southern approaches arrives from the east on I-72 WB (approximately 70% of all show-bound traffic). The recommended route for vehicles travelling to the show on this road is to take the exit at Argenta Road and follow signs through Oakley Road onto Reas Bridge Road. Additionally, there is another stream of show-bound vehicles that enter Oakley Road from the south.

As it can be seen in Figure 19 and Figure 20, the most congested 30 minute intervals on these approaches are the first 30 minutes of data collection on both days. After these 30 minutes, this route becomes progressively less congested. The majority of the roads had average densities that are less than one-fifth of the jam density. This suggests that there is more capacity on this route that could be used.

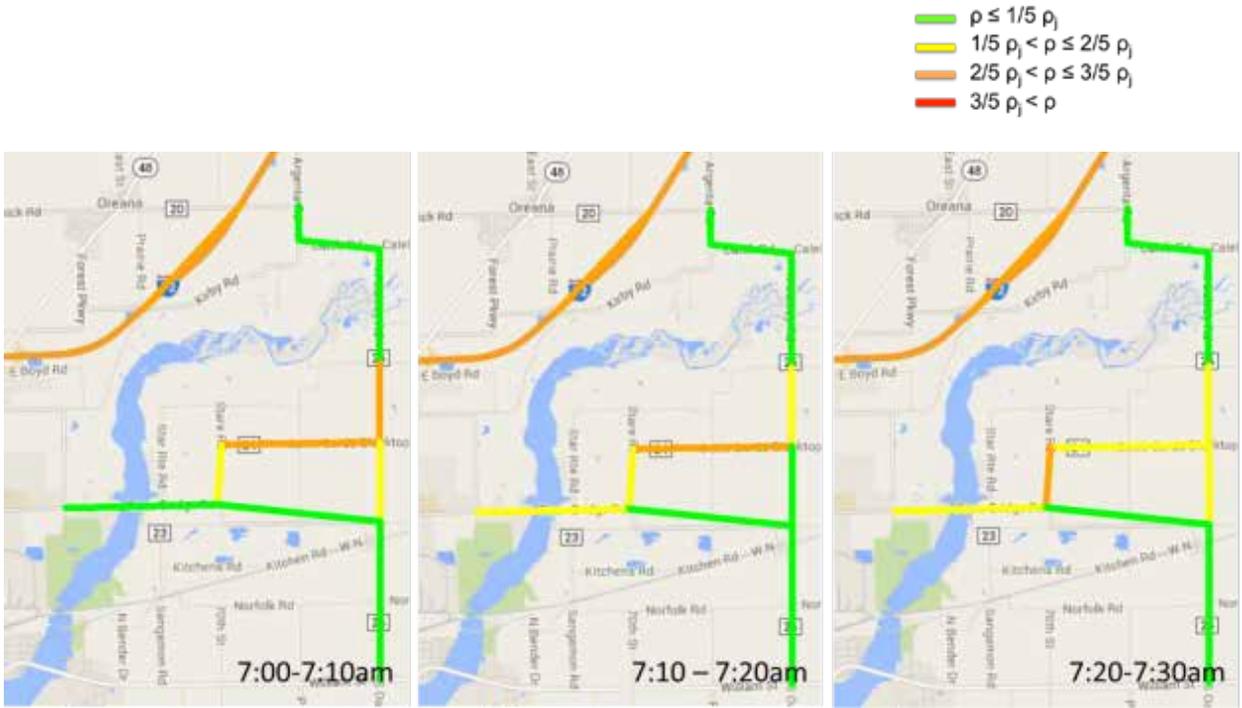


Figure 19. The most congested 30 minutes on the eastern and southern approaches to the show on August 27, 2013.

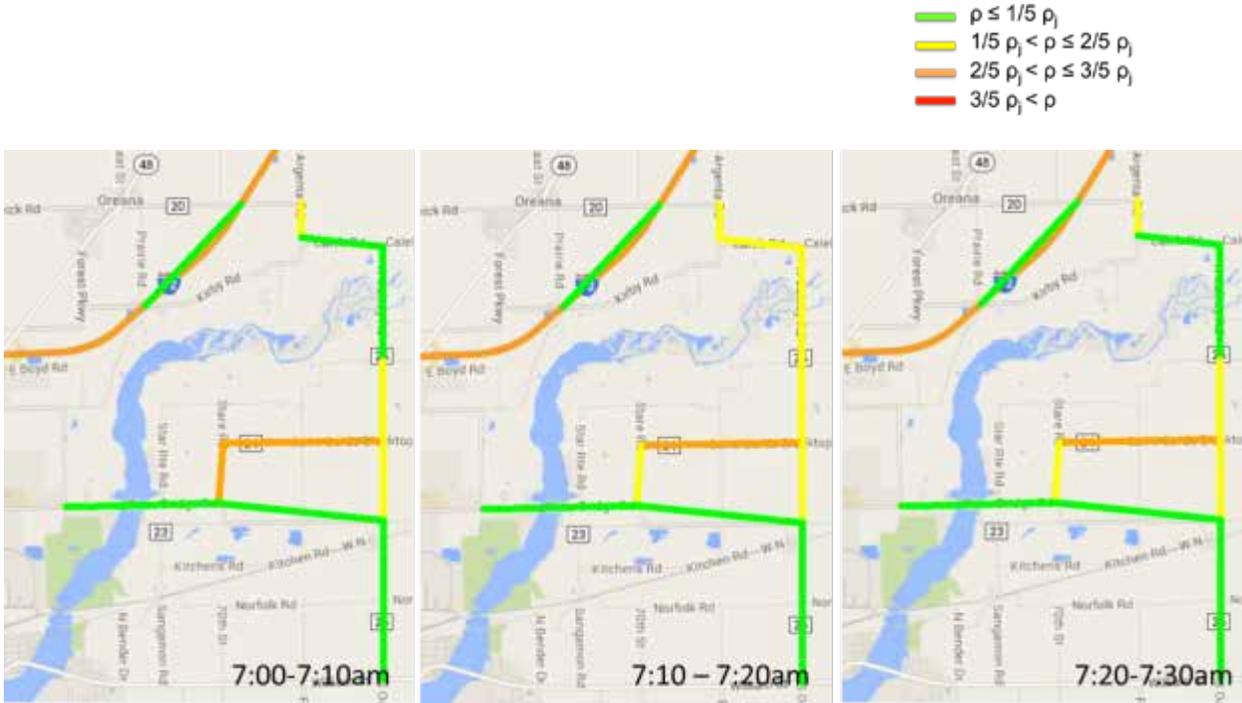


Figure 20. The most congested 30 minutes on the eastern and southern approaches to the show on August 28, 2013.

The utilization of this vehicle storage capacity depends on the amount of traffic that follows the recommended route to the show from the east.

The collected data suggests that only 65% of show-bound vehicles took the recommended route on both days of data collection. The rest of the show-bound traffic takes the exit at the IL 48 interchange. This is not ideal because this congests the already highly demanded Brush College and IL 48 roadways and potentially increases the queuing on the exit ramps from I-72 onto IL 48. In order to check whether it is possible to have all show-bound traffic take the recommended route without activating a new bottleneck, the demand and the vehicle storage capacity along the route can be estimated.

The demand at the Argenta exit in the case where all show-going traffic from the east takes the recommended route is shown in Figure 21 in terms of flow rates. The data collected at the intersection of Argenta Road and Illiniwick Road (Figure 22 and Figure 23) was taken as a proxy for the show-bound traffic taking the Argenta exit because data was not collected on Argenta Road at the I-72 WB exit ramp. It was assumed that the number of vehicles that joined Argenta Road from the north of the I-72 WB exit ramp remains the same as on the measured days. It also was assumed that the distribution of arrival rates at the Argenta Road remains the same.

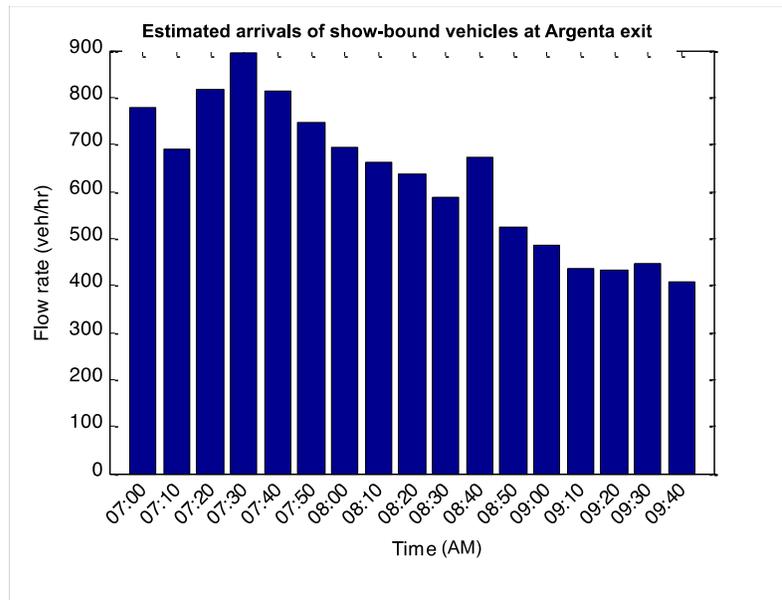


Figure 21. The estimated arrivals onto Argenta Road from I-72 WB if all show-bound vehicles followed the recommended route.

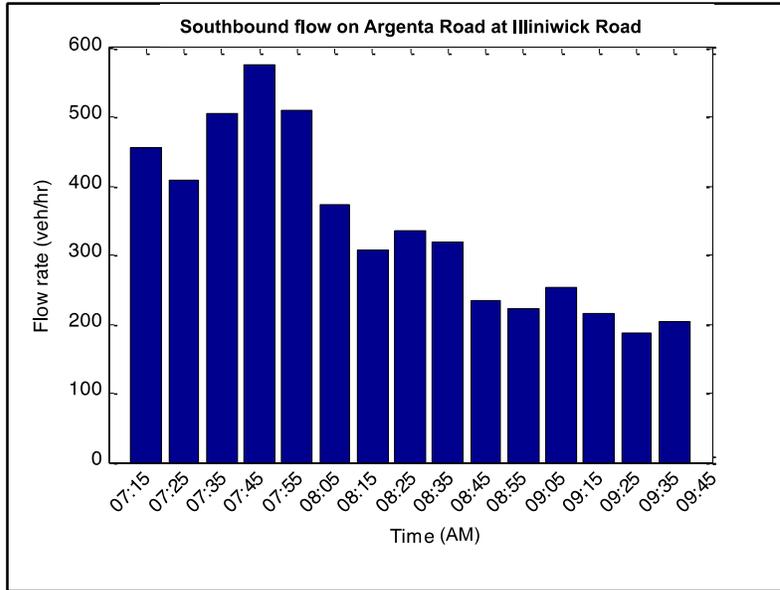


Figure 22. Southbound flow on Argenta Road at Illiniwick Road on August 27, 2013.

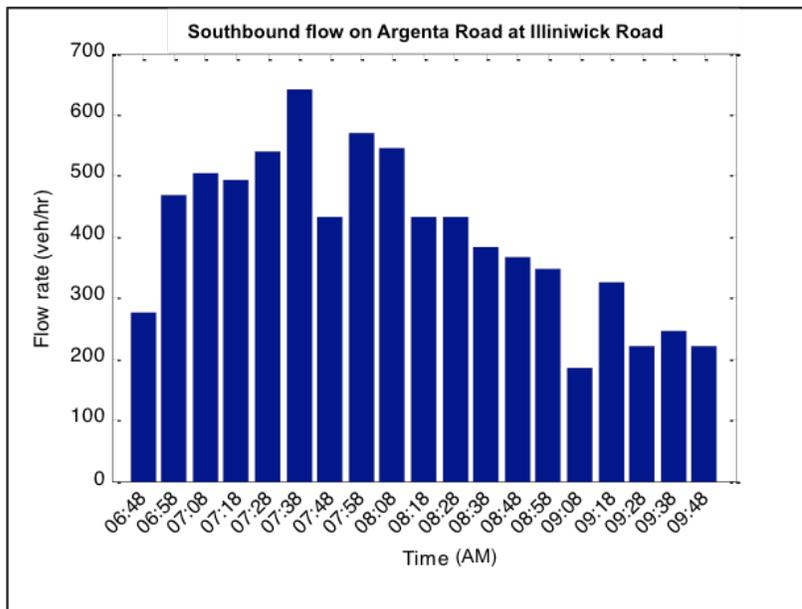


Figure 23. Southbound flow on Argenta Road at Illiniwick Road on August 28, 2013.

The number of show-bound vehicles over the entire data collection period was estimated to be 1857. This is 129% of the vehicle storage capacity in the route between I-72 WB exit ramp on Argenta to the intersection of Stare Road and Reas Bridge Road (calculated in Appendix F). Therefore, at one time, all vehicles taking the Argenta Road exit will not fit between the I-72 WB ramp on Argenta Road and the intersection of Reas Bridge Road and Stare Road. However, the time required to fill the entire route to jam density is

approximately 2 hours, which is a long enough time interval for a large majority of vehicles to traverse the 8.2 mile route.

On the days of data collection, the densities on the road segment just upstream of the Argenta exit on I-72 WB are shown in Figure 24 and Figure 25. On both days, the highest densities are seen at the beginning of the data collection period. On Day 1, the average density is between one-fifth and two-fifths of the jam density between 7:15 a.m. and 8:45 a.m. Then, the density is less than one-fifth of the jam density for the remainder of the data collection period. On Day 2, we saw a higher density at the beginning of data collection. For the first half hour of data collection between 7:00 a.m. and 7:30 a.m., the density on the road segment just upstream of Argenta exit on I-72 WB was between two-fifths and three-fifths of the jam density. Then, for the next 50 minutes, the density is between one-fifth and two-fifths of jam density. After 8:20 a.m., the density decreases to less than one-fifth of jam density for the remainder of the data collection for the day. These figures suggest that there is a moderate amount of congestion at the approach to this exit on Day 2, while on Day 1 there is relatively less congestion.

If all vehicles headed to the show took the recommended route, more congestion would be expected in this road segment. In order to check the magnitude of flow that can be serviced by this exit ramp without causing long queues, the potential capacity of the intersection between the I-72 WB ramp and Argenta Road can be checked.

For this calculation, it is assumed that the majority of traffic on the ramp is show-bound and is turning left from the exit ramp onto Argenta Road. This is a reasonable assumption because on both days of data collection, this fact has held true.



Figure 24. A visualization of the average density on the road segment just upstream of Argenta exit on I-72 WB on August 27, 2013.

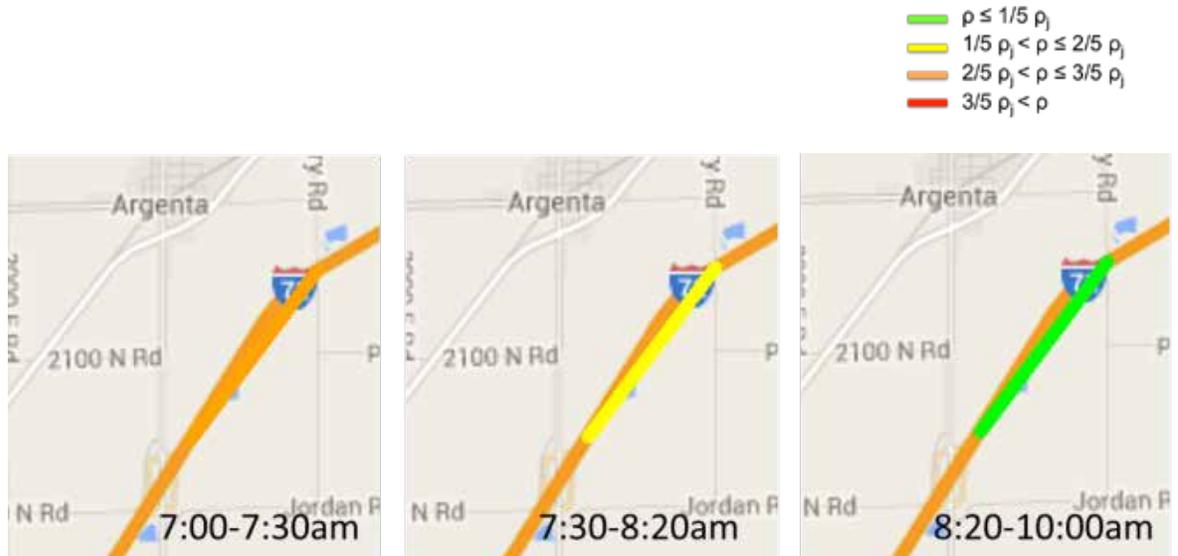


Figure 25. A visualization of the average density on the road segment just upstream of Argenta exit on I-72 WB on August 28, 2013.

Appendix E has a detailed description of the calculation performed. The capacity of the intersection was estimated to be 817 veh/hr. Therefore, this intersection is not capable of handling all show-bound vehicles arriving from the east on I-72 WB during the peak flow times. However, the estimated peak flow rate of show-bound vehicles was approximately 900 veh/hr and the peak flow occurred only for a short period of time between 7:20 a.m. and 7:50 a.m. Therefore, most vehicles would still be able to use this recommended route. In fact, it is estimated that up to 90% of vehicles can take the recommended route while not exceeding the capacity of the intersection of the I-72 WB exit ramp at Argenta Road.

## **CHAPTER 5      EVALUATION OF THE TECHNOLOGY**

### **5.1 TASK DESCRIPTION**

This section reports on the effectiveness, pros and cons of TrafficTurk, and its potential for more widespread use.

### **5.2 TASK OBJECTIVES**

The tasks associated with evaluating the technology include:

- Data collection on the functionality of the TrafficTurk application including data latency and energy efficiency.
- Scalability issues to support larger deployments.
- Recommendations on how to reduce deployment costs and the amount of logistical support needed.
- Recommendations on how the application and the supporting back-end infrastructure can be generalized to support fast deployment throughout the country.
- Possible future use cases and associated development challenges.

### **5.3 FUNCTIONALITY OF THE TRAFFICTURK APPLICATION**

Analysis of the functionality of the TrafficTurk application is important to inform future deployments of the technology. The analysis will specifically focus on studying the data latency and the energy efficiency of the application on smartphones.

#### **5.3.1 Data Latency**

The data latency of a TrafficTurk data record is defined as the time taken for a data record to be saved in the TrafficTurk database after it has been recorded on the application. In order to be able to do any kind of real-time analysis, the data latency has to be low. However, events such as the Farm Progress Show induce a high demand on the cell phone network over which TrafficTurk has to send its data. This causes slow transfer rates across the network. This is a known issue and TrafficTurk has been developed with this in mind. During the data collection at the Farm Progress Show, data latency numbers for every swipe made on the application were specifically collected. This allows us to evaluate the data latency in an actual field deployment.

Other factors that determine the data latency is whether the counting locations are in areas where the cell phone network reception quality is good. Some data collection associates were assigned to intersections away from the center of town, and their data was predicted to have higher data latency if the cell phone coverage was sparse or non-existent. As part of the testing of TrafficTurk prior to the Farm Progress Show, it was validated that each intersection had cell phone coverage. However, because of practical considerations, we could not validate that all intersections had adequate coverage on all cell network providers. The data latency also depends on whether the data collection associates turn on the data connection on their devices. Although the counters were instructed to turn on the data connections while counting, several counters turned off the data connection while counting either because they forgot to turn it on, or because they were not aware that it was turned off.

Figure 26 and Figure 27 show the cumulative distribution of data saved in the database as a function of latency. In other words, these plots show how much of the data reached the database with less than a given latency, in minutes. The plots show that almost 85% of data on both days made it to the database within 3 minutes of data collection. By the end of the first day of data collection, (10:00AM) the database had over 90% of the data that was collected up to that time. The remainder of the data came in later on during the day when data collection associates connected to the Internet on their phones (for example, via Wi-Fi). A couple of data collection associates actually did not connect to the Internet until after the second day of counting. By the end of the second day of counting (10:00AM), 98% of the data collected had been saved in the database. The remainder of the data was collected by manually connecting each of the phones that had not sent data to the Wi-Fi network at the Macon County Highway Department when data collection associates came to collect their compensation for the experiment.

These results are encouraging because a large majority of the data being collected was saved in the database relatively quickly considering that the Farm Progress Show created a very high demand for cell phone networks and that many data collection associates were in counting locations far away from the center of the town.

Possible ways to improve the data latency are to ensure that all data collection associates have their data connection switched on during the experiment. Alternatively, portable wireless hotspots could be set up in central locations or driven around by field support event managers to periodically gather data saved on the phones that are not connected to their data service.

Finally, it was also discovered that the data transmission protocol within TrafficTurk could fail to reconnect to the server if the application had been running for several hours. Because the data are locally saved on the phone until it receives acknowledgment of a successful transfer to the database, no data was lost. Moreover, the data was transferred to the server as soon as the application was restarted. Based on this possible failure scenario, the data transmission protocol has been upgraded to avoid this potential problem in future deployments.

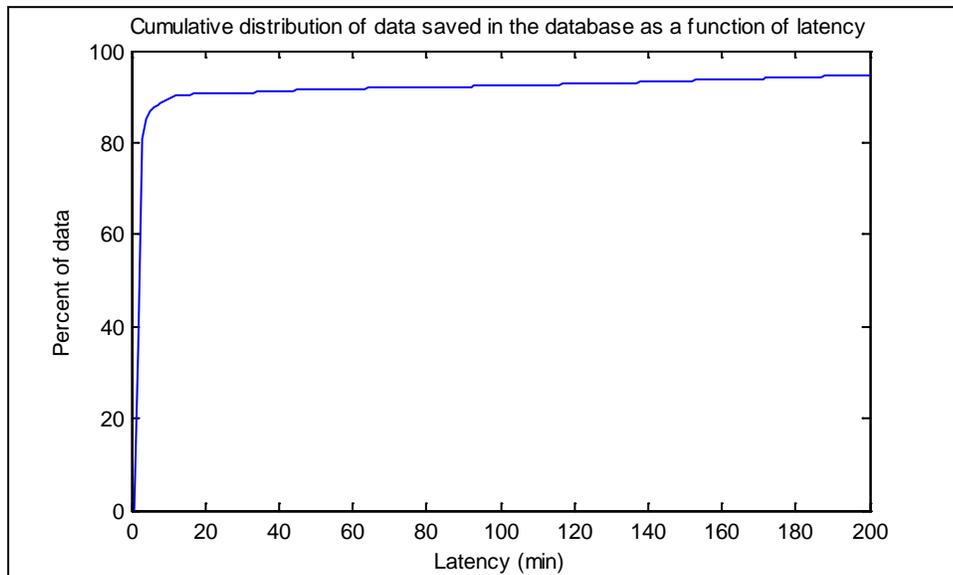


Figure 11. This plot shows the cumulative amount of data that has been saved in the database for a given value of latency on Day 1.

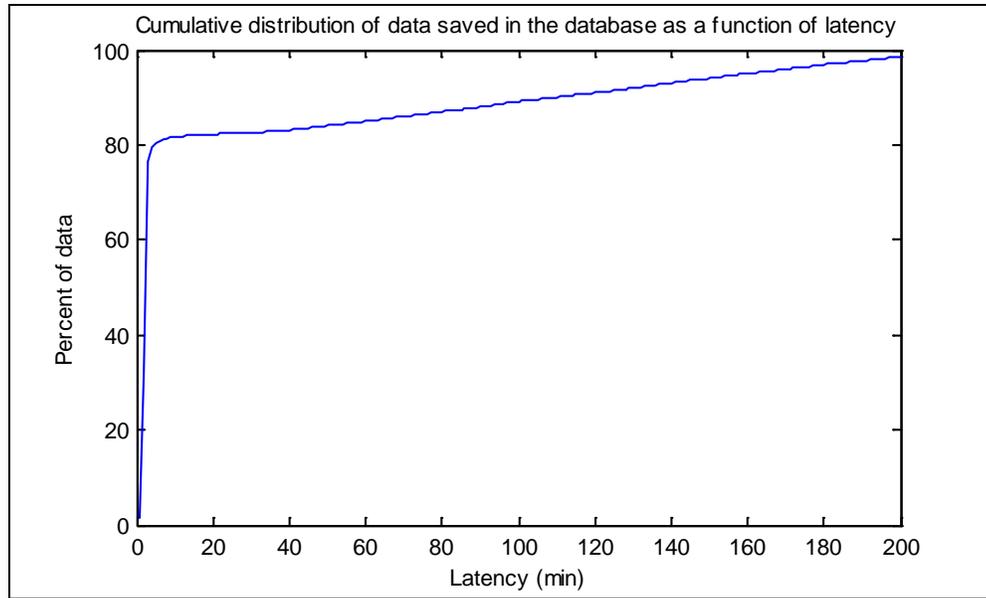


Figure 12. This plot shows the cumulative amount of data that has been saved in the database for a given value of latency on Day 2.

### 5.3.2 Energy Efficiency

It is important to monitor the energy efficiency of the application on smartphones to assess whether the application can be deployed for long periods of time without an external power source. By design, the application is moderately energy intensive because the phone screen is continuously on. As part of the application upgrades for this test, a number of battery life optimizations were performed to improve the energy efficiency.

The factors that influence the battery life of a phone when running TrafficTurk range from the size of the battery on the phone to the type of phone and the age of the battery. Therefore, a large number of phones with different manufacturers and different ages of batteries is required to reliably test the energy efficiency of the application.

As of the previous large-scale TrafficTurk deployment, it had been found that the application could run continuously on a new, fully charged phone for approximately three hours. The Farm Progress Show deployment offered a good chance to test the improvements that were made since the last deployment.

For this test, the average starting battery life over all data collection associates was 94.08% on Day 1 and 94.25% battery life on Day 2. The average ending battery life was 60.82% on Day 1 and 65.57% battery life on Day 2. However, many data collection associates had access to an external power source during the test and therefore the overall average battery drain is not a good indicator of energy efficiency. Figure 28 shows the battery life as a function of time for a phone that was not plugged in to an external power source, while Figure 29 shows a the battery life for a user who started charging their phone around 9:20 a.m. A total of 19 data collection associates on Day 1 and 17 data collection associates on Day 2 used an external power source to charge their phones while they were collecting data.

Therefore, we looked at the average starting and ending battery lives of data collection associates who never plugged their phone into an external power source for recharging and collected data for the entire three-hour period between 7:00 a.m. and 10:00

a.m. The average starting battery life of data collection associates who did not plug their phones into an external power source and collected data for the entire duration on Day 1 was 95.25% and the average ending battery life was 51.66%. On Day 2, these values were 95.36% and 46.21%, respectively. The highest battery drain over all data collection associates on Day 1 was 68% and on Day 2 was 70%. The lowest battery drain over all data collection associates on Day 1 was 20% and on Day 2 was 21%.

The average battery drain over three hours over both days is approximately 46% over three hours. Therefore, we estimate that the application can run on a phone continuously for over 6 hours, which is a significant improvement in energy efficiency compared with earlier versions of the application. Longer counting periods would also need to explore counter fatigue in addition to battery limitations.

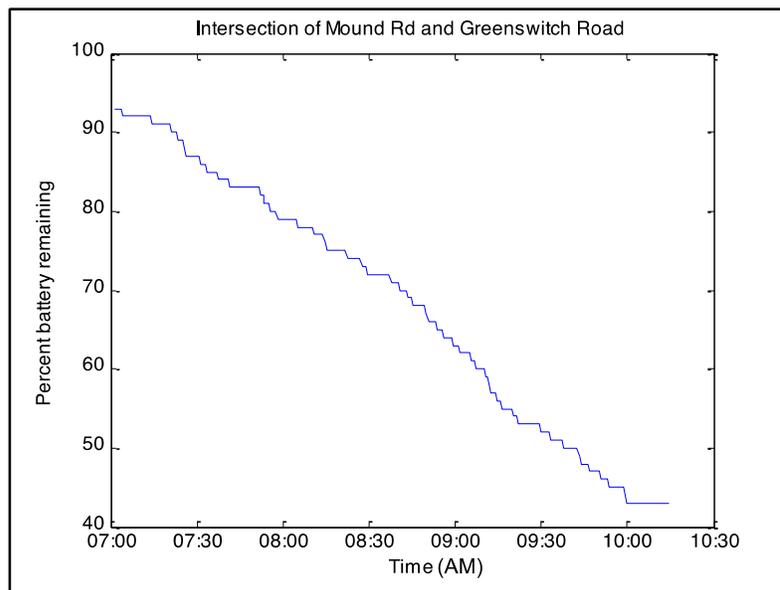


Figure 28. Battery life over time of a data collection associate who never plugged his or her phone into an external power source during a day's data collection period.

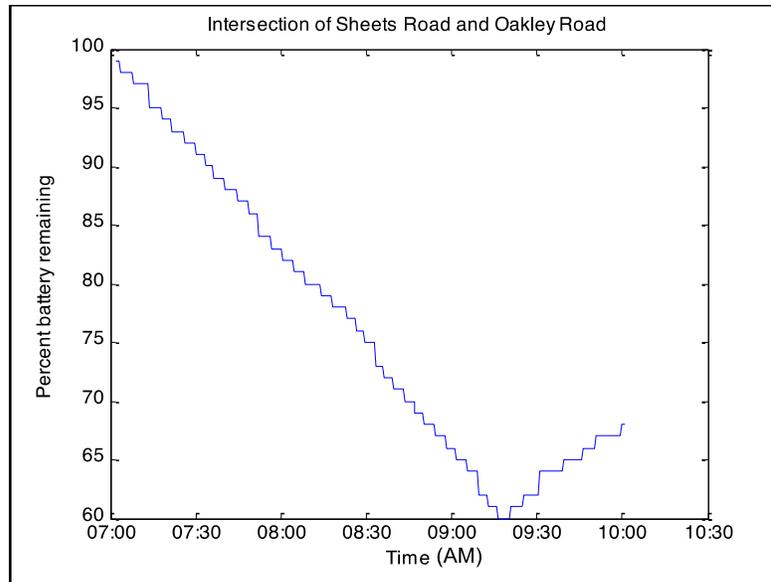


Figure 29. Battery life over time of a data collection associate who plugged his or her phone into an external power source during a day's data collection period.

## 5.4 SCALABILITY

The scalability of the TrafficTurk system to larger deployments and larger geographical areas is important for IDOT because this technology must have the capability to be easily deployed where and when it is required. This section describes current scalability issues and provides recommendations and plans for improving the scalability in the future.

### 5.4.1 Geographical Scalability

One of the key features of the TrafficTurk technology is its ability to collect data on an underlying map, so the data becomes easier to analyze after it has been collected. This feature also allows data to be collected by individuals who do not have a formal training in transportation engineering, because it allows the application to display street names at each intersection and prevents data collection associates from facing the wrong direction at the intersection. Moreover, the data collection associates do not have to enter the exact location or orientation of their recorded data before or after data collection and this makes the data collection process much simpler. The map also provides knowledge of the traffic network that can be used for prediction and control of traffic in real-time, although these algorithms are still under development.

The current underlying map used in TrafficTurk is a free, open-source, and crowd-sourced map called OpenStreetMap (<http://www.openstreetmap.org>). Because all digital maps have errors, OpenStreetMap provides a set of tools to quickly correct problems in the map through its website. Moreover, because OpenStreetMap is free and open source, it allows deployment of TrafficTurk anywhere in the world without paying data licensing fees.

However, the challenge in geographical scalability with this map is the enormous size of the map data. This is a major challenge because the application must be able to download and process the required map data when a new region of the world needs traffic

data collection. This is not a trivial process because the system has to pre-process the map and then create intersections and roads within the TrafficTurk database in a short amount of time. Another challenge with the OpenStreetMap data is that it is constantly changing. New roads and intersections are being added and corrected every day. Therefore, it must be ensured that any data collected on an old version of the map is not invalidated when a new map version is released.

Although the current TrafficTurk servers are capable of handling statewide deployment of TrafficTurk, deployment across the country for use by other DOTs will require some optimizations to the back-end infrastructure. Currently, scalability improvements to support TrafficTurk deployments anywhere in the United States are being explored.

#### **5.4.2 Deployment Scalability**

The largest deployment of TrafficTurk so far has been approximately 120 sensors in Urbana-Champaign during the 2012 University of Illinois homecoming football game. The deployment at the Farm Progress Show was 31 sensors. However, the eventual goal of TrafficTurk is to be able to be deployed at whatever scale is needed to track event-based congestion.

These deployments bring with them some issues of scale that must be investigated in order to make the TrafficTurk technology viable for widespread use. Because the technology relies on humans to collect and monitor data, efficient systems to recruit, train, support, and compensate data collection associates and event managers could further reduce the cost of data collection.

Thus far, the different strategies to recruit people that have been used include in-person recruitment at college campuses, fliers, mass emails through university list-serves, and advertisements in local newspapers and local TV and radio channels. These methods have supported deployments of up to 150 individuals. However, moving forward, strong social media campaigns can also be used to recruit people.

Training of data collection associates is always necessary when deployments are using the help of the general public to collect traffic data. These training sessions are used to reinforce the importance of safety and punctuality for the deployment. Training sessions generally accommodate about 15 people each and are about 45 minutes in length. However, this requirement can be greatly reduced with the introduction of in-application tutorials that let the user learn how to use the application as well as guide them through the safety considerations and punctuality requirements of the deployment. This feature is something that could be incorporated into the application in the future.

Another bottleneck with large deployments is the ability to compensate data collection associates for their work. Currently, data collection associates have been paid in cash at a central location in the area where data was collected. For larger deployments, online payment systems, such as credit to large online retailers or online payment platforms such as PayPal or Google Wallet, could be set up to compensate data collection associates remotely. This system will also require the development of algorithms to definitively assess the quality of the data before compensation is made.

Finally, all deployments rely on a team of event managers to provide support to data collection associates over the phone and in the field. This team is also trained and equipped with the necessary tools to provide support such as backup phones, phone chargers, computers, and cars/bicycles. For larger deployments of TrafficTurk where the general public is recruited to collect data, in-person support may not be feasible. However, more robust tutorials and troubleshooting help documents contained with the application and on

the TrafficTurk website will ensure that data collection associates can solve common issues independently. Moreover, a more developed monitoring system can help a small team of event managers to remotely predict issues and inform data collection associates through the application to take preventive action. For example, if an individual's phone battery is draining at a rate that will not let them collect data for the entire data collection period, the event managers may be able to send them a push notification that alerts them to the issue and recommends a course of action.

## **5.5 POTENTIAL FUTURE USE CASES**

The TrafficTurk system was designed as a way to quickly and inexpensively deploy traffic sensing infrastructure when and where it is required. More specifically, TrafficTurk was designed to be able to handle large pre-planned events that induce atypical traffic congestion such as sporting and cultural events and unplanned atypical traffic congestion caused by extreme weather or natural disasters. Currently, there are no comparable technologies available to acquire network-wide traffic conditions during events at the level possible with TrafficTurk. Improvements to the process of recruiting and deploying data collection associates could further reduce the costs of collecting data and analyzing it during future events.

In addition to collecting data on event-based traffic, TrafficTurk can also be used for regular traffic data collection for traffic signal optimization, and also for dynamic traffic management during events.

Because TrafficTurk is a turning movement counter, it could serve as a replacement for other turning movement counter boards to improve traffic signal coordination and timing plans. The advantage of using TrafficTurk to do this would be the possibility of collecting the data at multiple intersections simultaneously. Instead of understanding the performance of each signal individually, using TrafficTurk, it is possible to collect data on a network of signals. As was discussed at the October 31, 2013, TrafficTurk progress review meeting, in addition to providing a richer view of the true performance of a corridor, it is also likely to improve the consistency of counts at adjacent intersections. This could make the TrafficTurk application of interest to firms who currently perform traffic studies on behalf of transportation agencies. One barrier to this future use case is the absence of standards requiring firms to collect data at multiple intersections simultaneously.

A longer-term application of TrafficTurk is for prediction and control of traffic during atypical traffic congestion events. The development of real-time estimation algorithms that combine traffic models with data would allow traffic conditions to be estimated continuously throughout an event. Current systems relying on GPS data are often inaccurate during events, because GPS data rates are low, and historical traffic patterns are of limited use to predict event-based congestion. The data provided by TrafficTurk could allow more accurate estimates of the current traffic conditions to aid the commuting public or emergency vehicles.

Finally it could be possible to dynamically reroute traffic based on current traffic conditions. For example, the traffic congestion estimates could be used to inform future Farm Progress Show commuters of the best route to the show. If the freeway is uncongested, there is no need to reroute vehicles. The re-routing could be adjusted based on the real-time traffic conditions. Similarly, if a queue starts to form, the traffic control at various intersections on the main routes to the show could be coordinated to improve the throughput of the show-bound traffic. Obviously, these extensions would need future research and development before they could be field tested.

## CHAPTER 6 CONCLUSION

The goal of this project was to collect traffic data with TrafficTurk over the road network in Decatur between 7:00 a.m. and 10:00 a.m. on August 27 and 28, 2013, which is the time of peak traffic congestion during the Farm Progress Show. The TrafficTurk data was analyzed to infer the arrival rates over the network and to check the possibility of re-routing traffic to avoid congestion on I-72. Finally, the project tested the functionality of the TrafficTurk application.

The deployment of TrafficTurk at the Farm Progress Show 2013 was the third large-scale deployment for the TrafficTurk technology. During the deployment, a total of 178,162 vehicles were recorded over more than 182 person-hours of data collection. From this data, the arrival rates from all directions approaching the show were determined. An algorithm to estimate the densities on each road segment throughout each three-hour period was also proposed and implemented on the collected data.

The results of the preliminary data analysis suggest that there is an opportunity to reroute traffic successfully from I-72 EB at IL 121 through Mound Road and to the show. To ensure successful re-routing of traffic, traffic controllers such as police officers must be placed on IL 121 at the intersections of the I-72 EB ramp and Mound Road, so that the capacity of these intersections is fully utilized.

It was also observed that the recommended route for show-bound vehicles from the east does not have the required capacity for all show-bound vehicles, but rather only 90% of them. Currently, only 65% of show-bound traffic takes the recommended route. As a consequence, it is possible for another 25% of the show-bound vehicles to take the recommended detour, which would further mitigate congestion near the IL 48 exit.

In terms of the feasibility of the TrafficTurk application for future deployments, the main result is that TrafficTurk can be used to reliably collect traffic data during events at many points on the road network, which has historically been very difficult. The study found that TrafficTurk could be improved to efficiently recruit, train, and compensate data collection associates to make future monitoring applications easier to deploy. Tools such as tutorials for data collection associates, automatic error detection, automated payment protocols, and automated event management tools will greatly enhance the scalability and quality of the TrafficTurk technology. In addition, back-end systems can be upgraded to support quick deployment of the application anywhere in the country.

Another potential future use for the application is the collection of turning movement counts for the creation of traffic signal coordination and timing plans where the counts are collected simultaneously over an arterial or urban network.

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## APPENDIX A TRAFFICTURK APPLICATION TESTING

Table A.1. Results of Application Test at Counting Locations

Street 1	Street 2	Parking spot location	Safe place to sit/stand and count traffic? (Yes/No)	Preferred counting location	Wireless network quality (0-5)*	TrafficTurk app displays intersection correctly? (Yes/No)
72 WB Exit Ramp	IL 48	Farm northeast of this intersection	Yes	Any corner on grass	4	Orientation screen is not correct
72 EB Exit Ramp	IL 48	Gas station south of this intersection	Yes	Any corner on grass	4	Orientation screen is not correct
Brush College	IL 48	Gas station north of this intersection	Yes	Any corner	4	Yes
IL 51	Forsyth	Gas station north of this intersection	Yes	Any corner	4	Yes
I-72	Argenta	Grass on any corner of this intersection	Yes	Any corner	3	Yes
I-72	Bloomington	Park in grass surrounded by ramps	Yes	On the back slope of I 72. Hard to get there, though	4	Yes
I-72	Cemetery	Park somewhere on grass beside cemetery road	Yes	Walk to I72 backslope to count	2	Yes
I-72	Greenswitch	Park on Greenswitch and Boyd	Yes	Walk to I72 (two pics are taken as a guide)	3	Yes
I-72	Illiniwick	Park on the grass of Illiniwick	Yes	Walk to I72 backslope to count	3	Yes
I-72	Kirby	Park on Prairie road	Yes	Walk to I72 backslope to count	3	Yes
I-72 WB Exit Ramp	IL 121	Shoulder or grass	Yes	backslope of greenway	3	Yes
I-72 EB Exit Ramp	IL121	Shoulder or grass	Yes	backslope of greenway	3	Yes
Argenta	Caleb	grass nearby	Yes	Any corner of intersection	3	Yes
Argenta	Illiniwick	Park on grass nearby	Yes	Any corner of intersection	3	Yes
Brush College	College Park	Park on grass nearby	Yes	Any corner of intersection	4	Yes
Brush College	Garver Church	Park on grass nearby	Yes	Any corner of the intersection	4	Yes
Brush College	Mound	Big intersection, no parking nearby	Yes	Any corner of this intersection	4	Yes
Brush College	Reas Bridge	Big intersection, no parking nearby	Yes	Any corner of this intersection	4	Yes
Christmas Tree	Reas Bridge	Grass nearby	Yes	Any corner of this intersection	4	Yes

\*Wireless call quality determined by reading the signal strength directly off of a Samsung SIII. A score of 0 corresponds to no service.

(table continues next page)

Mound	22nd	Get dropped off	Yes	Any corner of this intersection	4	Yes
Mound	Greenswitch	Parking is hard to find	Yes	Any corner of this intersection	4	Yes
Mound	Water	Restaurant	Yes	Any corner of this intersection	4	Intersection name wrong (it's part of US 51, but it changes its name to N water street. In the app it is US 51 business)
Mound	IL 121	On grass nearby	Yes	Any corner of the intersection	3	Intersection name wrong (shown in app as Pershing Road; it should be IL Route 121)
Oakley	Angle Cr.	On grass nearby	Yes	Any corner of the intersection	3	Yes
Oakley	Caleb	On grass nearby	Yes	Any corner of the intersection	1	It's called County Highway 25 instead of Caleb in the app
Oakley	Cerro Gordo Blktop	On grass nearby	Yes	Count on any corner of this intersection	1	Yes
Oakley	Sheets	Parking on the grass nearby in the farm	Yes	Any corner of the intersection	1	Yes
Oakley	William	Parking on the grass nearby in the farm	Yes	Any corner of the intersection	3	Yes
College Park	Reas Bridge	Grass nearby	Yes	Any corner of the intersection	4	Yes
Stare	Cerro Gordo Blktop	Parking on the grass nearby	Yes	Count on any corner of this intersection	3	Yes
Stare	Reas Bridge	Parking on the grass nearby	Yes	Count on any corner of this intersection	3	Yes

## **APPENDIX B RECRUITMENT MATERIALS**

### **PURPOSE OF THE STUDY**

This study is a large-scale traffic data collection experiment. The goal of the experiment is to understand traffic flow during the Farm Progress Show. This experiment also tests the possibility of collecting traffic data through a crowd-sourced mobile application called TrafficTurk, which is being developed at the University of Illinois at Urbana-Champaign. The data will improve our understanding of citywide traffic flows during events and will lay the foundation for next generation participatory traffic monitoring systems worldwide.

### **REQUIREMENTS FOR PARTICIPATION IN THE STUDY**

- You must be over the age of 18.
- You must have access to an Android smartphone that runs Android 2.3 or higher.
- You will be asked to collect traffic data by recording swipes into the TrafficTurk application on your mobile phone at an intersection in Decatur, Illinois, on the morning of August 27, 2013, and/or August 28, 2013, between 7:00 a.m. and 10:00 a.m.
- You must attend a training session where researchers will help you to install the application onto your device. Training sessions are available on the following dates:
  - August 20, 2013, at 5:30 p.m.
  - August 20, 2013, at 7:00 p.m.
  - August 21, 2013, at 5:30 p.m.
  - August 21, 2013, at 7:00 p.m.

### **COMPENSATION**

You will be paid \$50 for each 3 hour counting session that you participate in. Students of the University of Illinois at Urbana-Champaign who are participating in the experiment will be provided transportation to Decatur from campus and back in addition to an extra \$20 per counting session to offset the time cost of travel.

You will receive compensation after the completion of the experiment. You must complete all of the required activities (i.e., attend a required training session, collect data from 7:00 a.m. to 10:00 a.m. on August 27, and/or August 28 at your assigned intersection) to receive compensation.

As an added bonus, you will also receive an awesome T-shirt!

### **NEXT STEPS**

Sign up using the registration form.

If you are selected to participate, you will receive an email before August 19, 2013. Note that preference will be given to people who are available to count on both days of the experiment. This email will also outline the next steps towards becoming a TrafficTurk Data Associate at the Farm Progress Show 2013.

## ONLINE SIGN-UP FORM

### Traffic Turk Experiment: Volunteer Information

By filling out this form, I am volunteering to participate in traffic data collection for the Farm Progress Show 2013 with Traffic Turk. I recognize that space is limited, and my spot is not guaranteed until I receive a confirmation email from [TrafficTurkExperiment@gmail.com](mailto:TrafficTurkExperiment@gmail.com).  
**\* Required**

**First Name \***

  
**Last Name \***  
**What kind of phone do you have \***  
e.g. Samsung Galaxy S3, HTC Hero, LG. (please be as descriptive as possible)  
**What version of Android are you running \***  
If you do not know the Android version you are running, you can find out by going to 'Settings' and 'About Phone' on your device. Note: this may vary from phone to phone.

4.1 or higher ▾

**Carrier \***

Verizon ▾

**What is your favorite mobile phone game? \***  
Angry birds, Fruit Shoot, etc, or I don't play games on my phone!  
**Cell phone number \***  
For contacting you during the experiment only. We need to be able to reach you during the event if there are problems.  
**How good is your battery? \***

Figure B.1. The sign-up form used on the TrafficTurk website used to recruit data collection associates. The live form is available at <http://goo.gl/MbLPFe>.

## APPENDIX C FLOW RATES OVER TIME AT CRITICAL INTERSECTIONS

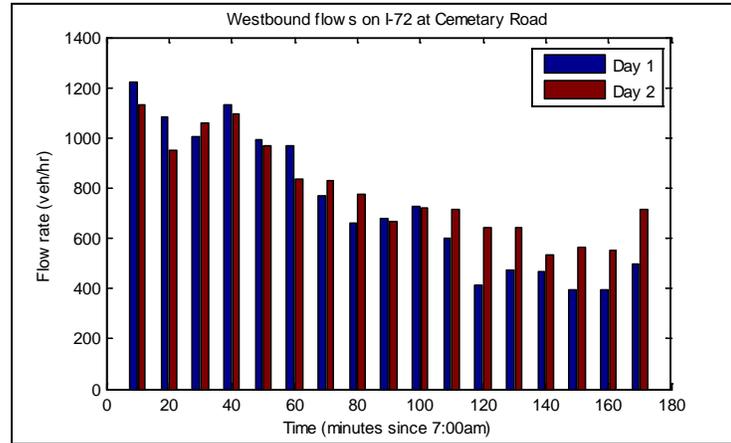


Figure C.1. The flows from the east on I-72 WB at Cemetery Road in 10-minute intervals.

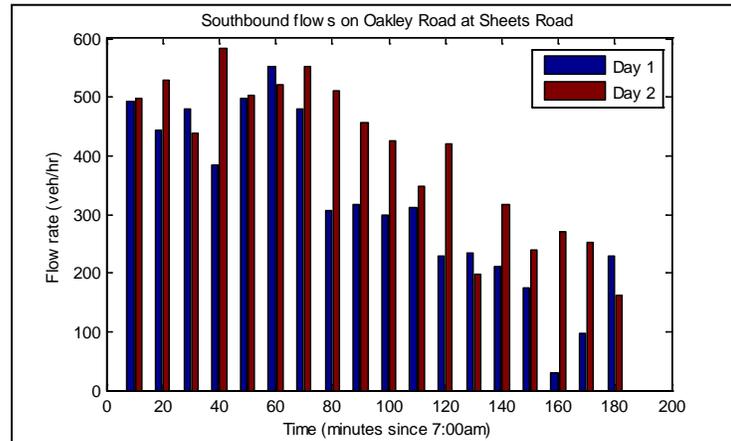


Figure C.2. The flows from the north on Oakley Road at Sheets Road in 10-minute intervals.

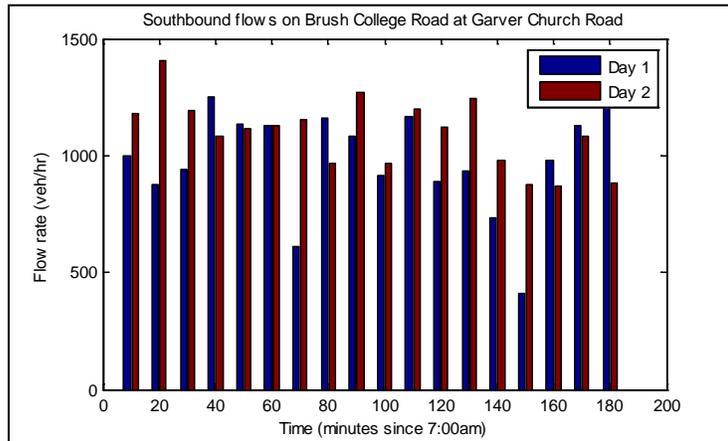


Figure C.3. The flows from the north on Brush College Road at Garver Church Road in 10-minute intervals.

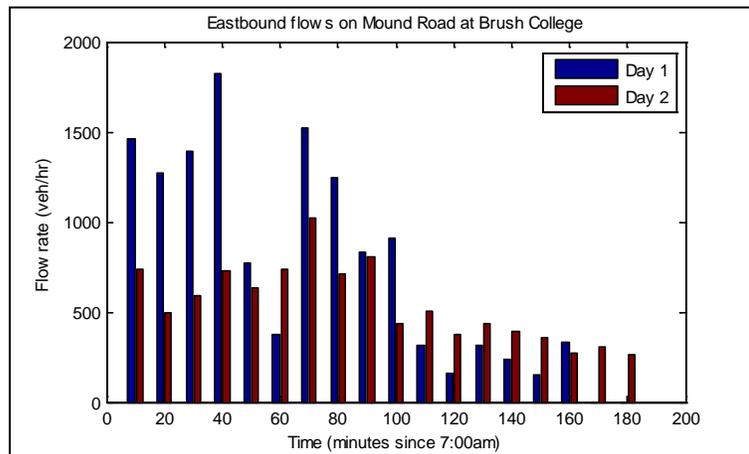


Figure C.4. The flows from the west on Mound Road at Brush College Road in 10-minute intervals.

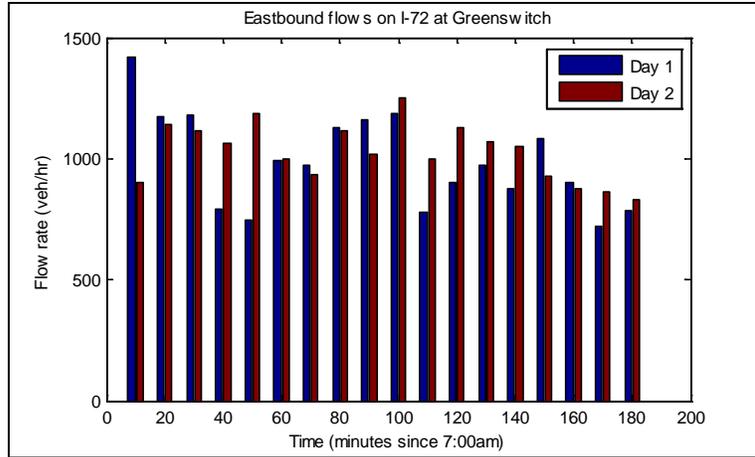


Figure C.5. The flows from the west on I-72 at Greenwich Road in 10-minute intervals.

## APPENDIX D NORMALIZATION OF DATA

### D.1 METHODOLOGY

In this section, the methodology used to normalize the data and calculate the estimated densities on road segments during the data collection period is described. The following describes the setup of the optimization problem that is solved in order to normalize the data.

Consider a link (stretch of roadway)  $l$  with an upstream data collection associate  $i$  and a downstream data collection associate  $j$ . Let  $s_l(k)$  denote the number of vehicles stored on the link at discrete time  $k$ , and let  $q_{in}^i(k)$  and  $q_{out}^j(k)$  denote the number of vehicles entering and exiting the link from time  $k$  to  $k + 1$ . The number of vehicles on the link at time  $k + 1$  can be computed as the sum of the number of vehicles  $s_l(k)$  at time  $k$  plus the number of vehicles that enter the link from time  $k$  to  $k + 1$ , minus the number of vehicles exiting the link over the same time interval. If we assume each data collection associate is biased to under count or over count vehicles at the intersection, we allow a correction factor  $\delta_i$  and  $\delta_j$  to scale the inflows and outflows of the link. Then, for each link, the following equation must hold:

$$s_l(k + 1) = s_l(k) + \delta_i(q_{in}^i(k)) - \delta_j(q_{out}^j(k)) \quad \forall i, j, k \text{ and } l,$$

Moreover, we know that the storage of vehicles on a link cannot be negative and it cannot exceed the maximum storage capacity of the link  $c_l$ . Therefore, we introduce the constraints,

$$0 \leq s_l(k) \leq c_l \quad \forall i, j, k \text{ and } l,$$

where  $c_l$  is the capacity of link  $l$ , which can be calculated based on the physical properties of the road segment including the link length and number of lanes. Additionally, we impose the constraint that  $\delta_i$  cannot be negative.

$$0 \leq \delta_i \quad \forall i.$$

We assume that the data collection associates are fairly accurate, so we expect most of the values of  $\delta_i$  to be close to 1, but unknown a priori. In addition, we can also reasonably assume that the vehicle storage on all links at the end of the data collection time period is low. Keeping this in mind, we can build the objective function and write the optimization problem for a network with  $n$  data collection associates and  $m$  links as:

$$\begin{aligned}
& \min_{\delta, s} \quad \sum_{i=1}^n (1 - \delta_i)^2 + \gamma \sum_{l=1}^m [s_l^*(k_f) - s_l(k_f)]^2 \\
& \text{subject to:} \\
& \quad s_l(k+1) = s_l(k) + \delta_i(q_{in}^i(k)) - \delta_j(q_{out}^j(k)) \quad \forall i, j, k \text{ and } l \\
& \quad 0 \leq s_l(k) \leq c_l \quad \forall k \text{ and } l \\
& \quad 0 \leq \delta_i \quad \forall i,
\end{aligned}$$

where  $s_l(k_f)$  is the desired vehicle storage on link  $l$  at the final timestep  $k_f$ , and  $\gamma$  is a weighting factor. The optimization problem solves for the correction factors  $\delta_i$  that are close to 1, while keeping the final storage on each link close to  $s_l(k_f)$ . It guarantees mass is conserved with the corrected flows, and that the storage on each link is nonnegative but under the total storage capacity of each link.

## D.2 RESULTS

The normalization is run across all links on the network simultaneously, and the results of the normalization have been visualized in videos named *08272013\_0715-1000hrs\_HD.wmv* and *08282013\_0700-1000hrs\_HD.wmv* for the two days of the show respectively, and can be found in the Dropbox folder (Gowrishankar and Work 2013). This visualization shows the vehicle storage evolution on road segments in the network over time. The vehicle storage levels have been displayed as green, yellow, orange, and red road segments on the map. These colors represent the following vehicle storage levels:

- Green represents vehicle storage values of less than one-fifth of the maximum vehicle storage capacity the road segment.
- Yellow represents vehicle storage values of greater than one-fifth but less than two-fifths of the maximum vehicle storage capacity.
- Orange represents vehicle storage values between two-fifths and three-fifths of the maximum vehicle storage capacity.
- Red represents values of more than three-fifths of the maximum vehicle storage capacity the road segment.

## **APPENDIX E INTERSECTION CAPACITY CALCULATIONS**

### **E.1 INTERSECTION OF I-72 EB RAMP AND IL 121 AS A SIGNALIZED INTERSECTION WITH A PROTECTED LEFT TURN PHASE**

Equation 10.5 from Garber and Hoel (2002) is used, where the number of lanes  $N$  is taken to be 1, and  $f_{LT}$ , the left turn adjustment factor is calculated assuming that the ramp is a shared left turn lane with protected phasing, because the ramp also serves vehicles that turn right and we assume that there will be some form of traffic control at this intersection. We also assume that the amount of non-show vehicles remains the same as in our dataset and therefore, the proportion of vehicles taking left turns is 97.6%.

Equation 10.5 yields an  $f_{LT}$  value of 0.672. This in turn yields an intersection capacity of 1277 veh/hr.

### **E.2 INTERSECTION OF IL 121 AND MOUND ROAD AS A SIGNALIZED INTERSECTION WITH A PROTECTED LEFT TURN PHASE**

We use Equation 10.5 from Garber and Hoel (2002) where the number of lanes  $N$  is taken to be 1, and  $f_{LT}$ , the left turn adjustment factor is calculated assuming that there is an exclusive left turn lane with protected phasing, because we assume that there will be some form of traffic control at this intersection.

A  $f_{LT}$  value of 0.95 is used for exclusive lanes with protected phasing and therefore the intersection capacity is estimated to be 1805 veh/hr of green time for the left turns from Route 121 to Mound Road.

### **E.3 INTERSECTION OF ARGENTA ROAD AND I-72 WB EXIT RAMP**

For this intersection, we use Equation 17-3 from TRB's *Highway Capacity Manual* (2000) to estimate the potential capacity of an unsignalized intersection. This is a measure of the maximum number of vehicles that can be accommodated under ideal conditions. It is derived using the gap acceptance model.

We assume a critical gap of 7.1 seconds and a follow up time of 3.5 seconds, which are the base values for a left turn from a minor street. We approximate the total conflicting volume as 154 veh/hr from the data collected at the intersection of Argenta Road and Illiniwick Road. This is calculated by summing the northbound flow and the estimated southbound flow from Argenta Road north of the I-72 WB exit ramp and taking the highest flow rate seen in a 10-minute time interval.

The potential capacity of the intersection of I-72 WB exit ramp and Argenta Road is calculated to be 817 veh/hr.

## APPENDIX F    MAXIMUM QUEUE LENGTH CALCULATION

### F.1 ROUTE FROM I-72 EB RAMP AT IL 121 TO THE INTERSECTION OF MOUND ROAD AND US 51

This route can be divided into two parts. The first part is the road segment of IL 121 from I-72 EB ramp to Mound Road. This part of the route should be considered as a one-lane road because most vehicles are turning left at Mound Road. The second part of the route from the intersection of Mound Road and IL 121 to the intersection of Mound Road and US 51 should be considered to have 2 lanes.

For both of these segments, we assume that the space taken up by a vehicle is approximately equal to 30 feet in one lane and we use the following equation to calculate the vehicle storage capacity vehicles on a road segment:

$$C_{max} = LN\rho_{max}$$

where  $C_{max}$  is the vehicle storage capacity the road segment in units of vehicles,  $L$  is the length of the road in miles,  $N$  is the number of lanes and  $\rho_{max}$  is the jam density in units of vehicles per mile.

For the first part of the route, we calculate the vehicle storage capacity to be 123 vehicles. The second part of the route is estimated to have a vehicle storage capacity of 807 vehicles.

### F.2 ROUTE FROM I-72 WB RAMP AT ARGENTA ROAD TO THE INTERSECTION OF REAS BRIDGE ROAD AND STARE ROAD

This entire road is a single lane road. The length of the route is approximately 8.2 miles. Therefore, we estimate the capacity to be 1443 vehicles using the following equation:

$$C_{max} = LN\rho_{max}.$$

## APPENDIX G TURNING MOVEMENT COUNTS BY COUNTING LOCATION

Table G.1. Turning Movement Counts from August 27, 2013, in the UTDF Format

Counting Location	EBL*	EBR	EBT	NBL	NBR	NBT	SBL	SBR	SBT	WBL	WBR	WBT
I-72 at Cemetery	0	0	920	0	0	0	0	0	0	0	0	2150
I-72 at Illiniwick	0	0	561	0	0	0	0	0	0	0	0	328
I-72 at Illiniwick	0	0	1332	0	0	0	0	0	0	0	0	808
I-72 at Kirby	0	0	945	0	0	0	0	0	0	0	0	719
I-72 at Greenswitch	0	0	3064	0	0	0	0	0	0	0	0	1199
I-72 at Greenswitch	0	0	1145	0	0	0	0	0	0	0	0	2836
I-72 at Bloomington	0	0	3466	0	0	0	0	0	0	0	0	1088
I-72 WB at Argenta Exit Ramp	0	0	0	0	0	0	0	910	1427	0	0	0
IL 121 and I-72 EB Ramp	207	0	886	0	0	0	293	57	0	0	94	670
E Boyd Rd and IL 48	18	65	10	12	18	529	58	97	5464	54	17	13
US 51 and W Forsyth Rd	73	119	132	66	252	767	271	30	2194	277	84	51
County HW 25 and Argenta Rd	0	0	0	0	0	856	14	0	171	1	12	0
County HW 25 and Oakley Rd	1	926	0	161	0	1	0	9	3	0	0	0
William St and N Oakley Rd	78	1	139	6	0	5	18	112	5	0	452	329
Sheets Rd and N Oakley Rd	22	6	1	6	1	155	0	9	981	8	3	2
Cerro Gordo and N Oakley Rd	29	7	45	384	7	70	14	919	83	37	42	138
N Oakley Rd and Angle Cr Rd	15	6	5	100	3	440	3	7	119	3	3	17

\*EBL denotes an eastbound left turn, EBR denotes an eastbound right turn, EBT denotes an eastbound through movement, NBL denotes a northbound left turn, etc.

(table continues next page)

Garver Church Rd and N Brush College Rd	0	1	0	1	7	53	14	80	2961	52	34	0
Argenta Rd and E Illiniwick Rd	24	41	0	103	0	122	0	50	858	0	0	0
N Brush College Rd and Hubbard Ave	4	416	676	519	640	19	214	71	193	61	3	285
Reas Bridge Rd and Stare Rd	62	0	19	0	0	0	2	1709	0	0	3	112
Cerro Gordo and Stare Rd	0	0	0	0	62	5	9	0	19	1630	6	0
E Mound Rd and IL 48	87	61	1122	160	340	611	57	117	569	81	24	111
W Mound Rd and US 51 Business	243	214	812	200	198	1355	755	120	1986	396	119	477
E Mound Rd and Greenswitch Rd	58	24	336	120	229	421	295	34	213	122	422	1217
E Mound Rd and N Brush College Rd	31	1966	236	1	1	3	25	40	2389	34	17	55
Christmas Tree Ln and Reas Bridge Rd	152	22	94	13	7	22	15	80	28	39	253	1458
IL Route 121 and 72 WB Off Ramp	50	0	1073	0	0	0	62	56	0	0	198	574
IL Route 121 and W Mound Rd	322	0	931	0	0	0	25	276	0	0	19	524
IL 48 and N Brush College Rd	0	75	696	24	72	0	0	0	0	3031	0	685
IL 48 and I 72 EB Ramp	0	0	0	0	34	61	0	0	154	413	1	0
I 72 WB Ramp and IL 48	0	0	0	0	198	261	81	0	596	728	25	0
Reas Bridge Rd and College Park	452	0	1088	0	0	0	20	50	0	0	111	268
Reas Bridge Rd and College Park	93	0	158	0	0	0	5	18	0	0	17	59
N Brush College Rd and College Park	0	0	0	0	10	12	58	0	457	19	21	0

Table G.2. Turning Movement Counts from August 28, 2013, in the UDF Format

Counting Location	EBL	EBR	EBT	NBL	NBR	NBT	SBL	SBR	SBT	WBL	WBR	WBT
I-72 at Cemetery	0	0	753	0	0	0	0	0	0	0	0	2345
I-72 at Illiniwick	0	0	946	0	0	0	0	0	0	0	0	1600
I-72 at Kirby	0	0	1600	0	0	0	0	0	0	0	0	975
I-72 at Greenswitch	0	0	3207	0	0	0	0	0	0	0	0	1178
I-72 at Bloomington	0	0	3257	0	0	0	0	0	0	0	0	966
I-72 WB at Argenta Exit Ramp	0	0	0	0	0	0	0	1089	1497	0	0	0
IL 121 and 72 EB Ramp	202	0	922	0	0	0	293	58	0	0	71	707
US 51 and W Forsyth Rd	62	127	142	77	247	744	318	32	2465	295	72	60
County HW 25 and Argenta Rd	0	0	0	0	1	1190	17	0	179	1	13	0
County HW 25 and Oakley Rd	2	1244	0	174	0	9	0	9	5	0	0	0
William St and N Oakley Rd	87	3	161	5	0	6	19	136	8	1	378	343
Sheets Rd and N Oakley Rd	11	7	4	7	3	129	5	11	1224	6	5	1
Cerro Gordo and N Oakley Rd	21	10	46	322	12	66	18	1102	103	39	49	120
N Oakley Rd and Angle Cr Rd	15	8	7	89	1	405	1	10	140	5	2	19
Garver Church Rd and N Brush College Rd	1	1	0	0	9	54	35	17	3265	43	34	1
Garver Church Rd and N Brush College Rd	0	0	0	0	1	11	2	1	414	2	3	0
Argenta Rd and E Illiniwick Rd	19	31	0	93	0	144	0	42	1246	0	0	0
N Brush College Rd and Hubbard Ave	2	470	749	475	823	30	281	80	238	78	0	243
Reas Bridge Rd and Stare Rd	55	0	15	0	0	0	3	1855	0	0	2	96
Cerro Gordo and Stare Rd	0	0	0	0	57	5	5	0	40	1943	4	0

(table continues next page)

E Mound Rd and IL 48	123	62	1214	147	269	623	50	131	573	57	18	114
W Mound Rd and US 51 Business	228	193	782	188	278	1319	790	161	1886	421	131	474
E Mound Rd and Greenswitch Rd	26	23	379	98	229	418	285	42	214	124	430	1278
E Mound Rd and N Brush College Rd	30	1466	180	0	0	7	392	54	2757	29	36	50
Christmas Tree Ln and Reas Bridge Rd	124	23	83	30	13	17	11	76	31	48	255	1564
IL 121 and I-72 WB Off Ramp	44	0	810	0	0	0	54	30	0	0	145	437
IL 121 and W Mound Rd	333	0	946	0	0	0	24	296	0	0	25	529
E Pershing Rd and N Jasper St	0	0	1	0	0	0	0	0	0	0	0	0
US 51 and Schellabarger Rd	0	0	0	0	0	1638	0	1018	2483	0	0	0
IL 48 and N Brush College Rd	0	93	684	17	85	0	0	0	0	3277	0	723
IL 48 and I-72 EB Ramp	0	0	0	0	217	450	5	0	1336	2520	28	0
IL 48 and I-72 WB Ramp	0	0	0	0	185	247	59	0	544	611	6	0
Reas Bridge Rd and College Park	489	0	1266	0	0	0	25	63	0	0	144	248

## APPENDIX H RAW DATA FORMAT

The raw data from the deployment is available in comma-separated value (csv) files named *rawData\_Day1.csv* and *rawData\_Day2.csv*. These files are located in a Dropbox folder (Gowrishankar and Work 2013).

The csv files contain data records of each and every vehicle that was recorded on the days of data collection.

Each row in the file represents a swipe on the phone's screen and is called a *maneuver count*. Within each row, the *node\_id* column represents the identification number of the counting location where the particular maneuver count was recorded.

In addition, a *session\_id* is provided. This number is a unique identification of a data collection session started by a data collection associate. Each session represents a continuous duration during which data was being collected. It is possible that some data collection associates collected data over multiple sessions with small gaps in the data and therefore, this identifier helps differentiate the case when the data collection associate is not collecting data and when there is no traffic at the counting location.

The next field is the *maneuver\_type*. This number represents the exact maneuver that each recorded maneuver count represents. The possibilities are:

- 1 – Invalid data record
- 1 – Southbound left (SBL)
- 2 – Southbound through (SBT)
- 3 – Southbound right (SBR)
- 4 – Westbound right (WBR)
- 5 – Westbound through (WBT)
- 6 – Westbound left (WBL)
- 7 – Northbound through (NBT)
- 8 – Northbound right (NBR)
- 9 – Northbound left (NBL)
- 10 – Eastbound left (EBL)
- 11 – Eastbound through (EBT)
- 12 – Eastbound right (EBR)

The last column is the *timestamp*. This represents *Unix epoch time* or *POSIX time* ([http://en.wikipedia.org/wiki/Unix\\_time](http://en.wikipedia.org/wiki/Unix_time)) of the recorded maneuver count in units of milliseconds.

