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16. Abstract The effectiveness of work zone operational or control strategies is conditioned on a good estimate of the traffic volume though the work zone and amount of traffic diverting to alternate routes, as well as their resulting traffic impacts. Unfortunately, the ability to reliably estimate traffic diverting from work zones has not been adequately addressed, either in the professional literature or in practice. This project conducts an empirical study of traffic diversion at freeway work zones based on the analysis of collected field data. In addition, this study provides an understanding of how drivers behave when they encounter a work zone ahead. Data from traffic detectors, Bluetooth technology and a driver survey are collected at two rural work zones near Portage, WI and Tomah, WI. The findings from this study are further used to define traffic diversion estimation model. Such a model could enable a reliable estimation of diversion traffic at a target work zone. The model can be readily implemented in travel forecasting software.			
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DEVELOPMENT OF A TRAFFIC DIVERSION ESTIMATION MODEL FOR FREEWAY CONSTRUCTION WORK ZONES

Final Report
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CHAPTER 1: INTRODUCTION

1.1 Research Background

Implementations of a variety of highway work-zone activities have been widely recognized as main contributors to the increasing amounts of non-recurrent congestion and to deteriorating traffic safety. To contend with the safety and delay related issues associated with work-zone activities, most state highway agencies over the past decade have devoted considerable resources to improve work-zone operations and to implement more sophisticated traffic control strategies. However, the effectiveness of those operational or control strategies is conditioned on a good estimate of the traffic volume though the work zone and amount of traffic diverting to alternate routes, as well as their resulting traffic impacts. Unfortunately, the ability to reliably estimate traffic diverting from work zones has not been adequately addressed, either in the professional literature or in practice.

This project conducts an empirical study of traffic diversion at freeway work zones based on the analysis of collected field data. In addition, this study provides an understanding of how drivers behave when they encounter a work zone ahead. Traffic patterns during work zones are the result of many different driver behaviors.

- Some drivers will plan ahead and carefully compare different alternate routes, and chose the one that saves travel time, travel cost, reliability, and familiarity.
- Some drivers will get their pre-trip information by the department of transportation or private sources.
- Some drivers will make more spontaneous decisions during their trip, making decisions based on the perceived state of the traffic system.
- Some drivers will behave irrationally due to habit, ignorance, or failure to properly comprehend information as it becomes available.

Data from traffic detectors, Bluetooth technology and a driver survey are collected at two rural work zones near Portage, WI and Tomah, WI.

The findings from this study are further used to define traffic diversion estimation model. Such a model could enable a reliable estimation of diversion traffic at a target work zone. The model can be readily implemented in travel forecasting software.

1.2 Research Objectives

This project has four main objectives.

- Investigate the state-of-the art literature and the current state or local DOT practices in order to synthesize available information on the analysis of traffic diversion at freeway work zones;
- Analyze newly collected or archived work-zone field data to identify key traffic diversion patterns and major factors that affect driver's decision to divert;
- Look at multiple traffic diversion modeling paradigms using the data collected, and develop a new (or updated) model that can best capture the traffic diversion characteristics under various types of work-zone conditions; and
- Provide guidelines for state highway agencies for the best methods of incorporating of the effects of work-zone diversion into their traffic control designs.

1.3 Report Organization

Based on the research objectives, this study has organized all primary results and key findings into six subsequent chapters. A brief description of the information contained in each chapter is presented next.

Chapter 2 performs a comprehensive review of available literature associated with the work-zone operations, including: (1) field data collected by federal, SWZDI states, and other state or local agencies; (2) analysis tools developed by federal, SWZDI, universities and other agencies; (3) operational strategies implemented by federal, SWZDI, and other state or local agencies, with valuable lessons learned; (4) experimental operational strategies that have been proposed in the literature but not yet implemented in practice; and (5) models of work zone diversion or models of drivers' path choice that have potential to be adapted to work-zone situations. The comprehensive review will be focused on several critical aspects, including methods to quantify work-zone capacities (for example, a recent study by UW-Milwaukee and Marquette University for SWZDI about freeway work zone capacity), models to represent demand diversion under various work zone conditions, and methods to estimate traffic impacts in work zones. This chapter also identifies broad paradigms for estimating work zone diversion (for example, empirical analysis results, economic/traffic equilibrium models, driver simulation or sequential choice-utility processes) and categorizes each model by paradigm.

Chapter 3 mainly presents the project background and data collection process, including the data collection site selection, technologies adopted for field data collection, description of data collection procedures, operational requirements for setting up all essential equipment for field data collection, survey design and implementation, and data filtering procedures to remove those observations contaminated by measurement noise. The data set described in this chapter forms the basis for empirical diversion analysis and the modeling diversion behaviors in later chapters.

Chapter 4 details the statistical procedures used to perform empirical diversion analysis, including the cutline analysis of diversion, Bluetooth analysis of diversion, and travel time studies, based on comparison of before-and-after data. Preliminary results from the statistical analysis reveals the traffic diversion patterns at the study sites and sheds the light on modeling diversion behaviors.

Chapter 5 reports the potential impacts of individual as well as traffic factors on the diversion decision of drivers encountering a freeway work zone based on a field survey of more than 400 drivers who either traveled through the work zone or likely bypassed the work-zone at the study sites. Assessment of the relevant nature of the driving population (such as familiarity with the diversion route, trip destination, trip purpose, and sensitivity to information) and drivers' rationale for making or not making a diversion choice were conducted.

Useful hypotheses regarding how drivers behave in response to the work zones include:

- traffic diversion exists and can be estimated by traffic volumes and Bluetooth technology;
- if there is a parallel alternate route with easy access, more drivers will divert when the freeway becomes congested;

- more drivers in rural areas will behave more irrationally in response to congestion on the freeway;
- drivers tend to make spontaneous decisions based on what they encounter;
- drivers are more prone to plan ahead and gain pre-trip information; and
- it will require slow speeds on the freeway and high perceived travel-time savings on the alternate route for drivers to divert in rural areas.

Chapter 6 presents a conceptual model of diversion that integrates user-equilibrium traffic assignment with a driver choice-utility process as applied over multiple vehicle and driver classes.

Chapter 7 summarizes the primary research findings and their potential applications to improving work zone operational efficiency. Recommendations for future research are also made.

CHAPTER 2: LITERATURE REVIEW

The Manual of Uniform Traffic Control Devices (2009) defines diversion as, "a temporary rerouting of road users onto a temporary highway or alignment placed around the work area". Diversion from work zones is still a hot topic in the engineering community, which can result in reductions in queue lengths at work zones by those drivers taking different routes. This literature review delves into within work zone congestion or recurring congestion and how they relate to diversion in general.

2.1 Work Zone Capacity and Queue Length

Work zone capacity and the queue length generated from oversaturated conditions can have an impact on diversion. Work zone capacity can be defined as the maximum flow rate (most likely 15-minute traffic counts converted to vehicles per hour) that accounts for the reduction in traveled lanes. Queue length refers to the distance from the start of the work zone to the last vehicle traveling at a speed of 30 MPH or less.

In the *Highway Capacity Manual* (2000), work-zone capacity estimates are based on data collected by the Texas Transportation Institute, and cannot be properly applied in other parts of the US due to driver behavior and weather conditions. Maze et al. (2005) have conducted a study on work zone capacity of a rural freeway (I-80 between US 61 and state highway74). The capacity varied from roughly 1,400 to 1,600 passenger car equivalents. Overall, the results showed queues could move upstream and downstream at fast rates, which can present safety issues at lane closures. Based on capacity and historical volumes, reasonable diversion rates can be created and accomplished through certain ATIS devices.

In Horowitz's study (2008), capacity values were generated at two work zones in Milwaukee, taking into account sensitivity factors like converting heavy vehicles to passenger car equivalents and taking into account the percent grade. Also, one of the work zones had the detector just downstream of the taper (reducing the number of traveled lanes). The capacity values varied from 1,920 vphpl (vehicles per hour per lane) to 2,115 vphpl, depending on whether there was relatively free-flow conditions or queued conditions.

Different programs like Quickzone and Queue and User Cost Evaluation of Work Zones (QUEWZ) have a tendency to overestimate queues due to the inability to show stabilization. The algorithm in QUEWZ (Copeland, 1999) was created by the Texas Transportation Institute in Texas, where there are many frontage roads to freeways, but frontage roads are not common in many other states. Quickzone (Miterek Systems, 2005) is a traffic-network based tool, which can include up to two alternate routes. In an urban setting, the tail of queue must reach to the diversion point before diversion takes place, which does not account for natural diversion. In a rural setting, the travel time on the alternate route must be shorter than the original route for diversion to take place.

There have been other techniques to predict traffic queues by considering shock wave theory, energy model, and mathematical analogy (Ullman and Dudek, 2003). The analogy consists of flow through a permeable pipe and traffic with lane closures. The flow across the permeable medium is perceived as diverted traffic. A shock wave theory is used to model the dispersion of traffic characteristics, like queues and reductions of speed, upstream of the work zone. The energy model of traffic flow is used to define the physics as the analogy relates to traffic, meaning the queue length (and reduction in speed) creates a pressure, which represents natural diversion near the work zone. The mathematical analogy represents the urban corridor as the fluid flow through a section of the permeable pipe, where a specific corridor permeability coefficient accounts for dissipating traffic flows. In order for concepts like these to be implemented as a work zone analysis tool, more research has to be done to address the factors that affect the permeability of the freeway.

Another attempt to estimate queue lengths was done by Chittur and Benekohal (2010), which is based on a previously proposed methodology (Chitturi et al., 2008). Queue lengths are estimated considering the effects that roads and traffic have on speeds, but looking at passenger cars and heavy vehicles separately. They are compared separately because the desired speeds of heavy vehicles can be consistently 5 MPH less than passenger cars. A twelve-step procedure is outlined, but major flaws include how heavy vehicle's speed varies from cars due to such conditions as narrow traveling lanes, speed enforcement, and work intensity.

2.2 Empirical Diversion Studies and Impacts

Traffic diversion is difficult to quantify and can differ across the country. A thorough review of the literature indicates that only a limited number of studies have been conducted to empirically estimate the natural diversion rates at work zones. Most of those studies show the existence of diversion varying substantially under different circumstances.

For rural work zones, Ullman (1996) looked at changes in volume and traffic operations at multiple study sites in Texas. The results show a stabilization of queue lengths, which can imply natural diversion, which is reinforced with the significant reduction in entrance ramp volumes. In the study by Khattak et al. (1994), drivers tended to "overstate their propensity to divert when compared to reported behavior". Approximately one-fifth (22%) of the drivers would divert from a work zone, even if they did not divert the work zone being analyzed. Lee and Kim (2006) did an experiment on I-15 in California, and the diversion rate was found to be around 17 to 18% in the peak hours. Wu et al. (2010) studied three different scenarios showing how much diversion can be created on a link-by-link basis. When the downstream occupancy rose to 20%, one of the arterials had a 5% increase in volume, and a 4% increase in occupancy. When there was a sudden downstream change, the diversion on the arterial streets was not as large as anticipated.

ATIS devices have been proven to increase diversion due to work zones due to the warnings of excessive delay on their current route. Levinson (2003) concluded that ATIS is beneficial to users and society overall and can presuppose alternate routes, but are not available everywhere. Although ATIS is helpful in route guidance, identifying the point at a time just before the roadway becomes oversaturated is necessary to obtain proper equilibrium in travel time for both the freeway and any alternate routes.

Quantifying the diversion rates of work zones due to the implementation of ATIS has been studied extensively at many different locations. The largest propensity to divert occurred when real-time traffic information was given on the alternate route. McCoy (2000) looked at diversion in Nebraska where an ATIS device was relaying one of the following messages; speed advisory, delay, or diversion. The diversion message displayed, “Consider Alt. Route”. The results showed traffic upstream of the Highway 6 interchange increased by 3%, while the mainline volume decreased by 3%. Another study by McCoy and Pesti (2001) evaluated the impacts of a changeable message sign (CMS) at work zones on I-80. They reported that when the CMS was off, the diversion rate was 8%, while it increased to 11% when CMS was on. Bushman et al. (2004) conducted a study of a Smart Work Zone System deployment on I-95 in North Carolina and found that diversion rates were 10.9% and 20.2% in uncongested and congested conditions, respectively. Chu et al. (2005) did an experiment in California based on a Computerized Highway Information Processing System, and found the diversion rates vary considerably at different times of a day. Fontaine and Edara (2007) looked at 15 successful deployments of smart work zones in eight states in order to access the benefits of transportation systems. The found that if the volume is just over the capacity of the lane closure, then a 5% diversion rate can provide the best overall system performance. They concluded that higher levels of diversion on alternate routes could cause a worse overall performance on the network due to lower travel speeds on the alternate route.

In Wisconsin, Horowitz et al. (2003) conducted a study where an ATIS device was giving travel time and speed to the end of the work zone. The diversion rate attributed exclusively to the ATIS device was near 10%. They concluded the reasons for failing to divert to an alternate route under ATIS could relate to the reported amount of delay and lack of knowledge of alternate routes, which should be taken into account in future studies. Horowitz and Notbohm (2003) conducted a different study in Green Bay, Wisconsin, where an ATIS device was giving drivers information about the actual speeds ahead. The diversion from the work zone was substantial, resulting in a 36% reduction in mainline volume just ahead of the taper of the work zone.

A summary of the empirical diversion rates at rural work zones is conducted by Song and Yin (2008) and shown in Table 2.1.

At urban work zones, due to the complexity of urban road network, very few empirical data are available for estimating the diversion rates. Zhang et al. (2008) conducted empirical diversion analysis for the I-15 Freeway Devore and the I-710 Long Beach reconstruction projects. They found that most demand diversions happen only during peak time periods and there is a clear adjustment process among travelers as the work zone project went on. Chen et al. (2008) studied four short-term work zones in Milwaukee focused on a hybrid process (micro-simulation and logistic regression) to imitate diversion behavior upstream of work zones. The process looked at the presence of exit and entrance ramps combined with queuing. The field results showed a significant decrease in volume on entrance ramps (by up to 40%), and an increase, by as much as 12%, in exit ramps. The diversion algorithm had good performance, but, like other modeling, needs further research before it can be integrated into a work-zone planning tool. Qin et al. (2010) further looked into the dynamics of traffic demand for short-term work zones. According to the Pearson correlation test, the following factors had a significant impact in the driver’s decision to divert:

TABLE 2.1 Summary of Empirical Diversion Rates in Rural Areas (Song And Yin, 2008)

Location	Facility	Work Zone	Diversion Rate	Information	Diversion Route	Source
Nebraska	I-80	Two lanes closed; Two-lane, two-way operation on the other side	8-11% (peak period)	CMS	One alternative route	McCoy and Pesti (2001)
Racine, Wisconsin	I-94	12miles One lane closure on two lanes each direction	10% (peak period)	CMS with travel time estimation	Yes, known to all regular drivers; runs in parallel	Horowitz et al. (2003)
Rocky Mount, North Carolina	I-95	1.25-2.5 miles	10.9-20.2% (peak period)	Smart Work Zone system	One alternative route	Bushman, et al. (2004)
Santa Clarita, California	I-5	1.3 miles, one lane closure on three lanes each direction	3-20% (average)	Automated work zone information system (AWIS)	One alternative route	Chu et al. (2005)
San Bernardino, California	I-15	4.5 km, closed half of eight lanes; two by three lane configuration on the left half	17-18% (peak hour)	AWIS coupled with multi-faceted proactive public outreach	I-10 and I-215	Lee and Kim (2006)

- Density of signalized intersection along the arterial route;
- Speed difference between normal conditions and conditions encountered in the work zone;
- Historical mainline traffic; and
- Alternate route distance.

The most notable conclusion from the gravity model and linear regression models is that the density of signalized intersections had the most noticeable impact on diversion. As the number of signalized intersections increases, drivers will be less likely to divert. Foo et al. (2008) studied the rush hour traffic in Toronto, Canada showed when the message changed from “Express and Collector Moving Well” to “Express Moving Slowly, Collector Moving Well”, there was an average of 2.69 percent increase in the diversion rate. In the reverse case, the diversion rate decreased but at a lower rate of 1.68 percent. A recent research report by Florida Department of Transportation (2011) estimated diversion rates due to incidents based on calculating the difference in the cumulative traffic volumes between an average typical non- incident day and the incident day based on traffic detector measurements. They conducted case studies at East-West section of state road 826 (SR-826) in Miami-Dade County, Florida. In the case study, the immediate three upstream detectors and the first downstream detector were selected to determine the diversion rate. It showed that for the selected incidents, diversion rates range from about 0% to 58.5%. About half of the examined incidents had a diversion rate of 10% or less and about two-third of the incidents had a diversion rate less than 20%. The average diversion rate was 12.97% and the 85-percentile value was 25.01%.

It can be summarized from the above review that diversion rates at both rural and urban work zones may vary significantly at different locations and times of a day, depending on the traffic conditions of the work zone and alternative routes as well as the provision of traveler information.

2.3 Modeling Diversion Behaviors

Stated Preference (SP) and Revealed Preference (RP) surveys are commonly used to examine the traveler diversion propensity. The SP method involves conducting a survey, where the surveyor creates hypothetical scenarios for drivers' reactions. The travelers are asked to make discrete choices between travel alternatives under different conditions; while the RP survey involves using field data to evaluate the effectiveness of ATIS technology on driver's route choice, along with a survey administered to drivers after they make a trip.

It is likely that traffic patterns during work zones will result in many different driver behaviors.

- Some drivers will plan ahead and carefully compare different alternate routes, and chose the one that saves travel time, travel cost, reliability, and familiarity.
- Some drivers will get their pre-trip information by the department of transportation or private sources.
- Some drivers will make more spontaneous decision during their trip, making decisions based on the perceived state of the traffic system.
- Some drivers will behave irrationally due to habit, ignorance, or failure to properly comprehend information as it becomes available.

Several early studies have conducted SP surveys to investigate the drivers' diversion behaviors in response to the recurrent or non-recurrent congestion. Khattak et al. (1993) found that significantly more commuters diverted to alternate routes when the motorists were informed that the queue length was higher. Mannering et al. (1994) analyzed a survey of commuters using I-5 to downtown Seattle, and observed that 5.8% of drivers surveyed diverted frequently on home-to-work trips and 13.7% on work-to-home trips. Ullman et al. (1994) conducted a study based on 44 participants, where a hypothetical situation was created and a time saved threshold value was created. The surveys were conducted on drivers from the Dallas metropolitan area traveling to the Dallas central business district (CBD). Each subject was asked if they would consider diverting if the travel time savings on the alternate route was 5 minutes (threshold value). The time interval was increased until the driver said yes. They found that each corridor, diversion location, and congestion location had impact on the averaged threshold value by as much as 7.4 minutes. The major factors for selecting different time saved threshold values include:

- Less access points to get to the alternate route;
- Accessing the alternate route is too difficult;
- Too many signalized intersections or stop signs on the alternate route; and
- Increased risk of problems occurring at the alternate routes at the location of diversion.

Peeta et al. (1995) conducted mail back, on-site, and web-based surveys to estimate the driver's response to dynamic message signs (DMS). It was revealed that the content of the message disseminated had a significant impact on drivers' responses; for example, drivers were more willing to divert to alternate routes when the message posted on DMS indicated that the incident type is an accident. The study by Madanat (1995) found that approximately 5% of the drivers surveyed were willing to divert when the delays expected were greater than half an hour. Schofer et al. (1997) conducted focus groups, or discussion sessions, to get the attitude of drivers toward route guidance. They found that drivers had a preference for real-time traffic information even without route guidance. Khattak (1993) analyzed driver survey data from Chicago and San Francisco, which showed that 42.5% of respondents in Chicago and 16.3% in San Francisco diverted when they experienced unexpected delays. Chatterjee et al. (2002) studied drivers' responses to CMS in London. According to their survey results, 24% of drivers stated that would divert when they encountered delays. Abdel-Aty and Abdalla (2004) conducted a study looking into factors that affect diversion under ATIS using a travel simulator. They had five different scenarios: no information, pre-trip information without advice, pre-trip information with advice, en route information, and en route information with pre-trip information. They concluded that travel time of both the normal route and alternate route are significant in encouraging drivers to divert. Also, more information given will cause more drivers to divert, but each increase is lower in comparison.

A recent study by Florida Department of Transportation (2008) conducted a stated preference survey to explore diversion at work zones using a discrete choice model. Discrete choice problems involve choices between at least two different separate and distinct choices. A choice model was calibrated from the stated preference survey. In the FDOT Study, the three biggest factors influencing diversion behavior include; travel time, work zone location, and weather conditions. Zhang and Levinson's study (2008) on determining the effects of ATIS on system performance showed that drivers prefer routes with lower travel time, higher speeds, fewer number of stops, and routes that are efficient, pleasant, and familiar. The attributes of travel time, distance, and number of stops are considered more important for commute, event, and visiting trips and less important for shopping and recreational trips. When making commute, event, and visiting trips, drivers tend to choose a more familiar route, and drivers with time pressure prefer a more reliable route. In most of the above quantitative works on traveler route choice, including the FDOT study, are based on the concept of utility theory. In utility theory, human behavior is explained by attempts to increase a utility or a measure of personal welfare.

Despite the extensive studies of traveler route choice behaviors from the SP surveys, very limited information is available about the actual diversion as reflected by field measurements (RP). Polydoropoulou et al. (1994) used stated preference and revealed preference approaches and examined the following four influences of route choice behavior: acquiring pre-trip information, pre-trip route choice, acquiring traffic information en route, and en route switching decisions. The data collection was divided up into two parts focusing on commuter trips, or recurring congestion, and consisted of 1,300 drivers in the first part and 898 in the second part. The results show 14% of the drivers had no flexibility in arrival time (which is common for commuting trips), 17% of the drivers had flexibility up to 15 minutes, and 37% of drivers had a flexibility of more than 1 hour. Also, the survey found that 76% of the drivers perceive commuting time as the most important factor in their route choice decision, and 61% perceive time of day as another important factor. The drivers own observations had a major role in their logic for switching to an alternate route. A later study by Polydoropoulou et al. (1996) compared reported and stated behavior under non-recurring congestion. The comparison formed the basis of a model for predicting reactions to ATISs considering travel time, congestion levels, and information provided. In the reported behavior, 48% of the drivers knew about the congestion by observing it, and only 17% of the drivers changed their route. The stated behavior showed the following results:

- 17% of drivers would definitely take the alternate route with an in-vehicle device that gives accurate information on delays;
- 38% of drivers would definitely take the alternate route with an in-vehicle device that gives the expected length of delay on your usual route;
- 40% of drivers would definitely take the alternate route with an in-vehicle device that gives the expected length of delay on your usual route and best alternate route;
- 41% of drivers would definitely take the alternate route with an in-vehicle device that gives predictive information, meaning it will give the present delay time and the delay 15 and 30 minutes into the future; and
- 43% of drivers would definitely take the alternate route with an in-vehicle device that gives prescriptive information, where the device tells you to take your best alternate route.

In an RP study of long-haul truck drivers (Knorring et al., 2005) in seven major urban areas in the United States, travel time is more significant than distance for route in urban areas. The authors stated, “truck drivers look for the shorter routes but take them only because they are also the minimum time route”.

With the enormous traffic data available from ITS devices deployed on the freeway systems, methods to estimate driver diversion based on archived ITS data have been of interest to many transportation agencies recently. Huo and Levinson (2006) conducted a study to evaluate the effectiveness of DMS located on the I-35E corridor in Minnesota. They studied a total of 45 messages displayed under different incident conditions, and developed a weighed probit model to estimate diversion behavior. They found that after DMS installation, travel time was reduced by 6.4% and the delay was reduced by 5%, with a diversion of about 8%.

2.4 Work Zone Diversion Estimation Models

Estimation of diversion rates of work zones is crucial for traffic engineers to develop effective mitigating and operational strategies. In most real-world projects and applications, estimation of diversion rates is usually based on engineering judgment. There are some quantitative models and tools developed to assist traffic engineers to estimate the diversion rates at work zones.

The conventional User Equilibrium (UE) concept has been used to estimate the diversion rates to the alternative route, based on Wardrop's first principle (Wardrop, 1954) by equalizing travel times on competing routes. However, the conditions of UE are not often observed for most work zones, so UE would not likely provide accurate estimates of diversion by itself.

Queue and User Cost Evaluation of Work Zones (QUEWZ) is an analysis tool developed by the Texas Transportation Institute for estimating the traffic impacts of work zone lane closures (Copeland, 1999). A diversion algorithm to estimate the natural diversion of traffic from the freeway work zone to unspecified alternative routes was developed, based on the comparison between the calculated queue length and a critical queue length (with a default value of 2.0 miles). No diversion occurs if the calculated queue length is less then the critical one, otherwise a certain amount of traffic will be diverted to prevent the queue length from exceeding the critical value. The diversion estimation module is QUEWZ is based on the following assumptions:

- The length of the alternate route equals the length of the work zone plus the critical length of queue;
- The travel time for diverting vehicles is equal to the time required for a vehicle at the end of the queue to travel through the queue and work zone;
- Diverting traffic maintains a uniform speed equal to the length of the alternative route divided by the travel time; and
- Trucks do not divert.

Through convenient and easy to implement, QUEWZ does not always provide accurate diversion estimates because the model is developed based on the Texas freeway work zones and may not apply to other states. In addition, one still needs to reply on engineering judgment to determine the value of critical queue length to estimate the diversion. QUEWZ suggests that drivers are biased to their original route.

Another notable tool for estimating diversion at work zones is Quickzone developed by Mitretek Systems with support from the Federal Highway Administration (Miterek Systems, 2005). Quickzone can quantify work zone delays and queue lengths given work zone capacity, traffic demand and work phasing. The diversion component in the Quickzone can apply in both urban and rural settings. In an urban application, the model assumes no diversion to the alternative routes until the tail of the queue reaches back to the diversion point, and traffic diverted onto the alternative routes cannot exceed 90 % of the spare capacity on the alternative route if a changeable message sign is not deployed. In a rural setting, the model assumes diversion occurs only when the travel time of the original route is greater than the alternative-route travel time, and the amount of diverted traffic depends on the percentage of the Local Traffic Traveling on Alternative Routes and the spare capacity of the alternative route.

Some researchers have developed theoretical models to estimate work zone diversion. Ullman and Dudek (2003) proposed a permeable pipe analogy approach to estimate natural diversion at short-term work zones on high-volume roadways in urban areas. However, application of the model depends on the calibration of the permeability coefficient, which limits its transferability. Song and Yin (2008) proposed a work zone diversion estimator based on a good understanding of travelers' diversion behaviors from a SP survey. They calibrated a binary logit route choice model and integrated it with user equilibrium assignment models to produce the diversion estimates. However, the calibrated choice model is solely based on the SP survey data. It is widely known that in the SP survey, the respondents frequently over-predict their responses. As a result the calibrated model may overestimate the diversion rate. For example, in their model when the travel times are equal, drivers are inclined to divert, which may not be necessarily consistent with actual behaviors observed at work zones. Chen et al. (2008) developed a diversion algorithm based on the logistic regression integrated with work zone simulation models to mirror the diversion phenomenon under varying traffic conditions in work zone approaching areas with a number of entrance/exit ramps. The algorithm was validated using field observations at four short-term work zones in Milwaukee and exhibited consistency in terms of the length of queue and traffic volume on the mainline and ramps.

2.5 Summary

The review of literature conducted in this chapter indicated that additional research is needed to develop a sensible and practical method to estimate driver diversion based on a good understanding of driver diversion behaviors and validation using RP data (e.g. archived ITS data).

CHAPTER 3: DATA COLLECTION

3.1 Data Collection Sites

This study has selected Portage and Tomah work zones in Wisconsin for data collection. Both work zones consist of lane closures due to bridge reconstruction in a rural setting. Figures B.1-B.4 in Appendix B show the detailed maps with locations of both work zones. In both work zones, northbound (NB) and southbound (SB) lanes were separated by Jersey wall barriers. In the Portage work zone, there were also Jersey wall barriers near the outside lane (or the lane farthest to the right).

The Portage work zone was a freeway crossover on I-39/I-90/I-94 between STH 60 and CTH CS near the city of Portage, WI. The number of lanes in each direction was reduced from 3 lanes to 2. Normally this stretch of freeway is well under capacity except for Fridays and Sundays, when this freeway serves as a gateway to popular vacation destinations such as Wisconsin Dells.

The Tomah work zone consisted of two freeway crossovers on I-90/I-94 between CTH C and CTH PP near the city of Tomah, WI and on I-94 approximately between CTH ET and Embassy Rd. near the city of Tomah, WI. In both work zones, the number of lanes was reduced from 2 lanes to 1 in each direction. Like the Portage work zone, the Tomah work zone is well under capacity except for Fridays, Sundays, and holidays.

3.2 Data Sources and Collection Plan

This research consists of utilizing stated preferences of drivers after they have driven through two rural work zones in Wisconsin, along with volume counts and vehicle tracking with Bluetooth technology. With Bluetooth technology, one can track a vehicle getting off the freeway and then getting back on the freeway. The volume counts give insights on driver behaviors, and the driver survey shows the factors that might cause drivers to divert.

3.2.1 Bluetooth Data

Bluetooth technology consists of using an electronic identifier called the Media Access Control (MAC) address. The MAC address is the basis for identifying each node in a digital network (for example, a printer can distinguish between two computers and a digital camera), and for obtaining traffic information. Figure 3.1 illustrates how Bluetooth technology can be used to obtain travel time information.

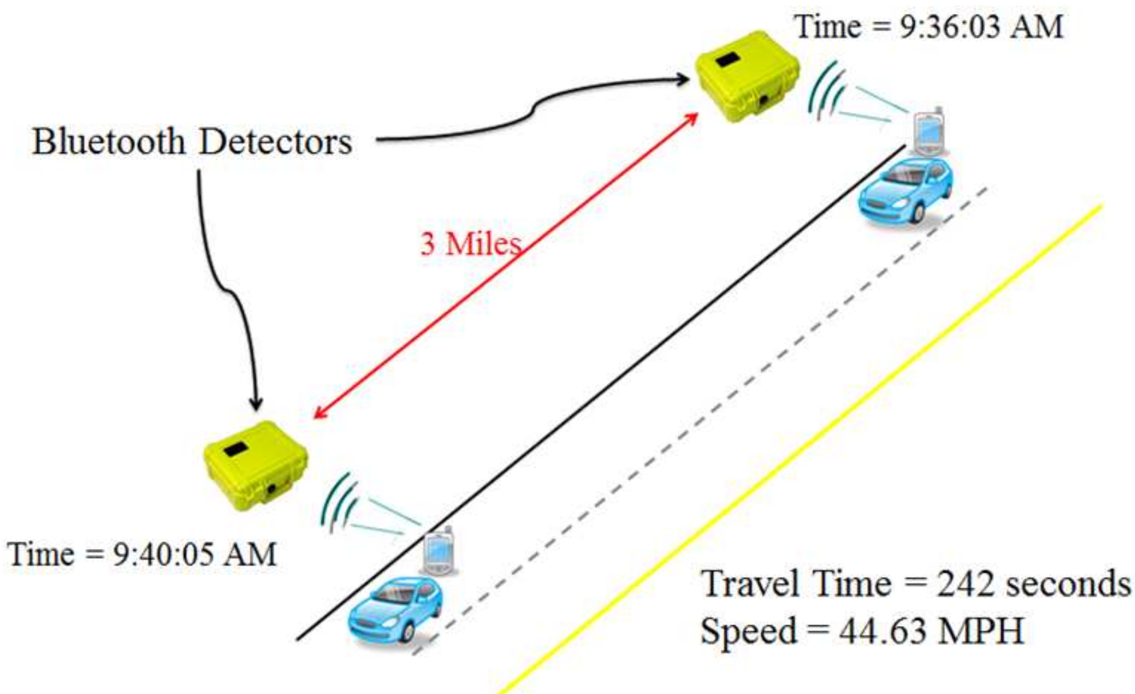

FIGURE 3.1 Illustration of Bluetooth Technology

As the vehicle passes the first Bluetooth device, the MAC address and a time stamp are recorded into the storage area. Then, if the same vehicle is detected at the second Bluetooth device, the travel time is formed. In the example of a pair of Bluetooth devices displayed in Figure 3.1, the length of the freeway segment is 3 miles and the travel time for the vehicle was 242 seconds, yielding an average speed of 44.63 MPH. There can also be triples and quadruples formed, in which the same vehicle passes three or four Bluetooth devices, but the capture rate is significantly lower.

By using the MAC address, the driver of each vehicle remains anonymous. The MAC address is not linked to any user accounts or specific vehicles. Instead, the MAC addresses are assigned at the Bluetooth electronic chip manufacturer. The users have the additional capability of making their device not detectable.

The company licensed by WisDOT was TrafficCast, which created the software for processing the data. Since real-time Bluetooth devices were used in this study, the data were downloaded directly from TrafficCast's website, and the data could be downloaded in CSV format in any hourly time increments chosen immediately in 14 day increments. Solar panels were used to charge the batteries of the Bluetooth devices so they could be used for the entire study period. In all of the studies, there were no reported power failures resulting in time intervals with no data.

3.2.2 Other Data Sources

There was other data collection sources used to get driver behavior and diversion characteristics. Tube counters were used to get traffic counts on freeway ramps and diversion routes. Wavetronix detectors were used for collecting data on the freeway. Other ITS data collection sources like Volume, Speed, and Occupancy Application Suite (V-SPOC) and TRAffic Database System (TRADAS) were utilized. V-SPOC stores data from the freeways and makes them easily accessible to traffic engineers and researchers.

An engineer or researcher can download the data, which is in CSV format, for any date and time interval dating back to 1996. It is still an evolving technology, and more detectors are getting placed in the rural areas. In Tomah, we were able to utilize multiple freeway mainline counts, which saved on the use of Wavetronix detectors. The detectors used in V-SPOC consist mostly of loop detectors, but also ATR stations and side-fire radar. The Automatic Traffic Recorder (ATR) stations were gathered using TRADAS. The ATR stations are more accurate than loop detectors, and are used in determining if a series of detectors in a corridor is malfunctioning. Finally, there was a driver survey conducted to get driver behavior of these work zones.

3.2.3 Portage Work Zone Data Collection

The Portage work zone had one obvious alternate route and one regional route. The goal of data collection was to capture traffic coming from all directions, considering both NB and SB traffic.

The Bluetooth detectors were placed at locations to capture long distance routes. The major factor in the placement of Bluetooth devices was to capture all of the traffic including Milwaukee, Chicago, Madison, Wausau, Eau Claire, La Cross, and the Wisconsin Dells. Appendix B shows the placement of the Bluetooth Devices along with the major detour routes for southbound traffic. The Bluetooth locations were created considering both northbound and southbound traffic. Table 3.1 shows the rationale behind the locations of the Bluetooth devices, and Tables 3.2 and 3.3 lists some example route choices captured by the combined Bluetooth stations at the Portage work zone. Appendix C.1 shows a complete list of Bluetooth pairs, triples, and quadruples at the Portage work zone for both directions.

TABLE 3.1 Rationale Behind the Placement of Bluetooth Detectors at Portage Work Zone

Device	Drivers Being Captured
BT1	Southern Wisconsin/Illinois drivers
BT2	Milwaukee/Chicago drivers
BT3	All other drivers from south or east
BT4	Madison drivers
BT5	Drivers going through work zone
BT6	Drivers taking the US 51 alternate route
BT7	Wausau/Northern Wisconsin drivers
BT8	Drivers taking STH 16
BT9	Drivers taking the US 12 alternate route
BT10	Wisconsin Dells drivers
BT11	Eau Claire/La Crosse drivers
BT12 & BT13	Travel time through the construction zone

TABLE 3.2 Example Route Choices Captured by Combined Bluetooth Stations at Portage Work Zone (Northbound/Westbound)

Combination of Stations	Route of Drivers
BT1 To BT3 To BT5	I-90/I-39 To I-94/I-90/I-39 through construction site (includes Illinois/Southern Wisconsin Drivers)
BT2 To BT3 To BT5	I-94 To I-94/I-90/I-39 through construction site (Includes Milwaukee Drivers)
BT3 To BT5	I-90/I-39/I-94 through construction site (includes Madison Drivers Taking Hwy 151)
BT1 To BT3 To BT6	I-90/I-39 To I-94/I-90 diversion route (Via Hwy 51) (includes Illinois/Southern Wisconsin Drivers)
BT1 To BT3 To BT6 To BT8	I-90/I-39 To I-94/I-90 diversion route (Via Hwy 51 & Hwy 16) (includes Illinois/Southern Wisconsin Drivers)
BT2 To BT3 To BT6	I-94 To I-94/I-90 diversion route (Via Hwy 51) (includes Milwaukee Drivers)
BT2 To BT3 To BT6 To BT8	I-94 To I-94/I-90 diversion route (Via Hwy 51 & Hwy 16) (includes Milwaukee Drivers)
BT3 To BT6	I-90/I-39/I-94 diversion route (Via Hwy 51) (includes Madison Drivers Taking Hwy 151)
BT3 To BT6 To BT8	I-90/I-39/I-94 To I-94/I-90 diversion route (Via Hwy 51 & Hwy 16) (includes Madison Drivers Taking Hwy 151)
BT1 To BT3 To BT5 To BT7	I-90/I-39 To I-39 through construction site (includes Illinois/Southern Wisconsin Drivers)
BT1 To BT3 To BT6 To BT7	I-90/I-39 To I-39 diversion route (Via Hwy 51) (includes Illinois/Southern Wisconsin Drivers)
BT2 To BT3 To BT5 To BT7	I-94 To I-39 through construction site (includes Milwaukee Drivers)
BT2 To BT3 To BT6 To BT7	I-94 To I-39 diversion route (Via Hwy 51) (includes Milwaukee drivers)
BT3 To BT5 To BT7	I-94/I-90/I-39 To I-39 through construction site (includes Madison drivers taking Hwy 151)
BT3 To BT6 To BT7	I-94/I-90/I-39 To I-39 diversion route (Via Hwy 51) (includes Madison drivers taking Hwy 151)
BT1 To BT9 To BT10	I-90/I-39 To Hwy 12 (Wisconsin Dells) (Hwy 12 diversion route)
BT1 To BT9 To BT11	I-90/I-39 To I-90/I-94 (STH 12 diversion route)
BT12 To BT13	Travel time through construction zone

TABLE 3.3 Example Route Choices Captured by Combined Bluetooth stations at Portage Work Zone (Southbound/Eastbound)

Combination of Stations	Route of Drivers
BT11 To BT5 To BT3 To BT1	I-94/I-90 To I-90/I-39 through construction site (includes Illinois/Southern Wisconsin drivers)
BT11 To BT5 To BT3 To BT2	I-94/I-90 To I-94 through construction site (includes Milwaukee drivers)
BT11 To BT5 To BT3	I-94/I-90 To I-94/I-90/I-39 through construction site (includes Madison drivers exiting at Hwy 151)
BT8 To BT6 To BT3 To BT1	I-94/I-90 To I-90/I-39 diversion route (via Hwy 16 & Hwy 51) (includes Illinois/Southern Wisconsin drivers)
BT8 To BT6 To BT3 To BT2	I-94/I-90 To I-94 diversion route (via Hwy 16 & Hwy 51) (includes Milwaukee drivers)
BT8 To BT6 To BT3	I-94/I-90 To I-94/I-90/I-39 diversion route (via Hwy 16 & Hwy 51) (includes Madison drivers exiting at Hwy 151)
BT11 To BT6 To BT3 To BT1	I-94/I-90 To I-90/I-39 diversion route (via Hwy 51) (includes Illinois/Southern Wisconsin drivers)
BT11 To BT6 To BT3 To BT2	I-94/I-90 To I-94 diversion route (via Hwy 51) (includes Milwaukee drivers)
BT11 To BT6 To BT3	I-94/I-90 To I-94/I-90/I-39 diversion route (via Hwy 51) (Includes Madison Drivers Exiting at Hwy 151)
BT7 To BT5 To BT3 To BT1	I-39 To I-90/I-39 through construction site (includes Illinois/Southern Wisconsin drivers)
BT7 To BT5 To BT3 To BT2	I-39 To I-94 through construction site (includes Milwaukee drivers)
BT7 To BT5 To BT3	I-39 To I-94/I-90/I-39 through construction site (includes Madison drivers exiting at Hwy 151)
BT7 To BT6 To BT3 To BT1	I-39 To I-90/I-39 diversion route (via Hwy 51) (includes Illinois/Southern Wisconsin drivers)
BT7 To BT6 To BT3 To BT2	I-39 To I-94 diversion route (via Hwy 51) (includes Milwaukee drivers)
BT7 To BT6 To BT3	I-39 To I-94/I-90/I-39 diversion route (via Hwy 51) (includes Madison drivers exiting at Hwy 151)
BT11 To BT9 To BT1	I-94/I-90 To I-90/I-39 diversion route (via Hwy 12) (includes Illinois/Southern Wisconsin drivers)
BT10 To BT9 To BT1	I-94/I-90 To I-90/I-39 diversion route (via Hwy 12) (includes Wisconsin Dells drivers)
BT13 To BT12	Travel time through construction zone

The traffic counts came from Wavetronix units on the freeway, Automatic Traffic Recorders (ATR stations) on the freeway, loop detectors on the freeway and alternate route, and tube detectors on the alternate route, on-ramps, and off-ramps. All of the detectors are permanent except for tube detectors and Wavetronix units. Wavetronix units were placed at the same location as Bluetooth detectors. Tube counters that were placed on the alternate route were used to create screen lines (cut lines). From the screen lines, a statistical test can be performed to see if diversion exists. Chapter 4 contains more information on screen lines and statistical testing.

Data were collected under both work zone and non-work zone conditions for comparison, including:

- Non-work zone conditions: March 11, 2011 – March 27, 2011; and
- Work zone conditions: September 3, 2010 – September 19, 2010.

A driver survey was conducted by UWM students at gas stations and rest areas. The driver survey contained questions relating to diversion. See Appendix A.1 for a list of the questions administered.

3.2.4 Tomah Work Zone Data Collection

The Tomah location was more difficult because it consisted of two work zones. One work zone was east of the I-90/I-94 split, and one construction zone was on I-94 west of the I-90/I-94 split. The Tomah work zones created different issues than the Portage work zone for determining Bluetooth device locations. There was not a logical regional route, and only one alternate route was chosen. Of most interest was traffic from the east (Madison/Milwaukee/Chicago), Eau Claire traffic, La Cross traffic, and internal traffic in Tomah.

Appendix B shows the location of the Bluetooth detectors and detectors with traffic counts. There were more factors considered than when placing Bluetooth devices at the Portage Work Zone. First, The Wal-Mart distribution center had to be taken into account (placement of BT109) because of its generation of heavy truck traffic. Since there are two work zones, there had to be separation between the traffic that diverts at the first work zone, traffic that diverts at the second work zone, and traffic that diverts for both work zones, which resulted in the placement of 5 Bluetooth devices on the alternate route (Bluetooth locations 110, 102, 105, 106, and 112). For example, northbound traffic diverting at the second work zone, the triple formed would be BT104 to BT102 to BT101. Also, consideration was given to traffic diverting at one work zone, then traveling to La Cross, in which case the triple BT108 to BT112 to BT103 can be formed. There were concerns about signal reception for one of the locations for a Bluetooth device in Tomah, which resulted in a minor change in the location of Bluetooth location 102. Table 3.4 shows the rationale behind the locations of the Bluetooth devices, and Tables 3.5 and 3.6 show some example route choices captured by the combined Bluetooth stations at the Tomah work zone. Appendix C.2 shows a complete list of Bluetooth pairs, triples, and quadruples at the Tomah work zone for both directions.

The traffic counts consisted of the same devices as the Portage work zone (Wavetronix units on the freeway and alternate route, loop detectors on the freeway, and tube detectors on on-ramps, off-ramps, and alternate routes). The construction zone east of the I-90/I-94 split had more delays than the other construction zone, which was expected. More detectors were placed on the alternate route, on-ramps, and off-ramps to get a better understanding of the location of diversion. The dates of the work zone and non-work zone conditions are:

- Non-work zone conditions: November 2, 2010 – November 21, 2010; and
- Work zone conditions: April 5, 2011 – April 24, 2011.

A similar driver survey was also administered. See Appendix A.2 for a list of the questions administered.

TABLE 3.4 Rationale Behind the Placement of Bluetooth Detectors at Tomah Work Zone

Device	Drivers Being Captured
BT101	I-94 drivers (Eau Claire)
BT102	Tomah drivers
BT103	I-90 drivers (La Crosse)
BT104	Drivers only diverting one work zone
BT105	Drivers taking the US 12 alternate route
BT106	Drivers taking the US 12 alternate route
BT107	Driving through the east work zone
BT108	I-90/I-94 drivers (Central/Eastern Wisconsin)
BT109	Drivers traveling to the Wal-Mart distribution center
BT110	Drivers diverting the west work zone
BT111	Tomah drivers

TABLE 3.5 Example Route Choices Captured by Combined Bluetooth Stations at Tomah Work Zone (Northbound/Westbound)

Combination of Stations	Route of drivers
BT108 to BT106	I-90/I-94 drivers diverting at STH 80
BT107 to BT106	I-90/I-94 drivers diverting at CTH C
BT107 to BT105	I-90/I-94 drivers diverting at Oakwood Rd.
BT108 to BT105 to BT103	I-90 drivers diverting at STH 80 & getting back at US 18/I-90 Interchange
BT108 to BT102 to BT103	I-90 drivers diverting at STH 80 & getting back on at STH 131/I-90 Interchange
BT107 to BT105 to BT103	I-90 drivers diverting at CTH C to US 18/I-90 interchange
BT107 to BT102 to BT103	I-90 drivers diverting at CTH C & getting back on at STH 131/I-90 Interchange
BT107 to BT106 to BT102 to BT103	I-90 drivers diverting & getting back on at STH 131/I-90
BT108 to BT102 to BT101	I-94 drivers diverting at STH 80 to Tomah Exit
BT107 to BT102 to BT101	I-94 drivers diverting at CTH C to Tomah Exit
BT106 to BT105	Travel time of US 18 (Alternate Route)
BT107 to BT104	Drivers going through construction zone, travel time
BT108 to BT106 to BT101	I-94 drivers diverting at STH 80
BT107 to BT106 to BT101	I-94 drivers diverting at CTH C
BT 108 to BT105 to BT101	I-94 drivers diverting at STH 80 to US18/I-90 Interchange
BT107 to BT105 to BT101	I-94 drivers diverting at CTH C to US 18/I-90 Interchange
BT107 to BT104 to BT103	I-90 driver going through construction zone
BT107 to BT104 to BT101	I-94 drivers going through construction zone

TABLE 3.6 Example Route Choices Captured by Combined Bluetooth Stations at Tomah Work Zone (Southbound/Eastbound)

Combination of Stations	Route of drivers
BT101 to BT102	I-94 drivers taking US 18 at Tomah exit
BT101 to BT102 to BT106	I-94 drivers continuing on US 18 past Oakwood Rd.
BT101 to BT106 to BT107	I-94 drivers getting back onto I-90/I-94 at CTH C
BT101 to BT106 to BT108	I-94 drivers continuing on US 18 and getting back onto I-90/I-94 at STH 80
BT103 to BT102	I-90 drivers taking STH 131 to US 18
BT103 to BT105	I-90 drivers getting off at US 18
BT103 to BT105 to BT106	I-90 drivers continuing on US 18 past Oakwood Rd.
BT105 to BT106	Travel time on US 18 (Alternate Route)
BT103 to BT106 to BT107	I-90 drivers getting back on at CTH C
BT103 to BT106 to BT108	I-94 drivers continuing on US 18 and getting back onto I-90/I-94 at STH 80
BT101 to BT104	I-94 drivers continuing through construction zone
BT103 to BT104	I-90 drivers continuing through construction zone
BT104 to BT107	Travel time through construction zone

3.3 Data Extraction, Correction and Validation

3.3.1 Bluetooth Data Extraction

A new concept in this project is using Bluetooth technology for diversion analysis. To accomplish this, there is a need for Bluetooth triples, which consists of a vehicle passing by three Bluetooth stations. The research team has developed special software to turn pairs into triples. The software is illustrated in Figure 3.2, and Table 3.7 shows how the software recognizes triples given pairs. Quadruples could also be assembled from three sets of pairs.

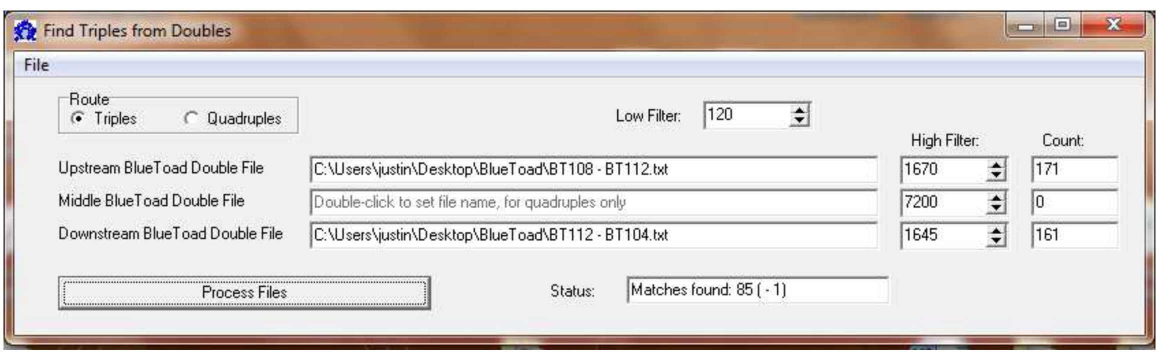

FIGURE 3.2 Screenshot of the Software Used to Create Triples Given Pairs

TABLE 3.7 Example Route Choices Captured by Combined Bluetooth Stations at Tomah Work Zone (Southbound/Eastbound)

BT1 – BT6		BT6 – BT11		
Travel Time	**BT6**	**Calculated BT6**	**Travel Time**	**BT11**
2341	2:20:22	1:34:35	2075	
1719	2:30:43	2:30:43	2188	
2465	2:58:14	3:20:18	2236	

The time stamp given to us was located at the downstream detector, so the upstream time stamp had to be calculated. Filters were applied to take out the pairs where drivers made a long term stop (more than 5-10 minutes depending on the distance between Bluetooth stations).

False positives could occur because of a relay effect. A relay includes a vehicle that was detected at the first and second Bluetooth stations. Then a second vehicle is registered at the second Bluetooth station at the exact same time as the first vehicle, and proceeds to the third Bluetooth station, while the original vehicle does not. The software could estimate the false positive rate, even though it could not identify specific false positives. Such false positives were found to be unlikely because the time stamps are recorded to the nearest second and the hit rate was low. For the example in Figure 3.2, the estimated number of false positives is shown as a negative number in the Status box. False positives could have been avoided if the database contained a unique identifier for each vehicle, but the database suppressed the MAC address to ally privacy concerns.

Another possible issue that has not been completely resolved is a speed bias. A typical Bluetooth device scans 32 different frequencies with detections every 10 ms to 10.64 seconds, randomly according to a uniform probability distribution. TrafficCast did not release any information on how its Bluetooth devices scan these different frequencies and whether their scanning was more efficient that typical. Long detection times imply that vehicles traveling at different speeds could be detected at different hit rates. A speed bias might influence hit rates between non-work zone and work zone conditions. If a vehicle is traveling 65 MPH, it will be in the range of the Bluetooth device for approximately 3.1 seconds, where as a vehicle traveling at 25 MPH is in the range of the Bluetooth device for 8.2 seconds.

Based on the Bluetooth placements, there is the potential for a speed bias for NB freeway traffic in the Portage work zone, and both EB and WB freeway traffic at the east work zone in the Tomah work zone. There is no bias for using Bluetooth hits for diversion, because the triples generated are utilizing Bluetooth stations that are not near any queues. After conducting correlation plots between volume and number of unfiltered hits, there is no speed apparent bias for traffic in any of the work zones.

3.3.2 VSPOC Correction

Data taken from the volume, speed and occupancy application suite (VSPOC), operated by the UW-Madison traffic operations and safety laboratory (TOPS Lab), may include compiling issues that result in errors at the 5-minute level. Sometimes, a 5-minute interval will get double the volume, and then the next 5-minute interval will be blank. Other times, a 5-minute interval will just be blank. See Table 3.8 below for a visual representation.

TABLE 3.8 Errors Encountered in VSPOC

Time	Volume	Time	Volume
8:00	46	13:25	259
8:05	49	13:30	264
8:10	88	13:35	279
8:15		13:40	
8:20	43	13:45	268

The data were corrected using averaging techniques. If the volume count before the blank includes the volume of the time interval in the blank, the following equation was used:

$$Volume_{Blank-1} = \frac{\left(\frac{Volume_{Blank-1}}{2}\right) + Volume_{Blank-2}}{2}$$

$$Volume_{Blank} = \frac{\left(\frac{Volume_{Blank-1}}{2}\right) + Volume_{Blank+1}}{2}$$

For example (From Table 3.8),

$$Volume_{8:10} = \frac{\left(\frac{88}{2}\right) + 49}{2} = 47\ veh$$

$$Volume_{8:10} = \frac{\left(\frac{88}{2}\right) + 43}{2} = 44\ veh$$

If the volume counts before the blank looks like the normal volume, it is left alone, and the following equation was used to get the volume in the blank:

$$Volume_{Blank} = \frac{Volume_{Blank-1} + Volume_{Blank+1}}{2}$$

For example (from Table 3.8),

$$Volume_{13:40} = \frac{279 + 268}{2} = 274\ veh$$

3.3.3 Flow Balance for Loop Detector Data

A flow balance may need to be created to minimize the errors associated with loop detectors. To conduct a flow balance, a non-linear program in Microsoft Excel was created utilizing the solver function. The GEH statistic (shown below and named after Geoffrey E. Havers) was used and minimized in the solver function.

$$GEH = \sqrt{\frac{2(M-C)^2}{M+C}}$$

Where,

M = New traffic count (after iteration)

C = Old traffic count (from detector)

The old traffic count was used for the M and C to start. Then constraints were created to make the solver function create a flow balance with proper values. For example, a volume could not go below zero and certain volumes had to be equal (mainline volume + off-ramp volume = mainline volume after the off-ramp). Figure 3.3 shows the program in Excel.

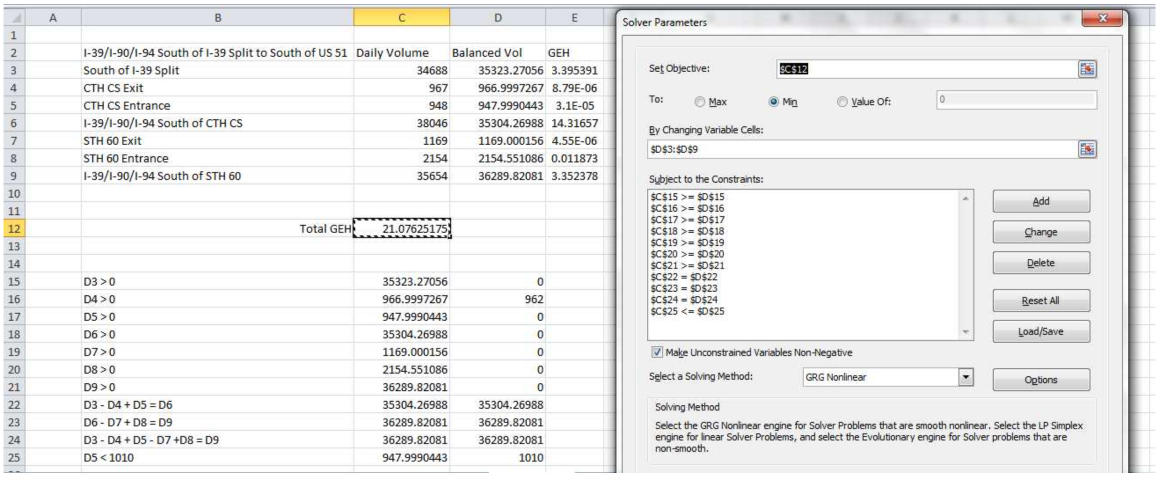

FIGURE 3.3 A Non-linear Program in Microsoft Excel for Flow Balancing

CHAPTER 4: EMPIRICAL TRAFFIC DIVERSION ANALYSIS

This chapter presents the empirical traffic diversion patterns identified at two work zones based on the analysis of collected data. Cut line, Bluetooth, and ramp volume analysis of diversion compose the core part of this chapter.

4.1 Cut Line Analysis of Diversion

A cut line is an artificial boundary over which traffic can flow on two or more roads. Cut lines allow for comparison of volumes between freeways and alternate routes. Ideally, a cut line will consist of freeway volume between interchanges inside the work zone, and alternate route volumes in the same general area. For both Portage and Tomah work zones, cut lines were designed for statistical testing and analysis of diversion.

4.1.1 Location of Cut Lines

For the Portage work zone, two cut lines were created to capture all of the obvious options for diversion. The first cut line (Cut line I, see Figure 4.1) incorporates traffic taking the US 51 alternate route and US 12 regional route. The second cut line (Cut line II, see Figure 4.2) incorporates traffic taking a longer alternate route utilizing state trunk highway (STH) 16. The detectors on the alternate routes were located at BT9, BT6, and BT8. The detectors on the freeway were located at BT5 and on I-90/I-94 east of CTH A near Wisconsin Dells.

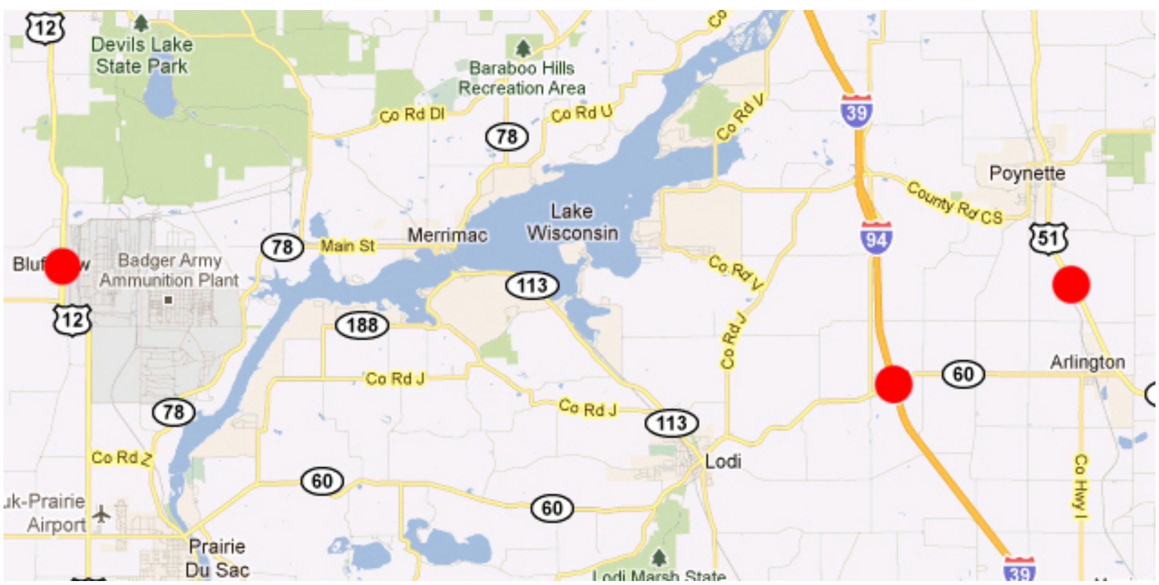

FIGURE 4.1 Cut Line I South End of the Work Zone at Portage

FIGURE 4.2 Cut line II Northwest of the Work Zone at the Portage

The Tomah work zone had two cut lines that only factor in the east work zone, because the west work zone did not encounter congestion during the closure time period. The first cut line (Cut line I, see Figure 4.3) is at the east end of the work zone. The second cut line (Cut line II, see Figure 4.3) is west of CTH N. Both of the cut lines incorporate traffic taking the US 12 alternate route. The detectors on the alternate route were located at BT112 and BT105. The detectors on the freeway were located at BT107 and BT104.

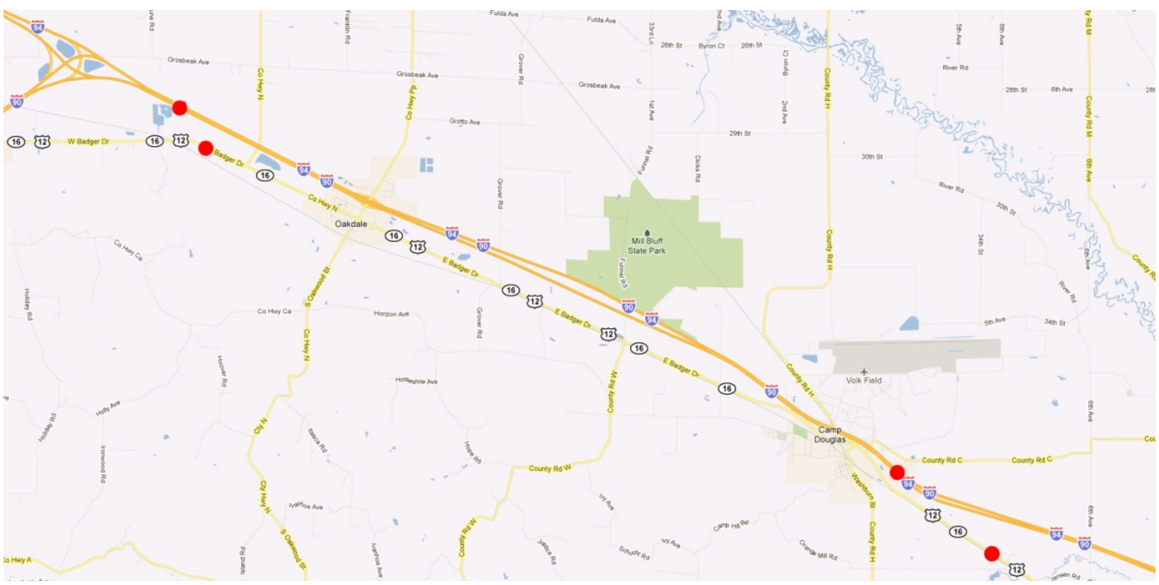

FIGURE 4.3 Cut line I East End of the East Work Zone and Cut line II West of the East Work Zone at Tomah

4.1.2 Daily Diversion Patterns

The research team employed the chi-square test (contingency table analysis) to identify the daily diversion patterns. In diversion analysis, the distribution of daily traffic volumes is being compared between non-closure and closure time periods. The days of the week are broken up into weekdays and weekends. Weekdays consist of Monday through Thursday, and weekends consist of Friday through Sunday. Friday was considered a weekend, because many drivers are traveling to vacation destinations starting in the afternoon. The Portage work zone had 2 days with significant congestion, resulting in queues over 1 mile long. The Tomah work zone had more days with congestion, but some of the congestion was incident induced, and detectors were only out for one day of congestion due only to the work zone itself.

The test results are summarized in Tables 4.1 - 4.4 with the confidence level for both work zones set at 99%.

TABLE 4.1 Chi-Square Test Results at Cut Line I of the Portage Work Zone

Weekday

Chi-Square Test: Mainline, US 12, US 51

```
Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

             Mainline     US 12     US 51   Total
Non-Closure  42833        14620     4822    62275
             43474.64     13913.59  4886.77
             9.470        35.866    0.858

Closure      51193        15472     5747    72412
             50551.36     16178.41  5682.23
             8.144        30.845    0.738

Total         94026     30092    10569     134687

Chi-Sq = 85.921, DF = 2, P-Value = 0.000
```

Weekend

Chi-Square Test: Mainline, US 12, US 51

```
Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

             Mainline     US 12     US 51    Total
Non-closure  52566        13514     3139     69219
             52078.89     13351.64  3788.47
             4.556        1.974     111.341

Closure      61229        15660     5139     82028
             61716.11     15822.36  4489.53
             3.845        1.666     93.955

Total        113795       29174     8278     151247

Chi-Sq = 217.337, DF = 2, P-Value = 0.000
```

TABLE 4.2 Chi-Square Test Results at Cut Line II of the Portage Work Zone

Weekday

Chi-Square Test: Mainline, STH 16

Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

	Mainline	STH 16	Total
Non-closure	29200	3148	32348
	29314.52	3033.48	
	0.447	4.324	
Closure	32087	3194	35281
	31972.48	3308.52	
	0.410	3.964	
Total	61287	6342	67629

Chi-Sq = 9.145, DF = 1, P-Value = 0.002

Weekend

Chi-Square Test: Mainline, STH 16

Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

	Mainline	STH 16	Total
Non-closure	37903	3434	41337
	37792.65	3544.35	
	0.322	3.436	
Closure	43358	4187	47545
	43468.35	4076.65	
	0.280	2.987	
Total	81261	7621	88882

Chi-Sq = 7.026, DF = 1, P-Value = 0.008

TABLE 4.3 Chi-Square Test Results at Cut Line I of the Tomah Work Zone

Weekday

Chi-Square Test: Mainline, US 12

Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

	Mainline	US 12	Total
Non-closure	17609	2093	19702
	17769.39	1932.61	
	1.448	13.310	
Closure	25035	2545	27580
	24874.61	2705.39	
	1.034	9.508	
Total	42644	4638	47282

Chi-Sq = 25.300, DF = 1, P-Value = 0.000

Weekend

Chi-Square Test: Mainline, US 12

Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

	Mainline	US 12	Total
Non-closure	31695	1579	33274
	31085.74	2188.26	
	11.941	169.631	
Closure	27699	2602	30301
	28308.26	1992.74	
	13.113	186.275	
Total	59394	4181	63575

Chi-Sq = 380.960, DF = 1, P-Value = 0.000

TABLE 4.4 Chi-Square Test Results at Cut Line II of the Tomah Work Zone

Weekday

Chi-Square Test: Mainline, US 12

Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

	Mainline	US 12	Total
Non-closure	26779	2990	29769
	26399.46	3369.54	
	5.457	42.751	
Closure	26552	3817	30369
	26931.54	3437.46	
	5.349	41.907	
Total	53331	6807	60138

Chi-Sq = 95.464, DF = 1, P-Value = 0.000

Weekend

Chi-Square Test: Mainline, US 12

Expected counts are printed below observed counts
Chi-Square contributions are printed below expected counts

	Mainline	US 12	Total
Non-closure	32621	2838	35459
	32124.24	3334.76	
	7.682	74.000	
Closure	30110	3674	33784
	30606.76	3177.24	
	8.063	77.669	
Total	62731	6512	69243

Chi-Sq = 167.414, DF = 1, P-Value = 0.000

It can be observed from Tables 4.1 - 4.4 that the chi-square test shows significantly different (p-value < .01) traffic volumes on freeway mainline and alternative routes between non-closure and closure periods, which indicate the diversion to parallel roads is present during the work zone time period.

The percentage splits across each cut line for both work zones are also summarized in Tables 4.5 - 4.8. It can be observed that more diversion exists on weekends than on weekdays at the Portage work zone, and there is slightly more diversion to the US 51 than other alterative routes. However, for the Tomah work zone, one can observe significant diversion during the entire closure time period and weekends exhibit more diversion than weekdays. Overall, the Tomah work zone is showing more diversion than the Portage work zone. Figures 4.4 and 4.5 illustrate the time-dependent percentage splits across the cut line I during the weekends at both work zones.

TABLE 4.5 Weekday Percentage Splits for the Portage Work Zone

	Cutline (Weekday)			
	I South End Work Zone		II North of Work Zone	
	Non-Closure	Closure	Non-Closure	Closure
Mainline (I-39/I-90/I-94 or I-90/I-94)	68.7%	69.0%	89.7%	90.9%
US 12 (Regional Route)	23.5%	22.6%	-	-
US 51 (Alternate Route)	7.7%	8.4%	-	-
STH 16 (Alternate Route)	-	-	10.3%	9.1%

TABLE 4.6 Weekend Percentage Splits for the Portage Work Zone

	Cutline (Weekend)			
	I South End Work Zone		II North of Work Zone	
	Non-Closure	Closure	Non-Closure	Closure
Mainline (I-39/I-90/I-94 or I-90/I-94)	72.6%	70.3%	84.7%	83.8%
US 12 (Regional Route)	18.7%	18.0%	-	-
US 51 (Alternate Route)	8.7%	11.8%	-	-
STH 16 (Alternate Route)	-	-	15.3%	16.2%

TABLE 4.7 Weekday Percentage Splits for the Tomah Work Zone

	Cutline (Weekday)			
	I East End Work Zone		II West of Work Zone	
	Non-Closure	Closure	Non-Closure	Closure
Mainline (I-90/I-94)	92.9%	90.9%	90.0%	87.4%
US 12 (Alternate Route)	7.1%	9.1%	10.0%	12.6%

TABLE 4.8 Weekend Percentage Splits for the Tomah Work Zone

	Cutline (Weekend)			
	I East End Work Zone		II West of Work Zone	
	Non-Closure	Closure	Non-Closure	Closure
Mainline (I-90/I-94)	95.4%	91.4%	93.2%	89.2%
US 12 (Alternate Route)	4.6%	8.5%	6.8%	10.8%

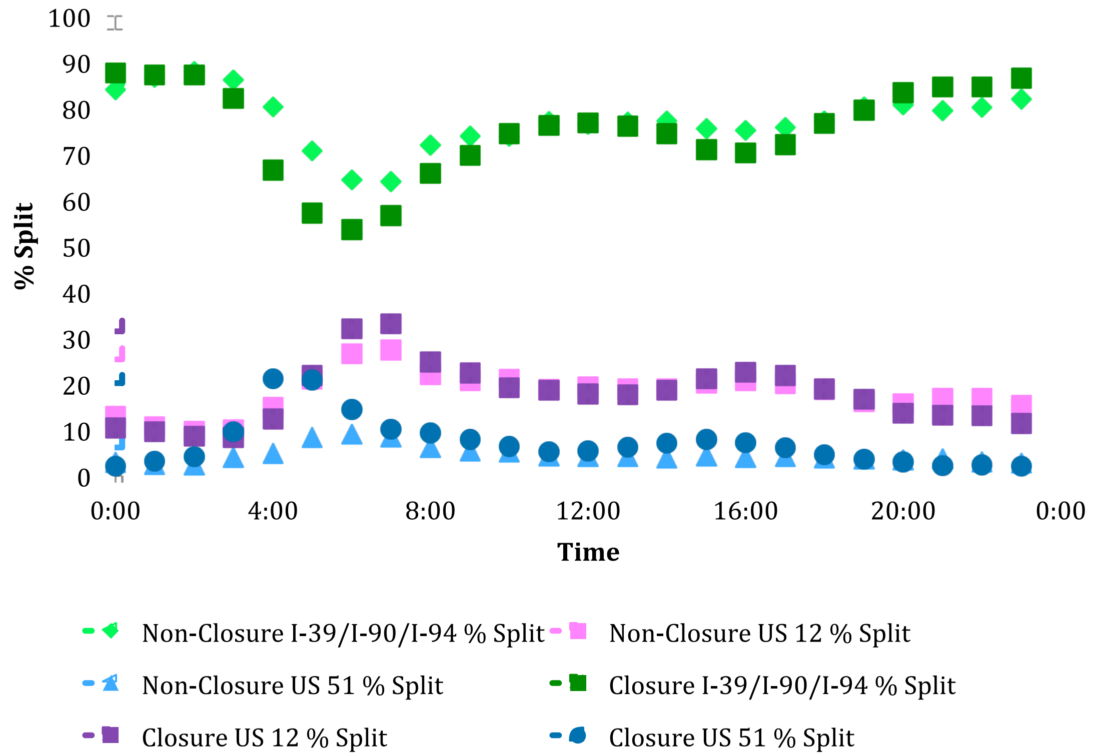

FIGURE 4.4 Time-Dependent Percentage Splits across Cutline I at the Portage Work Zone (Weekend, NB)

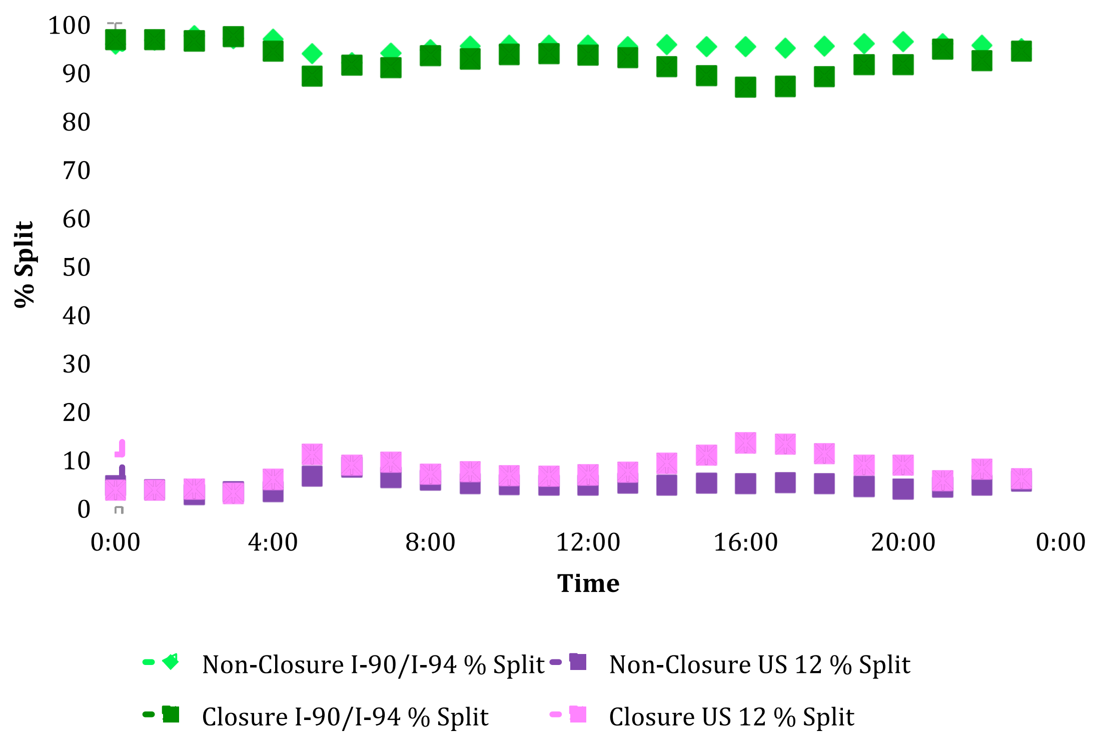

FIGURE 4.5 Time-Dependent Percentage Splits Across Cutline I at the Tomah Work Zone (Weekend, WB)

As shown in Figure 4.4, the percentage splits across the cut line going northbound at Portage work zone exhibit variation in different time intervals. More pronounced diversion can be observed during the peak periods (up to 12% of split change) due to the large amount of trips traveling from/to vacation destinations. Again, US 51 sees larger diversion percentages than other alternative routes during the peak periods. The Tomah work zone exhibits similar patterns of percentage splits change, and the largest percentage of split change is about 10% during the peak periods (see Figure 4.5).

4.1.3 Time-dependent Diversion Percentages

In addition to the analysis daily diversion patterns on the cut lines, the research team has further estimated the time-dependent diversion percentages for both work zones. Figures 4.6 and 4.7 illustrate cumulative volume curves for both work zones during closure and non-closure periods (September 2009), and the difference between the cumulative curves indicates the diversion. Calculation of diversion rates in time periods with queues are summarized in Table 4.9.

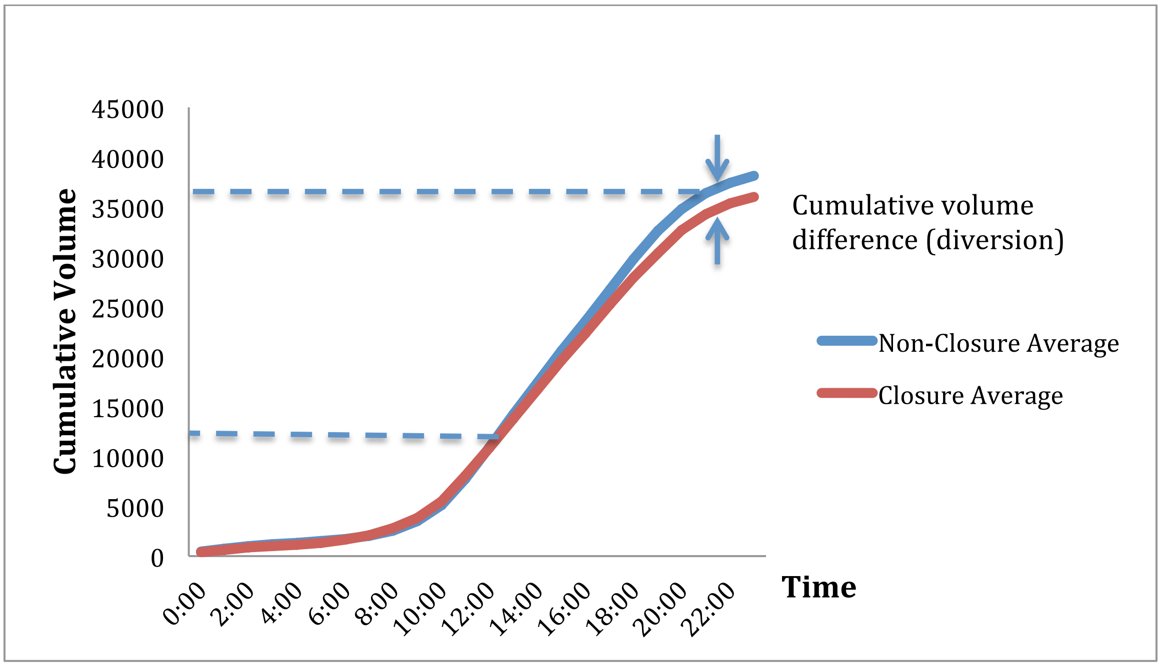

FIGURE 4.6 Time-Dependent Cumulative Diversion Percentages across Cutline I at the Portage Work Zone (Weekend, NB)

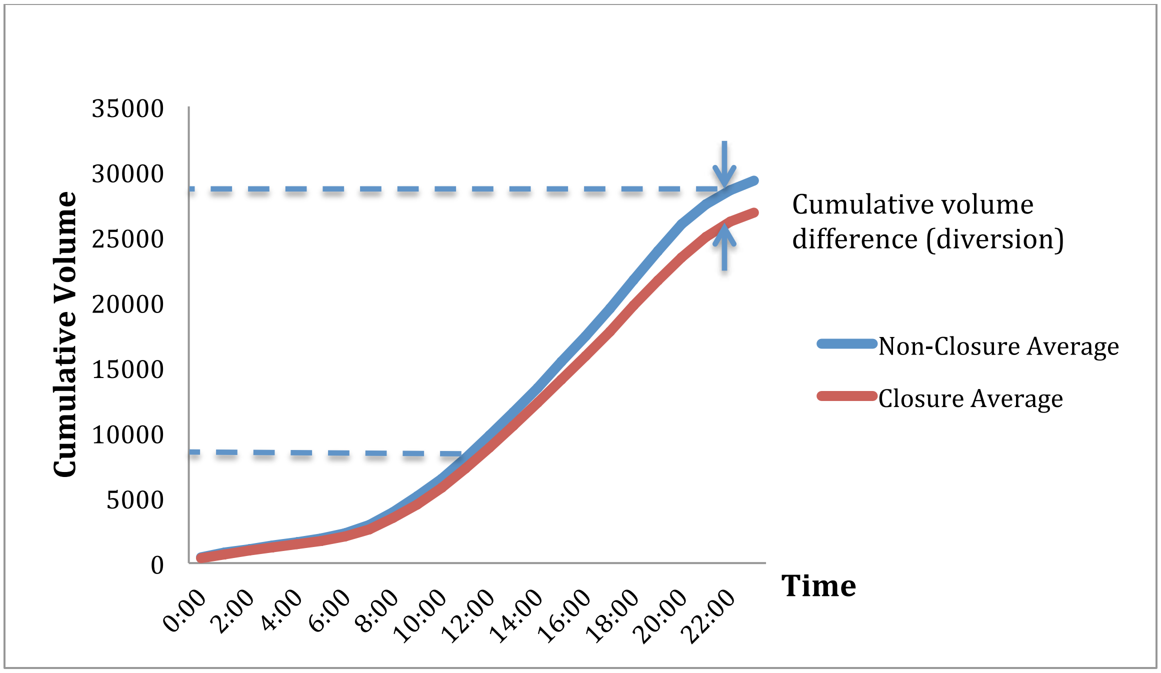

FIGURE 4.7 Time-Dependent Cumulative Diversion Percentages across Cutline I at the Tomah Work Zone (Weekend, NB)

TABLE 4.9 Time-Dependent Cumulative Diversion Percentages at both Work Zones

	I-39/I-90/I-94 (north of CTH DM) SB	I-90/I-94 (east of CTH A) SB (EB)
	Diversion %	Diversion %
11:00	6.2	9.9
12:00	5.4	9.6
13:00	5.3	8.9
14:00	5.6	8.6
15:00	5.6	8.9
16:00	4.7	8.9
17:00	4.4	9.0
18:00	3.1	9.1
19:00	3.8	9.3
20:00	3.8	9.9
21:00	3.8	9.0
Daily	3.7	8.4

It can be observed that both work zones exhibit substantial amounts of diversion of traffic during the closure period from 11:00AM to 9:00PM in which queue exists, and the Tomah work zone exhibits larger diversion percentages than the Portage work zone. It should be mentioned that the cut lines may not capture all possible diversion activities, so diversion percentages estimated in this section are approximate values but are still useful reference for engineering judgment in planning future work zones with rural settings.

4.2 Bluetooth Analysis of Diversion

4.2.1 Bluetooth Triple Hits

The Bluetooth analysis of diversion is the most conclusive evidence of diversion, where a vehicle is tracked as it gets off the freeway, diverts around the work zone, then gets back on as part of a long distance route. Tables 4.10-4.12 show the triple hits for diversion off the freeway.

TABLE 4.10 Portage Diversion Bluetooth Triples (SB/EB Direction)

EB (SB) Alternate Route (US 51)		
Triple	**Non-Closure**	**Closure**
BT11 - BT6 - BT1	0	11
BT11 - BT6 - BT2	0	4
BT11 - BT6 - BT4	0	4
BT10 - BT6 - BT1	0	2
BT10 - BT6 - BT2	0	1
BT10 - BT6 - BT4	0	1
BT8 - BT6 - BT1	1	3
BT8 - BT6 - BT2	0	0
BT8 - BT6 - BT4	0	1
BT7 - BT6 - BT1	1	5
BT7 - BT6 - BT2	0	0
BT7 - BT6 - BT4	0	9

TABLE 4.11 Portage Diversion Bluetooth Triples (NB/WB Direction)

WB (NB) Alternate Route (US 51)		
Triple	**Non-Closure**	**Closure**
BT1 - BT6 - BT11	0	1
BT1 - BT6 - BT10	1	2
BT1 - BT6 - BT8	0	2
BT1 - BT6 - BT7	0	0
BT2 - BT6 - BT11	0	1
BT2 - BT6 - BT10	0	1
BT2 - BT6 - BT8	1	0
BT2 - BT6 - BT7	1	1
BT4 - BT6 - BT11	0	1
BT4 - BT6 - BT10	0	2
BT4 - BT6 - BT8	1	7
BT4 - BT6 - BT7	0	3

TABLE 4.12 Tomah Diversion Bluetooth Triples (WB Direction)

WB (NB) Alternate Route (US 12) East WZ		
Triple	**Non-Closure**	**Closure**
BT108 - BT105 - BT102	3	11
BT108 - BT106 - BT102	2	8
BT108 - BT112 - BT102	0	6
BT108 - BT105 - BT109	8	14
BT108 - BT106 - BT109	2	26
BT108 - BT106 - BT104	2	64
BT108 - BT112 - BT104	3	85
BT108 - BT106 - BT105 - BT103	2	10
BT108 - BT112 - BT105 - BT103	0	5
BT112 - BT106 - BT105	46	88

TABLE 4.13 Tomah Diversion Bluetooth Triples (EB Diversion)

EB (SB) Alternate Route (US 12) East WZ		
Triple	**Non-Closure**	**Closure**
BT102 - BT105 - BT108	3	20
BT102 - BT106 - BT108	0	63
BT102 - BT112 - BT108	0	32
BT103 - BT105 - BT108	3	40
BT103 - BT106 - BT108	0	59
BT103 - BT112 - BT108	0	61
BT109 - BT105 - BT108	13	34
BT109 - BT106 - BT108	1	48
BT105 - BT106 - BT112	47	127

The results show some diversion at the Portage work zone (pronounced increase in the Bluetooth triple hits during the work zone period), but the numbers are small in comparison to the Tomah work zone. The Bluetooth analysis reinforces the findings from the cut line analysis in the previous section. Also, there is evidence that more vehicles are diverting from the east work zone more than from the west work zone, which can be attributed to the splitting of I-90 and I-94. The west work zone is after I-90 splits from I-94, which will produce a higher chance the volume will be under capacity.

4.2.2 Bluetooth Travel Time v. Alternative Route Volume

Based on the travel time data from the Bluetooth detectors, a significant number of drivers are making spontaneous decisions, or link-by-link decisions, meaning they will divert only if they see congestion, at both the Portage work zone and the Tomah work zone. In both the Portage and Tomah work zone, the majority of the diversion triples are occurring during days of congestion. Fridays and Sundays are more prone to congestion in rural areas of Wisconsin, but not all Fridays and Sundays encountered congestion. Figures 4.8-4.15 show the increase in volume on the alternate route with a plot of the travel times (average traveling speed) through both work zones. The average speed covers all usable speeds (which is derived from travel time) occurring in an hour (for example 5:00 – 6:00). The non-closure volume is an average of all volumes occurring on a certain day of the week (for example in Figure 4.8, the non-closure volume averages all Sundays in the non-closure time period). The non-closure speed is an average of all speeds occurring on a certain day of the week, similar to the non-closure volume.

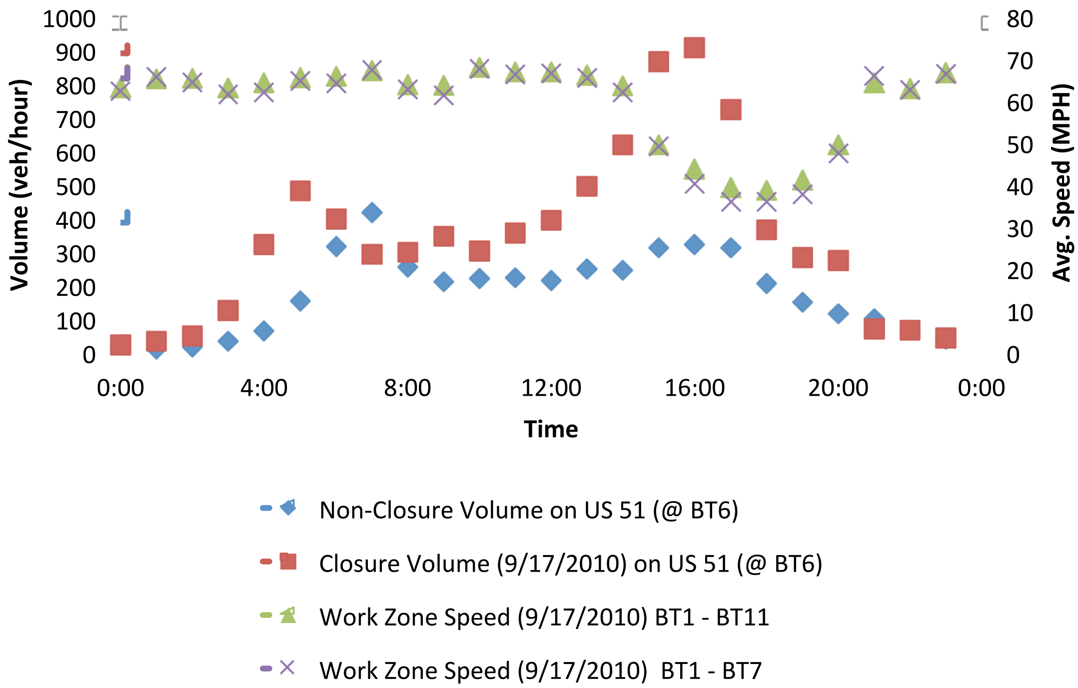

FIGURE 4.8 Comparison of Volume on the Alternate Route (US 51) and Speed for NB Freeway Traffic at the Portage Work Zone (With Congestion)

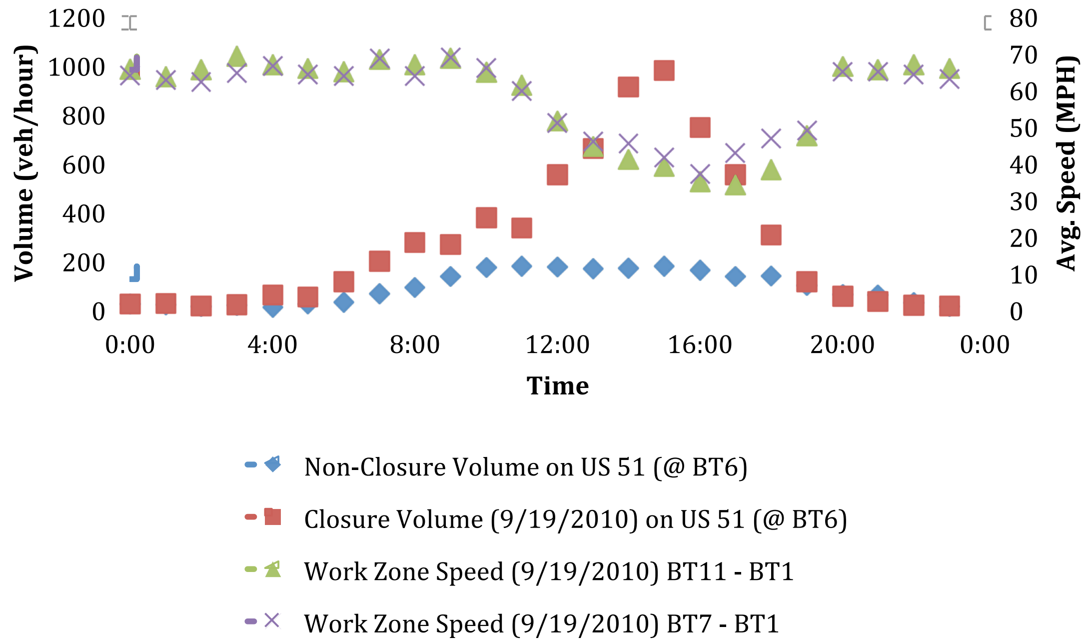

FIGURE 4.9 Comparison of Volume on the Alternate Route (US 51) and Speed for SB Traffic at the Portage Work Zone (With Congestion)

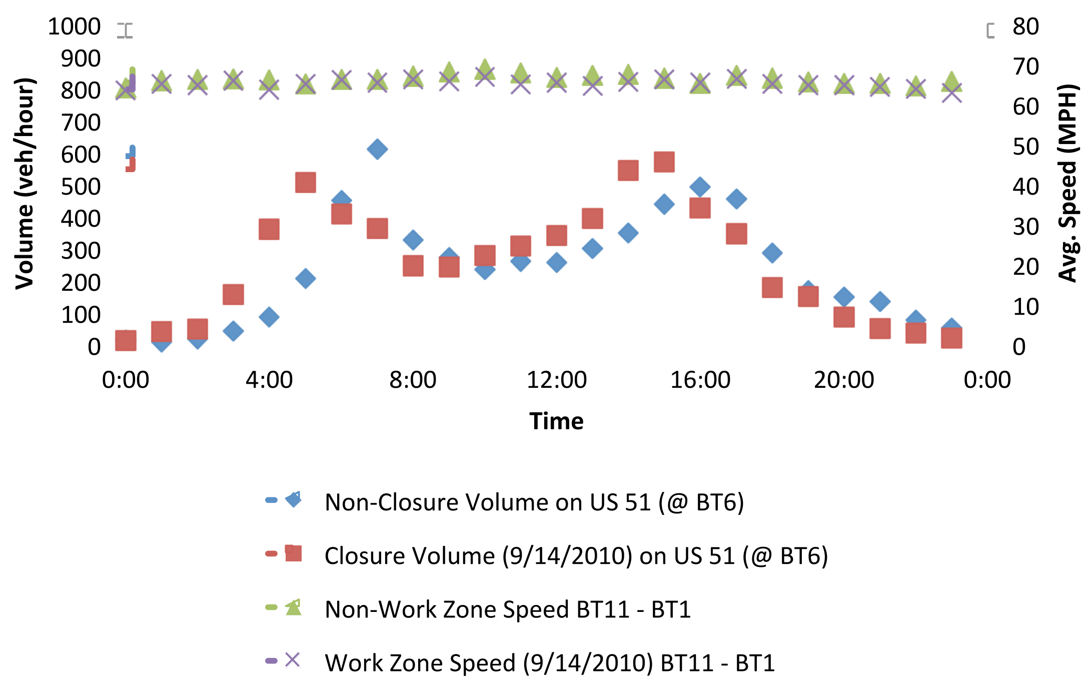

FIGURE 4.10 Comparison of Volume on The Alternate Route (US 51) and Speed for NB Freeway Traffic at the Portage Work Zone (Without Congestion)

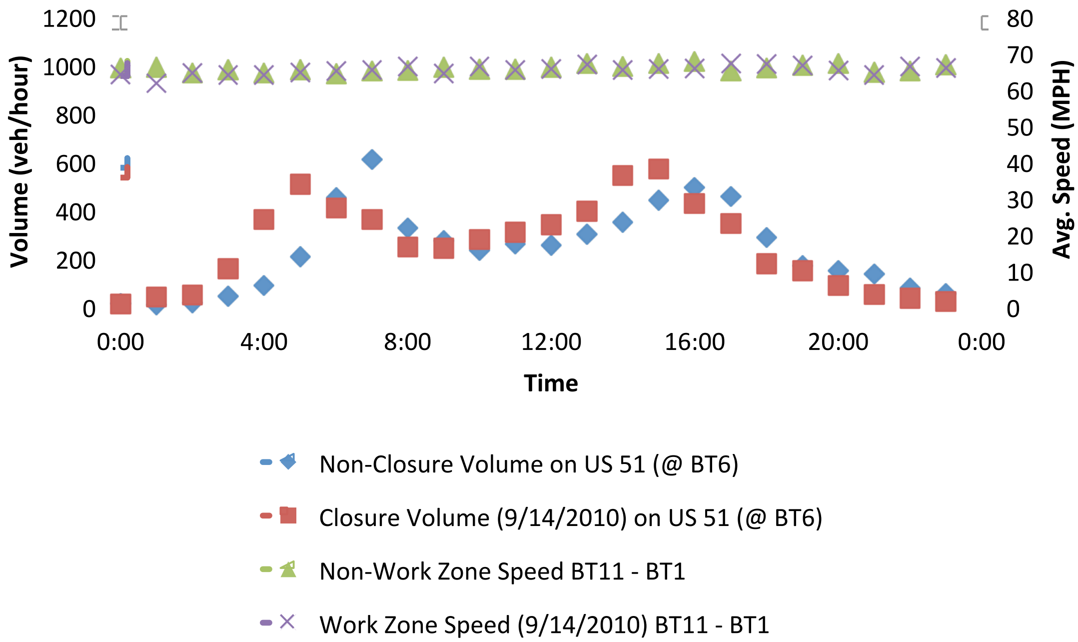

FIGURE 4.11 Comparison of Volume on the Alternate Route (US 51) and Speed for SB Freeway Traffic at the Portage Work Zone (Without Congestion)

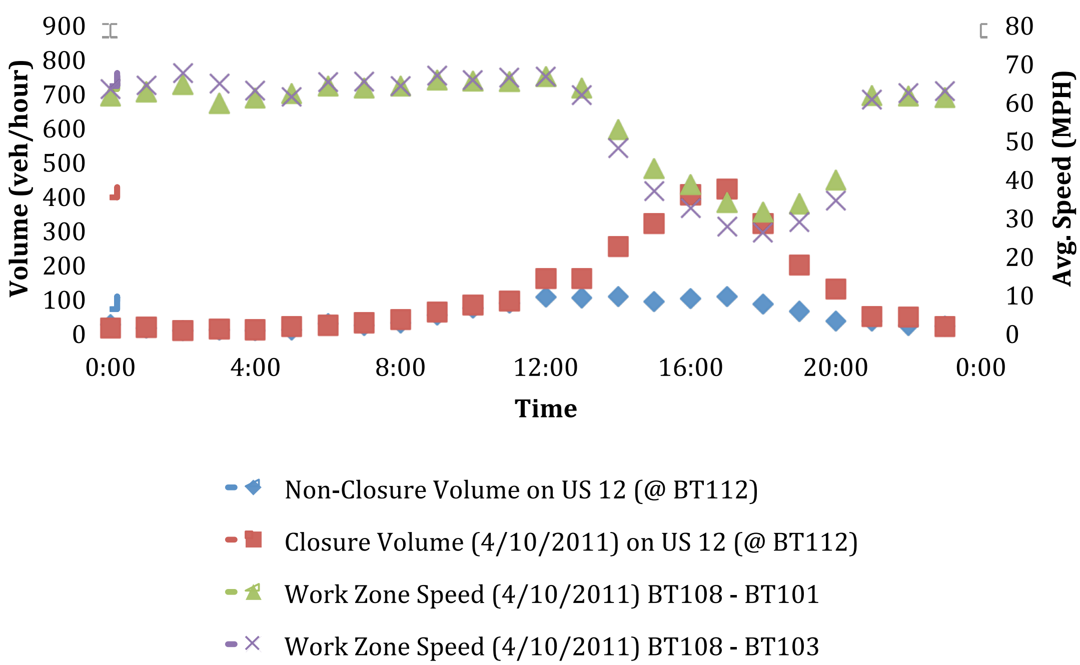

FIGURE 4.12 Comparison of Volume on the Alternate Route (US 12) and Speed for EB Freeway Traffic at the Tomah Work Zone (With Congestion)

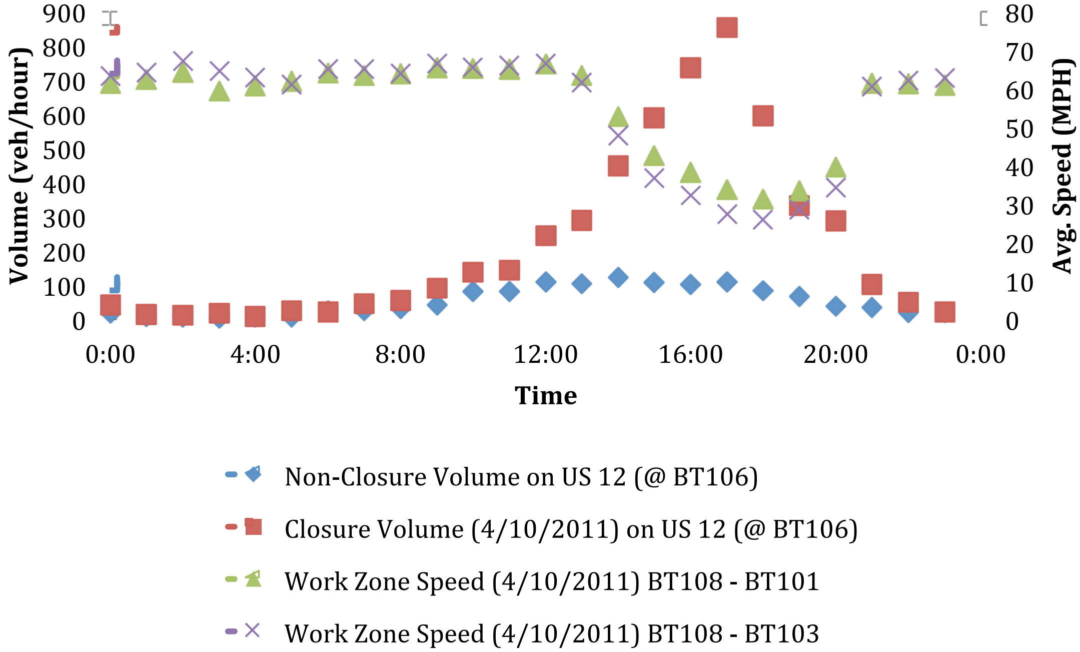

FIGURE 4.13 Comparison of Volume on the Alternate Route (US 12) and Speed for WB Traffic at the Tomah Work Zone (With Congestion)

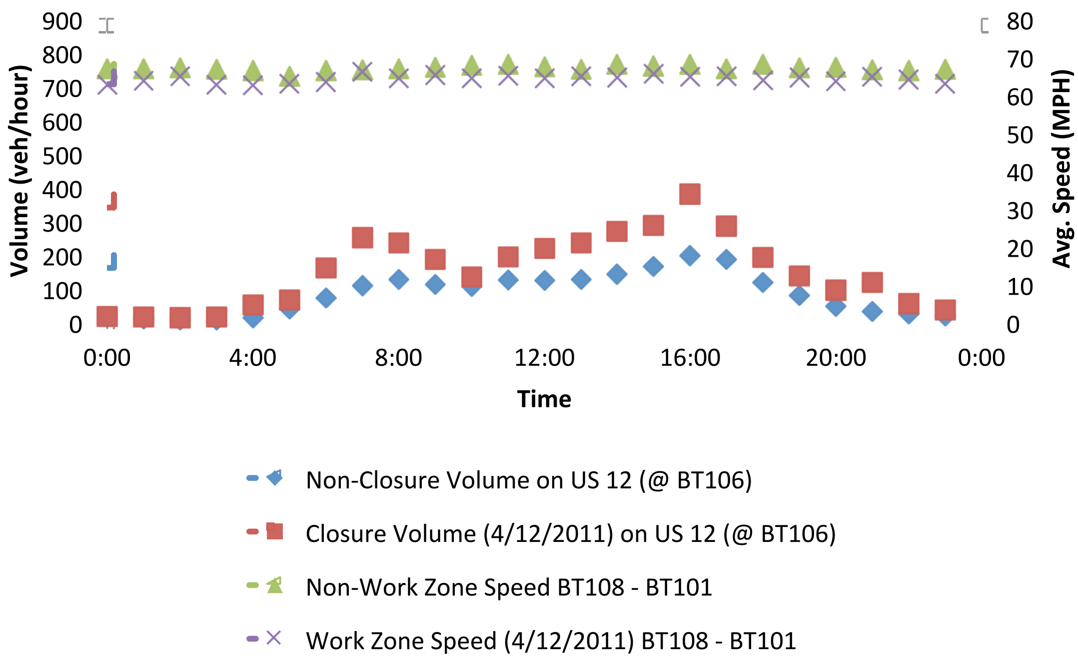

FIGURE 4.14 Comparison of Volume on the Alternate Route (US 12) and Speed for EB Freeway Traffic at the Tomah Work Zone (Without Congestion)

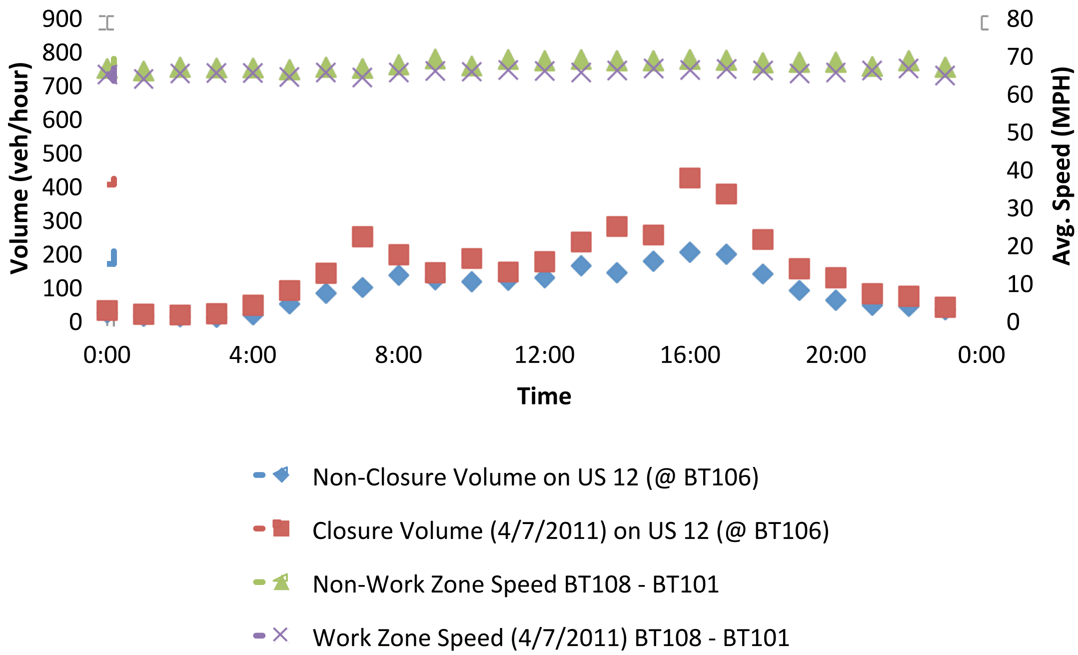

FIGURE 4.15 Comparison of Volume on the Alternate Route (US 12) and Speed for WB Freeway Traffic at the Tomah Work Zone (Without Congestion)

The graphs above show drivers are getting both pre-trip information and basing their decisions on a link-by-link basis. On days without congestion, drivers are diverting from both rural work zones, but at a much smaller rate than when congestion occurs. The best comparison occurs at the Portage work zone, where data were collected on two Fridays and two Sundays, with noticeable congestion and queuing on one Friday (9/17/2010) and one Sunday (9/19/2010), and no noticeable congestion and queuing on the other Friday and Sunday. This is the best evidence of gaining pre-trip information prior to making their trip, or from prior experience (encountering congestion two days earlier going NB). Drivers making link-by-link decisions primarily occur during the week, where congestion is expected to be low. In the Tomah work zone, on a day with congestion (4/10/2011), the volume peak is roughly seven times the non-closure volume, where a Tuesday (4/12/2011) with no congestion produces a peak that is almost double the non-closure value. An analysis of a Thursday (4/7/2011) also produced the same result, concluding that more drivers are more willing to drive through the work zone when the travel time is not expected to be reduced.

4.3 Analysis of Diversion from Ramp Volumes

The ramp volumes can be another indication of diversion taking place. A decrease in on-ramp volume can indicate natural diversion or demand suppression (for example, less people stopping at that point), while an increase in off-ramp volume can indicate drivers diverting around the work zone. A decrease in off-ramp volume inside the work zone can indicate diversion too (e.g., drivers that live in the area got off the freeway at a location before they would normally would). Due to the lack of data for the Portage work zone, ramp data will only be analyzed for the Tomah work zone. Tables 4.13-4.14 show the average 15-minute traffic counts for all of the ramps for both EB and WB traffic. In some of the ramps, there were detector malfunctions, resulting in no data for one of the time periods.

TABLE 4.14 Ramp Volumes for WB Traffic at the Tomah Work Zone

	Avg. 15 Min Volume (Weekday)		Avg. 15 Min Volume (Weekend)	
Ramp	**Non-Closure**	**Closure**	**Non-Closure**	**Closure**
I-90/I-94				
STH 80 off-ramp	11.6	11.6	12.5	13.6
STH 80 on-ramp	11.5	9.5	9.6	7.8
CTH C off-ramp	5.5	4.9	4.5	5.9
CTH C on-ramp	9.7	7.0	7.4	4.5
CTH PP off-ramp	18.7	21.4	15.8	18.2
CTH PP on-ramp	27.1	30.6	24.7	28.8
I-94				
Forbes Rd. on-ramp	12.5	11.9	10.3	9.3
STH 21 on-ramp	7.8	7.9	10.0	9.6
US 12 on-ramp	18.1	17.8	16.9	16.5
CTH EW off-ramp	4.5	4.1	5.2	4.4
CTH EW on-ramp	2.0	1.8	2.3	2.2
CTH O on-ramp	3.5	2.8	3.1	2.5
I-90				
US 12/STH 16 off-ramp	12.8	12.1	10.3	9.6
US 12/STH 16 on-ramp	7.3	7.8	5.0	6.7
STH 131 on-ramp	20.6	19.2	13.4	15.3

TABLE 4.15 Ramp Volumes for EB Traffic at the Tomah Work Zone

Ramp	Avg. 15 Min Volume (Weekday) Non-Closure	Avg. 15 Min Volume (Weekday) Closure	Avg. 15 Min Volume (Weekend) Non-Closure	Avg. 15 Min Volume (Weekend) Closure
I-90				
STH 131 off-ramp	21.6	20.8	16.8	16.9
STH 131 on-ramp	6.8	10.4	5.6	5.5
US 12/STH 16 off-ramp	6.0	7.3	4.0	6.3
US 12/STH 16 on-ramp	11.4	11.1	8.5	8.7
I-94				
CTH O off-ramp	2.5	2.2	2.9	2.1
CTH O on-ramp	2.6	2.1	3.9	2.3
CTH EW on-ramp	4.2	3.9	5.1	4.5
US 12 off-ramp	24.4	24.0	26.6	23.5
US 12 on-ramp	15.1	11.7	13.9	10.1
STH 21 on-ramp	40.0	39.9	38.1	34.1
Forbes Rd. off-ramp	12.2	12.2	9.5	9.2
Forbes Rd. on-ramp	14.8	13.9	11.1	9.6
I-90/I-94				
CTH PP off-ramp	26.0	29.0	-	-
CTH PP on-ramp	17.9	21.3	15.4	18.1
STH 80 off-ramp	10.6	9.2	8.9	7.7
STH 80 on-ramp	10.4	12.4	11.2	13.0

The ramp volumes show shows some diversion during the weekdays, especially at ramp locations close to the work zone, but the most diversion is on weekends. In the east work zone, more drivers are diverting ahead at STH 80. Also, more drivers are not using the on-ramp at CTH C, and the CTH PP on-ramp is elevated, concluding that drivers are diverting from the second work zone.

The increase in off-ramp volume and decrease in on-ramp volume indicates diversion, but the quantity and location can give some insights to driver behavior. In the Tomah work zone, the WB STH 80 off-ramp had a noticeable increase in the averaged weekend volume, indicating a large number of drivers are diverting, and in most cases with no observation of stopped vehicles ahead on the freeway. This suggests that drivers are either getting some pre-trip information or learning from past experiences. However the negligible increase in the WB STH 80 off-ramp occurring during the weekdays, would indicate a different pattern to driver behavior, which cannot be fully explained by the existing data. These drivers are less prone to divert.

4.4 Summary of Findings

This chapter has conducted empirical analysis of traffic diversion at two rural Wisconsin work zones. Data from traffic detectors and Bluetooth technology provided insights as to how much traffic is diverting and where traffic is diverting, and the causes for diversion. The following findings can be reached based on empirical data.

- Both work zones had a significant shift in volumes, which indicates diversion, at the 99% significance level. The level of diversion varied between weekdays and weekends, ranging from 4% to 10%. The Bluetooth devices can be used for diversion, and can either track a vehicle as it diverts from the freeway as part of a long distance trip or track how many vehicles are traveling on an alternate route for a modest distance. The most pronounced increases for long distance diversion came from the Tomah work zone.
- If there is a parallel alternate route with easy access, more drivers will divert when the freeway becomes congested, which can be demonstrated by referencing the Portage and Tomah work zones. The Tomah work zone had an obvious alternate route that was close to the freeway, where the Portage work zone required a driver to divert a longer distance from the freeway. The Tomah work zone had more increases in volume and Bluetooth hits, indicating more diversion taking place.

CHAPTER 5: MODELING DIVERSION BEHAVIORS

From a diversion standpoint, the most critical opinions for state DOTs are causes of drivers to pass through the work zone, speeds that will cause drivers to divert, and perceived travel time savings on an alternate route that will cause drivers to divert. The Portage and Tomah surveys were combined to form the "rural setting", and consisted of responses from 485 drivers (279 drivers at Portage and 206 drivers at Tomah, see Appendix A.1 and A.2 for questions used in the survey). Drivers were surveyed at rest stops and gas stations that were located a short distance downstream from the work zones.

5.1 Attributes of Surveyed Drivers

Table 5.1 shows the socioeconomic attributes of drivers obtained from the survey at Portage and Tomah work zones and those for all drivers on US trips (both urban and rural) with a distance of greater than 31 miles from the 2009 National Household Travel Survey (NHTS). It can be observed that drivers varied in age and gender in a way similar to the general driver population, but the survey had slightly fewer older drivers than would have been expected. Nonetheless, the opinions are still considered to be representative of the whole driver population in the corridor.

TABLE 5.1 Attributes of The Drivers Who Filled out the Survey Compared to US Data

	Portage work zone		Tomah work zone	NHTS
Gender	Male	64.8%	74.9%	66.0%
	Female	35.2%	25.1%	34.0%
Commercial truck	Yes	5.6%	16.2%	
	No	94.4%	83.8%	
Age	16 - 25	6.6%	6.1%	4.5%
	26 - 45	36.2%	31.5%	26.9%
	46 - 65	46.9%	54.3%	51.8%
	66 or more	10.3%	8.1%	16.8%

Figures 5.1 and 5.2 show the distribution of trip purposes for surveyed drivers at both work zones. At the Portage work zone, the results showed most of the trip purposes were leisure. Leisure trips include all vacation travel, for which the freeway is a gateway to the Wisconsin Dells among the many recreational destinations. For the Tomah work zone trip purposes are distributed across leisure, work, and business. The Tomah segment of freeway is a gateway to Eau Claire and Minneapolis, which are business centers.

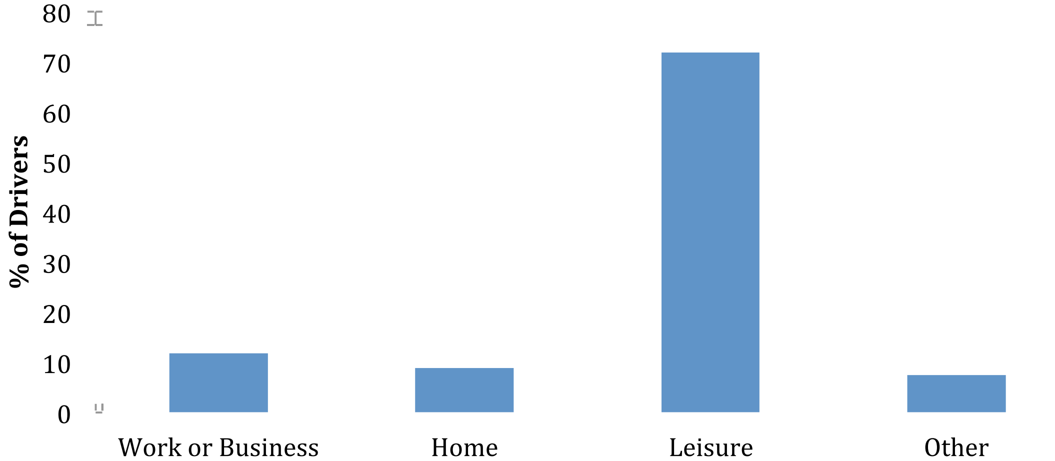

FIGURE 5.1 Distribution of Trip Purposes for Drivers at Portage Work Zone

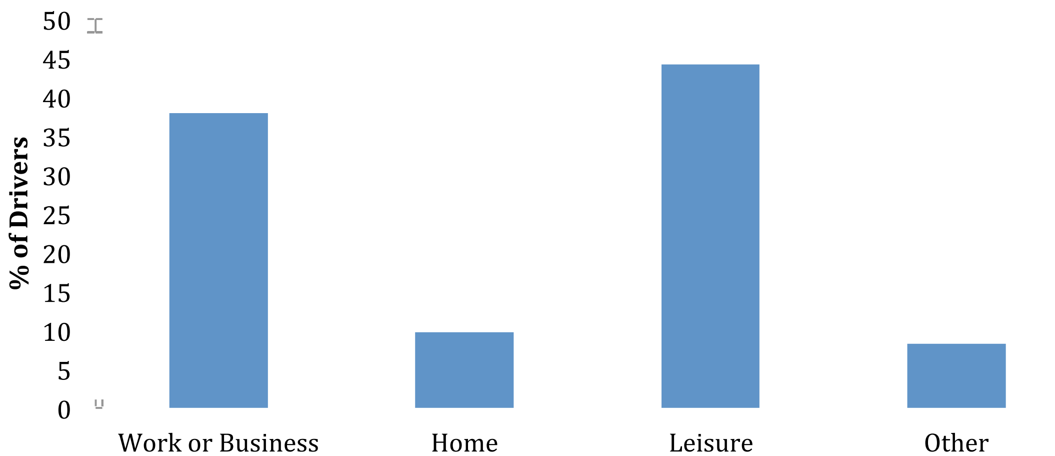

FIGURE 5.2 Distribution of Trip Purposes for Drivers at Tomah Work Zone

Figures 5.3 and 5.4 summarize the distribution of trip frequencies for drivers at both work zones. Results show a varied mix of the drivers using this freeway several times per month or rarely, which is expected with vacation or leisure trips.

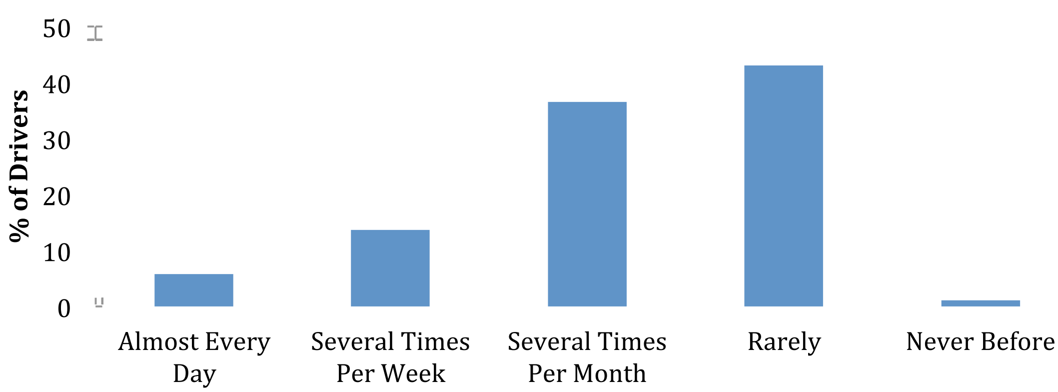

FIGURE 5.3 Distribution of Trip Frequencies for Drivers at Portage Work Zone

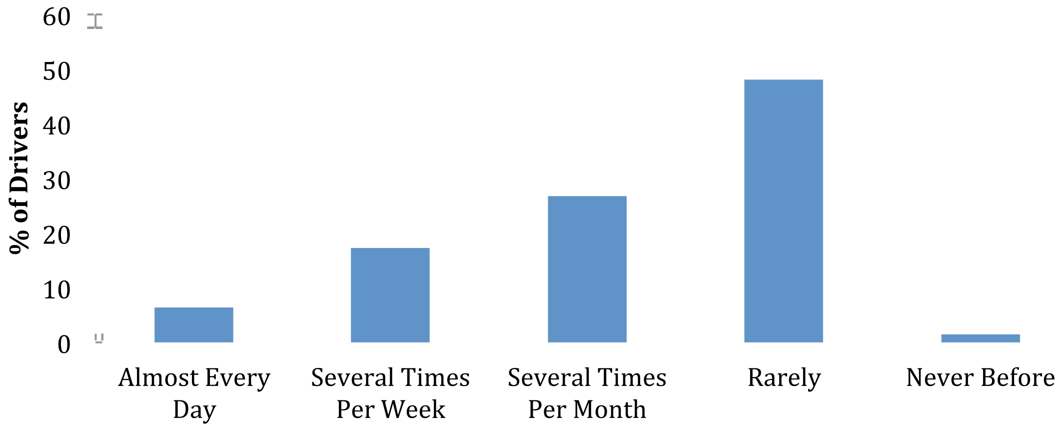

FIGURE 5.4 Distribution of Trip Frequencies for Drivers at Tomah work zone

5.2 Driver Diversion Decisions

Figure 5.5 shows the deciding factors for surveyed drivers passing through the work zone rather than diverting. In both work zones, almost nobody is passing through the work zone because they observe few cars taking the alternate route. Some drivers did not divert because of the lack of guidance on the alternate route. In the Tomah driver survey, there were fewer drivers that stated they were unfamiliar with an alternate route and fewer drivers that said the alternate route is much longer than the original. These statements are validated by the volume data in Chapter 4 of this report showing more diversion for the Tomah work zone as compared to the Portage work zone. The alternate route for the Tomah work zone is in close proximity and runs parallel to the freeway, and the freeway is visible to the driver on some parts of the alternate route.

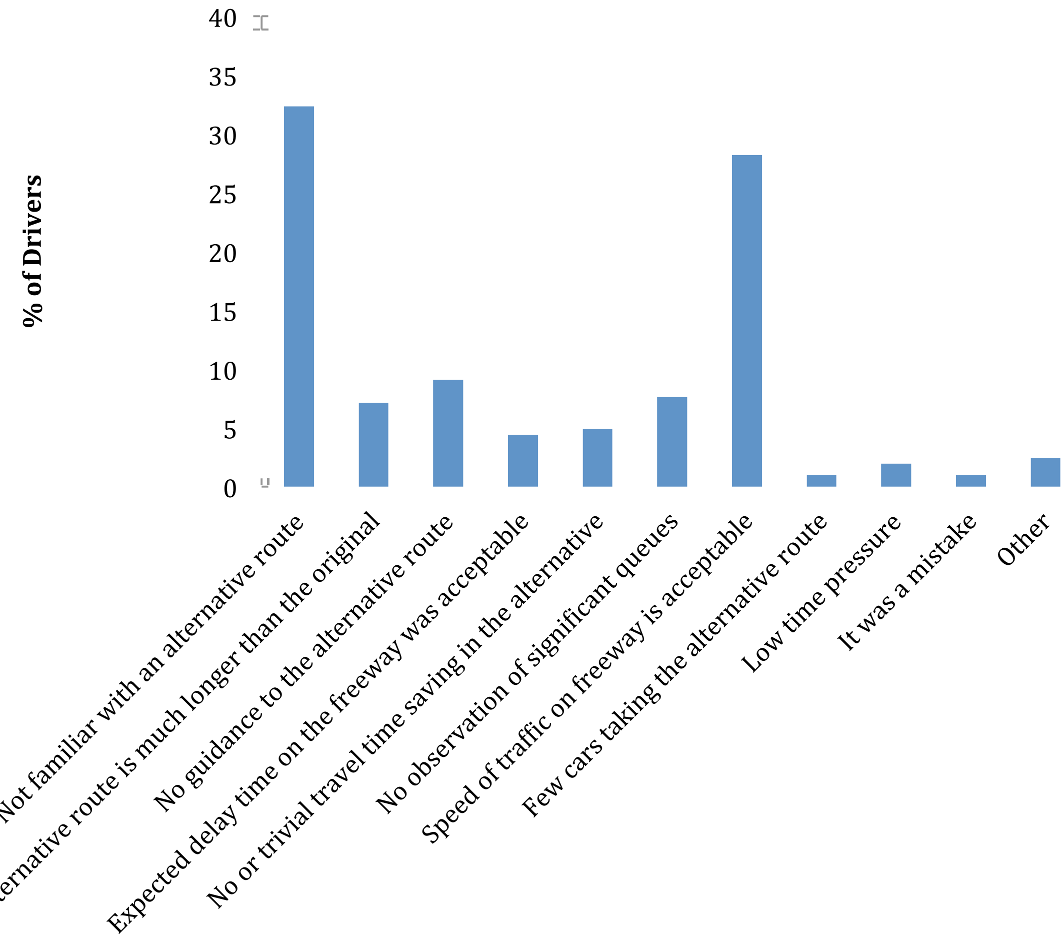

FIGURE 5.5 Factors for Drivers Traveling through the Work Zone (Portage and Tomah Combined)

Figure 5.6 shows the factors encouraging drivers to circumvent the work zones. The most important factors for taking an alternate route involve time savings.

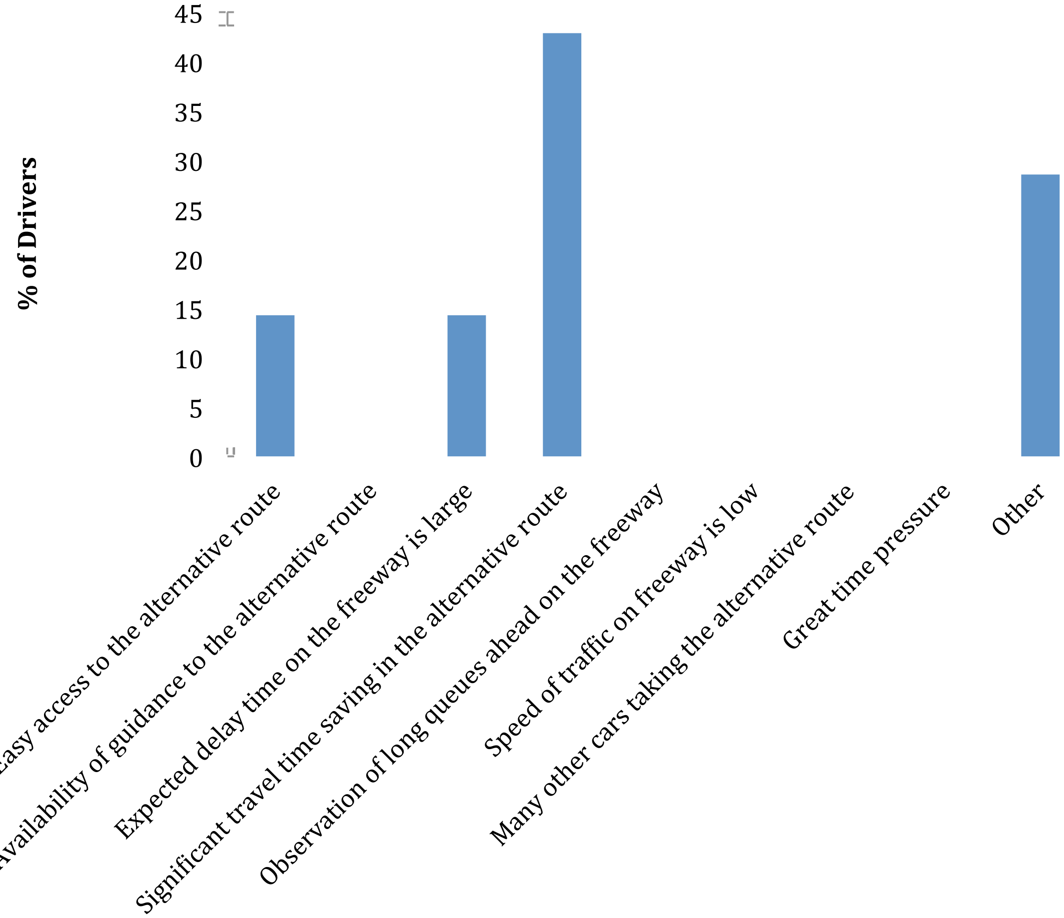

FIGURE 5.6 Factors Encouraging Drivers to Take an Alternative Routes (Portage and Tomah Combined)

This study has also investigated how speeds and travel time savings affect decisions to divert from the freeway. In work zones with a rural setting, it takes relatively slow speeds (see Figure 5.7) on the freeway for drivers to change their route, and a significant number of drivers would not change their route regardless of speed. The biggest factor for resistance to change could be the lack of knowledge of an alternate route. In rural areas, many drivers are traveling to vacation destinations, where the arrival time is not critically important.

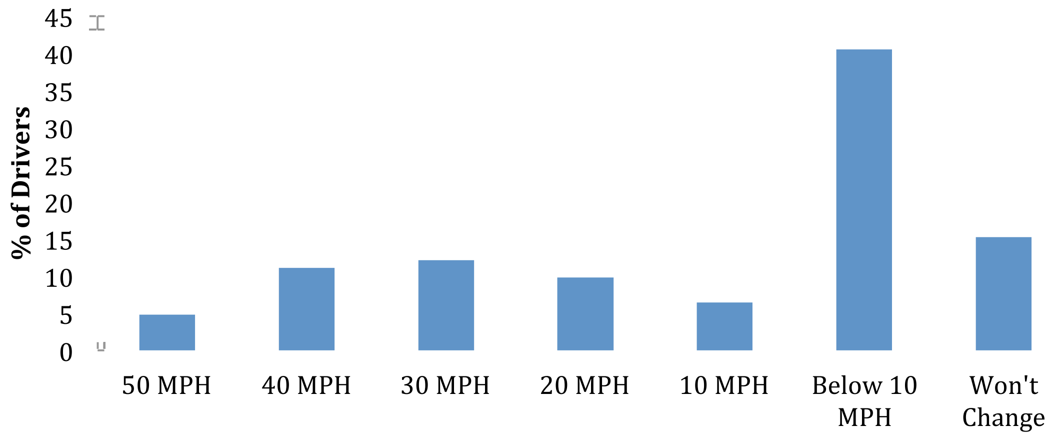

FIGURE 5.7 Speed on the Freeway before Drivers Would Change Their Route (Portage and Tomah Combined)

Large travel time savings are needed for drivers to divert at the two rural work zones (see Figure 5.8), which is comparable to the low speeds on the freeway, as explained before. Also, there were even a higher percentage of drivers that stated they would not change. Large requirements for travel time savings are most likely related to the long distance of most rural trips. On a long distance trip, such as Milwaukee to the Wisconsin Dells, a possible savings of 15 to 20 minutes might not be worth the consequences of making a mistake.

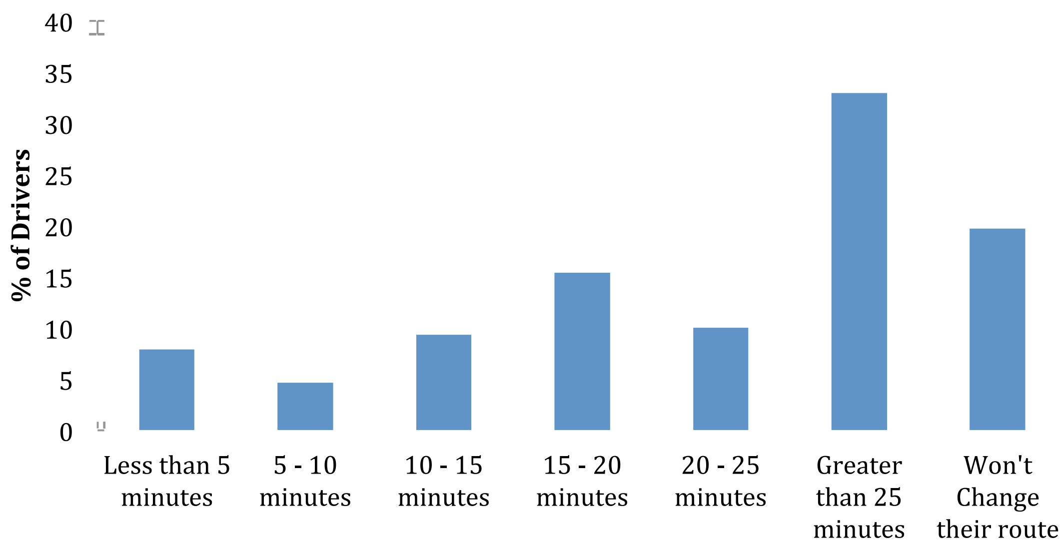

FIGURE 5.8 Perceived Travel Time Savings on the Alternate Route to Divert from the Freeway (Portage and Tomah Combined)

5.3 Summary of Findings

This chapter focuses on exploring drivers' diversion behaviors at rural work zones using field driver survey data. We can observe the following findings:

- Drivers tend not to plan ahead and tend not to gain pre-trip information for rural work zones.
- It will require slow speeds (less than 10 mph) on the freeway and high perceived travel time savings (more than 25 min) on the alternate route for drivers to divert from a rural work zone. Approximately 20% of drivers expressed a stubborn attitude saying they would not divert.
- As public concerns have increased about delays due to highway lane restrictions and the need for travel time reliability, state DOTs need to obtain a better understanding of the decision-making process of drivers when being presented with the availability of alternate routes. Surveys, such as the one presented here, are helpful in this regard.

CHAPTER 6: CONCEPTUAL MODEL OF DRIVER ROUTE SELECTION NEAR WORK ZONES

6.1 Current Route-Choice Paradigm

Observations of traffic in rural and urban work zones, combined with questionnaire results, suggest that drivers, as a group, behave in complex ways when dealing with work zones. For decades, urban travel models have relied heavily on an elementary principle: all drivers minimize some measure of resource expenditure, often called "impedance" or "disutility", while reaching their destinations. Traditionally, travel time alone has been a proxy for impedance, but many models have been built where impedance involves travel distance and travel costs, as well. Recently, there has been some interest by planners in including travel time reliability in impedance. If all drivers are able to minimize their own impedance when selecting routes, the network is said to be in equilibrium. Algorithms are available for finding the theoretical equilibrium, referred to as Wardrop's first principle, on a travel network. However, data suggests that for short-term urban work zones and for rural work zones, the actual traffic patterns do not correspond to an equilibrium situation. Wardrop's first principle states that all used paths between an origin and destination should have equal impedances, a state that often does not exist when there is a work zone. Wardrop's first principle can be achieved in reality only when drivers have very good information about anticipated travel times on all possible routes and drivers are willing to act on that information. The survey of Chapter 5 negates both of these requirements.

Not all drivers receive complete information about work zone conditions and delays, and many other drivers fail to correctly incorporate work zone information into their route choice decision-making. Rural work zones have many occasional drivers who may not have experienced a particular work zone first-hand or who are unfamiliar with alternative routes. Short-term urban work zones have for the most part familiar drivers, but these drivers may not have had sufficient time to learn which route is best for them.

Travel models theoretically have the ability to assign drivers to paths using a variety of rules. Simulated drivers can be divided into "classes" and each class can be treated quite differently. Different classes can be given different impedance functions that vary in the amount of emphasis placed on travel time, travel distance and costs (and possibly reliability). Furthermore, different classes may be restricted from certain routes. Finally, simulated drivers of different classes can be given different sets of travel times, depending upon the quality of information they are assumed to have obtained prior to commencing their trips. Simulated drivers could be given any one of the following sets of travel times in a dynamic traffic assignment (DTA).

- *Free travel times:* Link (road segments) and node (intersections) traversal times are calculated as if traffic was very light. Free travel times are usually almost constant over time, but could vary with time-dependent changes in traffic controls.
- *Static travel times:* Link times and node times are calculated when loaded with normal traffic, but simulated drivers are routed only with the travel times for the time interval in which the trip commences.
- *Dynamic travel times:* Link times and node times are calculated when loaded with normal traffic, and simulated drivers are routed with travel times for all time periods covering their trips.

Travel times are computed averages across all drivers within a single time interval.

The different sets of travel times represent different levels of knowledge and different levels of willingness to act on that knowledge. Models incorporating Wardrop's first principle often assume that drivers have perfect knowledge of delays, as reflected in dynamic travel times, on all alternate routes, which is acceptable for normal, weekday urban traffic conditions. Emerging methods of handling reliability in travel forecasting models recognize that there are day-to-day variations in travel times as faced by a single driver due to randomness in traffic flow and driver behavior. However, Wardrop's first principle still applies.

6.2 Driver Behavior in and around Work Zones

Disequilibrium is often observed in parts of road systems near work zones. Driver surveys for this project in Portage and Tomah, as well as a similar survey for I-94 in Milwaukee, conducted by this research team, identify two types of drivers.

- *Resigned drivers:* Resigned drivers will always go through the work zone, if possible. Resigned drivers are unaware of the work zone, or do not possess enough information to make a choice, or are reluctant to travel on an alternative route. Tourists may be typed as "resigned", because of their unfamiliarity with the local geography and road system.
- *Aware Drivers:* Aware drivers have information about work zone delays, either from information obtained pre-trip or en route or from personal experience. These drivers may or may not go through the work zone, depending upon the perceived amount of delay. Aware drivers vary greatly in their sensitivity to delays, but are biased toward their originally planned route.

Furthermore, traffic data (see Figures 4.4 and 4.5) suggest that there is a small class of drivers who will avoid certain work zones, regardless of traffic conditions.

- *Avoiders.* Avoiders prefer the relative certainty of a specific travel time on an alternative route over the possibility of a severe delay through the work zone.

Results from questionnaires suggest that aware drivers are acting somewhat differently in rural and urban work zones. Specifically, rural aware drivers are more reluctant to change to an alternate route. The difference is likely due to the longer length of the a rural trip, the difficulty of obtaining information well ahead in rural travel, and the lack of experience of rural drivers with a particular work zone.

Traffic patterns also indicate driver behaviors that may be difficult to represent within a traditional travel model. For example, some drivers divert when traveling in the opposite direction of a work zone. A plausible explanation is that a few drivers, once having established a path to a destination, will employ the exact reverse path for the return trip out of habit.

6.3 Operationalizing Driver Behavior

Much of what has been observed can be operationalized in a travel model by following these principles:

There are three classes of drivers who might have considered passing through the work zone:

- Congestion sensitive: Congestion sensitive drivers consist of those aware drivers who make a decision to avoid the work zone if travel times exceed those on alternate paths. The behavior of this class is created within a model by assigning this class to shortest paths with the work zone in place and congestion on all paths is fully reflected in link and node travel times, using dynamic path building.

- Congestion insensitive: Congestion insensitive drivers consist of all resigned drivers and all aware driver who make a decision to travel through the work zone. The behavior of this class is created within a model by assigning this class to shortest paths as if there was not a work zone. Either static or dynamic path building would be suitable.
- Work zone avoidance: This class consists only of drivers who will avoid the work zone. The behavior of this class is created in a model by placing large impedances on links approaching and within the work zone. Either static or dynamic path building would be suitable.

An attempt should be made to achieve an equilibrium solution using the method of successive averages (MSA), but it is likely that Wardrop's first principle cannot be satisfied, given the large number of drivers who are insensitive to work zone delay.

Aware drivers make a choice of route. There is little evidence in available data as to how drivers make this decision. Do drivers plan their whole path or do drivers make link-by-link choices en route? Travel models inherently build paths as if drivers planned them holistically, so in the absence of additional behavioral data, it is prudent that a standard path-building algorithm be used. Evidence from surveys of drivers suggest that drivers willingness to divert relates to the remoteness of the work zone, the amount and quality of information provided, the purpose of the trip, and the length of the trip. These attributes are correlated to some extent. Some link-by-link choices en route were evident in data from a full freeway closure in Milwaukee, which happened in parallel with this project. However, the same behavior was not observed in the Portage and Tomah work zones.

Path split is most conveniently done for all drivers between an origin i and a destination j. Let t_{ij} be the travel time with the work zone and let τ_{ij} be the expect travel time under normal conditions. Then, the probability that a driver stays on the original route is:

$$p_{ij}^{orig} = f(t_{ij}, \tau_{ij}, b_{ij})$$

where f() is a suitable choice function (such as logit or probit) and b_{ij} is an original-route bias constant. The original-route bias constant should vary with the location of the work zone and the amount of information available to drivers. The original-route bias factor would likely differ between work zones, but could be obtained by a questionnaire similar to the ones used in this study.

The total number of simulated drivers staying on their original routes is:

$$T_{ij}^{orig} = T_{ij}(r_{ij} + (1 - r_{ij})p_{ij}^{orig})$$

where r_{ij} is the fraction of resigned drivers and T_{ij} is the number of drivers with their origin at i and their destination at j.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research is to provide an understanding of how drivers divert when they encounter a work zone ahead. In this study, data from traffic detectors, Bluetooth technology and a driver survey provided insights as to how much traffic is diverting, where traffic is diverting, and the causes for observed diversion. Two rural work zones were chosen near Portage and Tomah, WI for analysis.

This research is organized to confirm that significant traffic diversion exists and further to investigate potential factors that may affect traveler diversion in rural settings. The following findings are summarized based on empirical data and analysis:

1. Traffic diversion exists and can be estimated by traffic volumes and Bluetooth technology. Both work zones had a significant shift in volumes, which indicates diversion, at the 99% significance level. The level of diversion varied between weekdays and weekends. The most significant increases for long distance diversion came from the Tomah work zone. The Tomah work zone had an obvious alternative route, which the Portage work zone did not.
2. Many drivers in rural areas seem to behave irrationally. It will require slower speeds on the freeway and higher perceived travel time savings on the alternate route for drivers to divert, and approximately 20% of drivers had a stubborn attitude saying they would not divert regardless of speeds and delays. Traffic patterns also indicate certain driver behaviors that may be difficult to represent within a traditional travel model. Drivers are acting out of habit, cannot assimilate detail information, or are distrustful of good advice.
3. However, most drivers will make spontaneous decisions based on what they encounter. At the Portage and Tomah work zone, there was some diversion during days with no congestion, but such diversion was very small. This absence of diversion even occurred on days that are known for high levels of volume (Friday and Sunday). Even on congested days, the amount of diversion does not spike until the peak hours of travel.
4. To estimate the diversion of traffic, an attempt should be made to achieve an equilibrium solution, but it is likely that Wardrop's first principle cannot be satisfied, given the large number of drivers who are insensitive to the work zone delay observed at Portage and Tomah. By considering different classes of drivers who might have considered passing through the work zone, this research further developed a conceptual model for estimation of the amount of traffic remaining on the original route during the work zone situation.

Based on the research findings from this study and the increasing demand of mitigating the impact of planned and unplanned highway lane restrictions, SWZDI DOTs may consider taking the following actions:

1. Consider using Bluetooth technology in future diversion studies as it can either track a vehicle diverting from the freeway as part of a long distance trip or track how many vehicles are traveling on the alternate route for a significant distance.
2. Better understand the decision-making process of drivers in response to the availability of alternate routes. Questionnaires similar to those used in this

study are cost-effective to administer and can help learn of drivers reaction to other work zones.

3. Experiment with ITS technologies to increase driver knowledge of delays and improve usage of alternative routes, when appropriate.
4. Employ travel models that have robust route-choice capabilities to estimate diversion, considering that some drivers are resistant to any diversion, some drivers will always divert, and some drivers will make a choice but are likely biased to their original route. The critical variable in a diversion decision is the difference in travel time between the original and alternate route.

It should be mentioned that a parallel study of an urban work zone in Milwaukee is underway at the time of this writing. The Milwaukee study is using some of the same methods and technologies. Thus, it is possible to compare the experiences of both work zones to ascertain differences between driver behaviors between rural and urban work zones.

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APPENDIX A

QUESTIONAIRE

A.1 PORTAGE DRIVER SURVEY

Read to Respondent: I am working for the University of Wisconsin — Milwaukee and the Wisconsin Department of Transportation to gather opinions about traffic diversion from highway construction zone at I-94/I-39. Can you take 4 minutes to answer a few questions? (If "no", then thank the person and end interview.)

1. Trip Origination ______________________________ Trip Destination______________________________
2. What is the purpose of your trip? ☐ Work or business ☐ Home ☐ Leisure
3. How often do you use I-94/I-39?
   ☐Almost every day ☐ several times per week ☐ several times per month ☐rarely ☐ never before
4. Were you aware of the work zone on I-94/I-39 regarding traffic conditions before making this trip?
   ☐Yes ☐No
5. Did part of your trip include passing through the work zone on I-94/I-39 near Portage? ☐Yes ☐No
6. (If the answer to 5 is no) which route did you take to circumvent the work zone?
   ☐ US 51 ☐ US 12 ☐ US 51 and Highway 16 ☐ Other____________________________
7. (If the answer to 5 is no, otherwise ask question 9) why did you circumvent the construction work zone?
   ☐ Would not have ordinarily gone through the work zone
   ☐ Would have ordinarily gone through the work zone but planned ahead to avoid it
   ☐ The trip was rerouted because of the reasons listed in question 8
   ☐Other____
8. (If choose "the trip was rerouted" in question 7) what factors made you reroute?

☐ Easy access to the alternative route ☐Availability of guidance to the alternative route
☐Expected delay time on the freeway is large ☐Significant travel time saving in the alternative route
☐Observation of long queues ahead on the freeway ☐Speed of traffic on freeway is low
☐Many other cars taking the alternative route ☐Great time pressure
☐Other____

9. (If the answer to 5 is yes) why did you pass through the work zone?

☐Not familiar with an alternative route ☐Alternative route is much longer than the original
☐No guidance to the alternative route ☐Expected delay time on the freeway was acceptable
☐No or trivial travel time saving in the alternative route ☐No observation of significant queues
☐Speed of traffic on freeway is acceptable ☐Few cars taking the alternative route
☐Low time pressure ☐It was a mistake
☐Other____

10. How slow does traffic on the freeway have to be moving before you would change your route?
    ☐50 mph ☐40 mph ☐30 mph ☐20 mph ☐10 mph ☐Below 10 mph (stop and go)

11. How many minutes of travel time saving in the alternative route would make you to change your route?
    ☐< 5 min ☐5 – 10 min ☐10 – 15 min ☐15 – 20 min ☐20-25 min ☐ > 25 min

12. Estimate how long your trip was delayed because of the work zone, either avoiding it or going through it.
    _______ hours ________ minutes

(Questions 13-15: interviewers should fill out if possible)

13. Gender ☐ Female ☐ Male
14. Were you driving a truck for this trip? ☐Yes ☐No
15. In which of the following categories does your age fall? ☐ 16-25 ☐ 26-45 ☐ 46-65 ☐ 66 or more

A.2 TOMAH DRIVER SURVEY

Read to Respondent: I am working for the University of Wisconsin — Milwaukee and the Wisconsin Department of Transportation to gather opinions about traffic diversion from highway construction zone at I-90/I-94. Can you take 4 minutes to answer a few questions? (If "no", then thank the person and end interview.)

1. Trip Origination ____________________________ Trip Destination ____________________________
2. What is the purpose of your trip? ☐ Work or business ☐ Home ☐ Leisure
3. How often do you use I-90/I-94?
☐Almost every day ☐ several times per week ☐ several times per month ☐rarely ☐ never before
4. Were you aware of the work zone on I-90/I-94 regarding traffic conditions before making this trip?
☐Yes ☐No
5. Did part of your trip include passing through the work zone on I-90/I-94 near Tomah? ☐Yes ☐No
6. (If the answer to 5 is no) which route did you take to circumvent the work zone?
☐ US 12 ☐ STH 21 to STH 80/STH 58 ☐ Other__________________________
7. (If the answer to 5 is no, otherwise ask question 9) why did you circumvent the construction work zone?
☐ Would not have ordinarily gone through the work zone
☐ Would have ordinarily gone through the work zone but planned ahead to avoid it
☐ The trip was rerouted because of the reasons listed in question 8
☐Other____
8. (If choose "the trip was rerouted" in question 7) what factors made you reroute?
☐ Easy access to the alternative route ☐Availability of guidance to the alternative route
☐Expected delay time on the freeway is large ☐Significant travel time saving in the alternative route
☐Observation of long queues ahead on the freeway ☐Speed of traffic on freeway is low
☐Many other cars taking the alternative route ☐Great time pressure
☐Other____

9. (If the answer to 5 is yes) why did you pass through the work zone?
☐Not familiar with an alternative route ☐Alternative route is much longer than the original
☐No guidance to the alternative route ☐Expected delay time on the freeway was acceptable
☐No or trivial travel time saving in the alternative route ☐No observation of significant queues
☐Speed of traffic on freeway is acceptable ☐Few cars taking the alternative route
☐Low time pressure ☐It was a mistake
☐Other____

10. How slow does traffic on the freeway have to be moving before you would change your route?
☐50 mph ☐40 mph ☐30 mph ☐20 mph ☐10 mph ☐Below 10 mph (stop and go)

11. How many minutes of travel time saving in the alternative route would make you to change your route?
☐< 5 min ☐5 – 10 min ☐10 – 15 min ☐15 – 20 min ☐20-25 min ☐ > 25 min

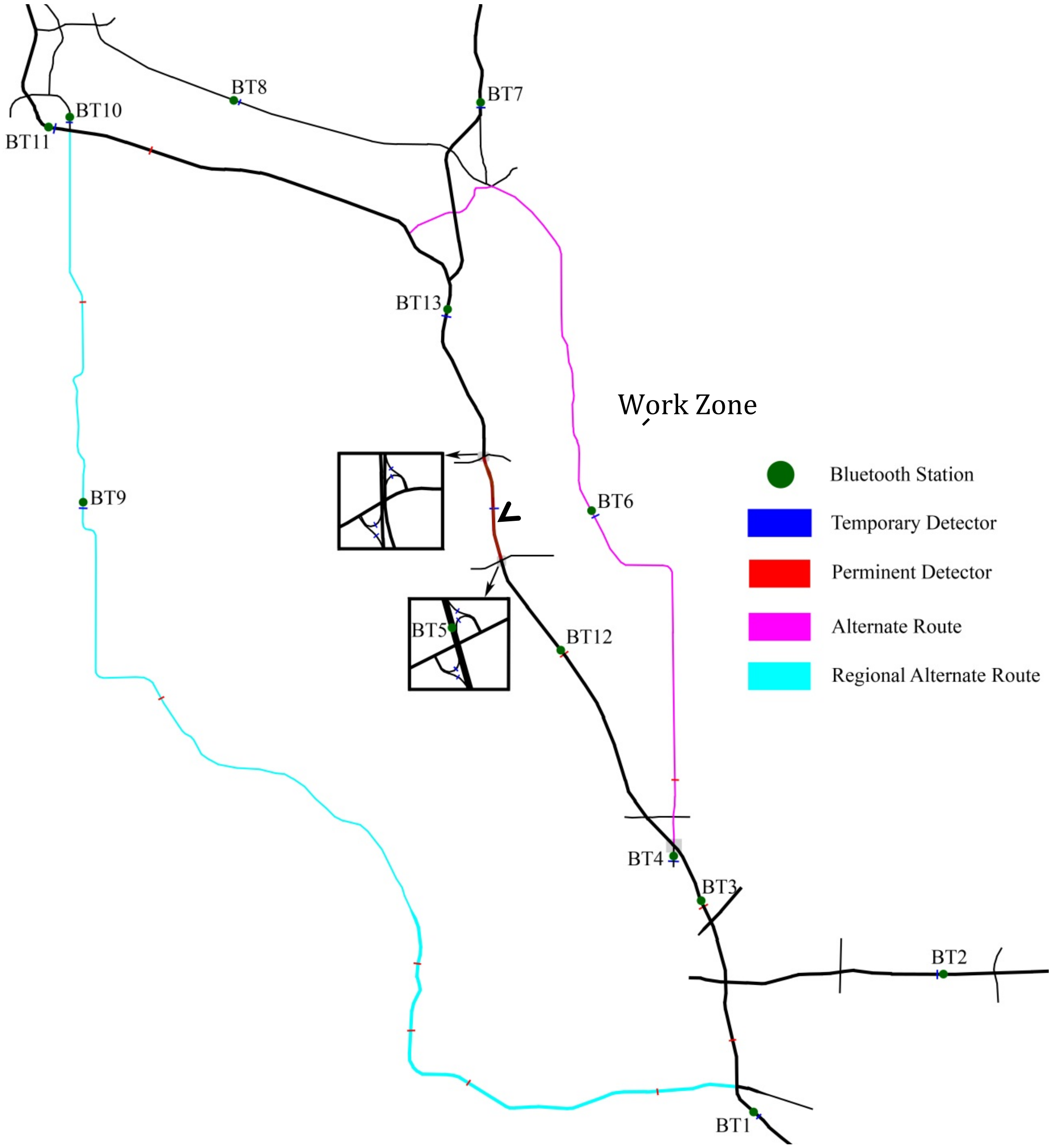
12. Estimate how long your trip was delayed because of the work zone, either avoiding it or going through it.
_______ hours ________ minutes

(Questions 13-15: interviewers should fill out if possible)
13. Gender ☐ Female ☐ Male
14. Were you driving a truck for this trip? ☐Yes ☐No
15. In which of the following categories does your age fall? ☐ 16-25 ☐ 26-45 ☐ 46-65 ☐ 66 or more

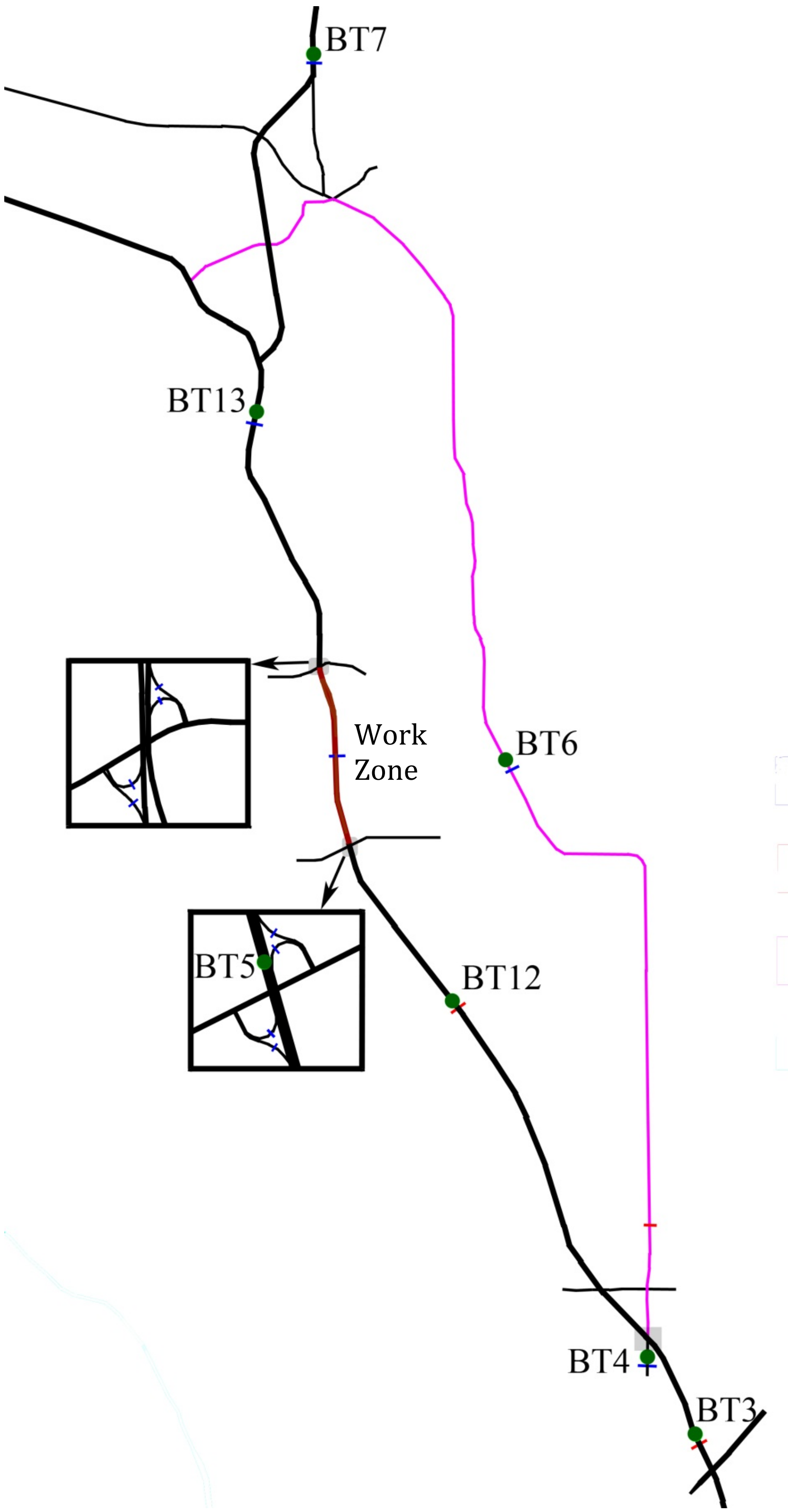
APPENDIX B

WORK ZONE MAPS

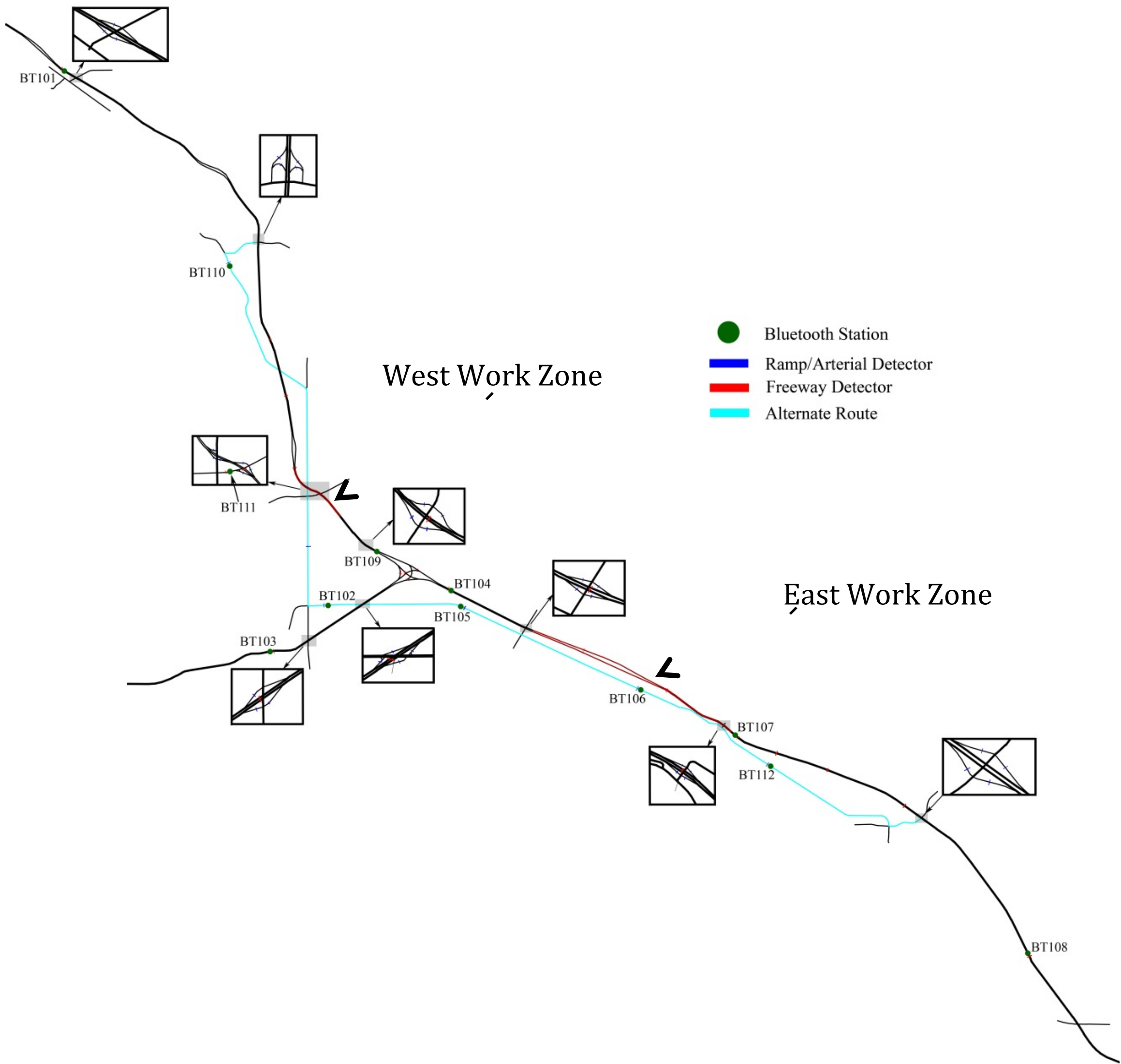
B.1 Portage Work Zone



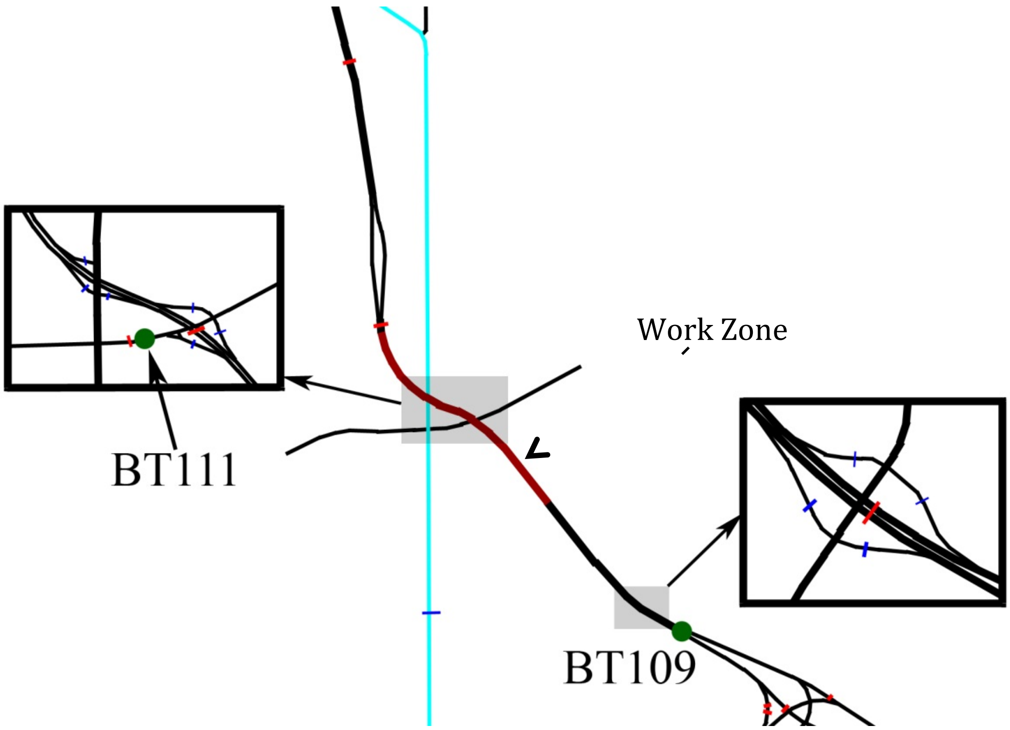
B.2 Portage Work Zone Location



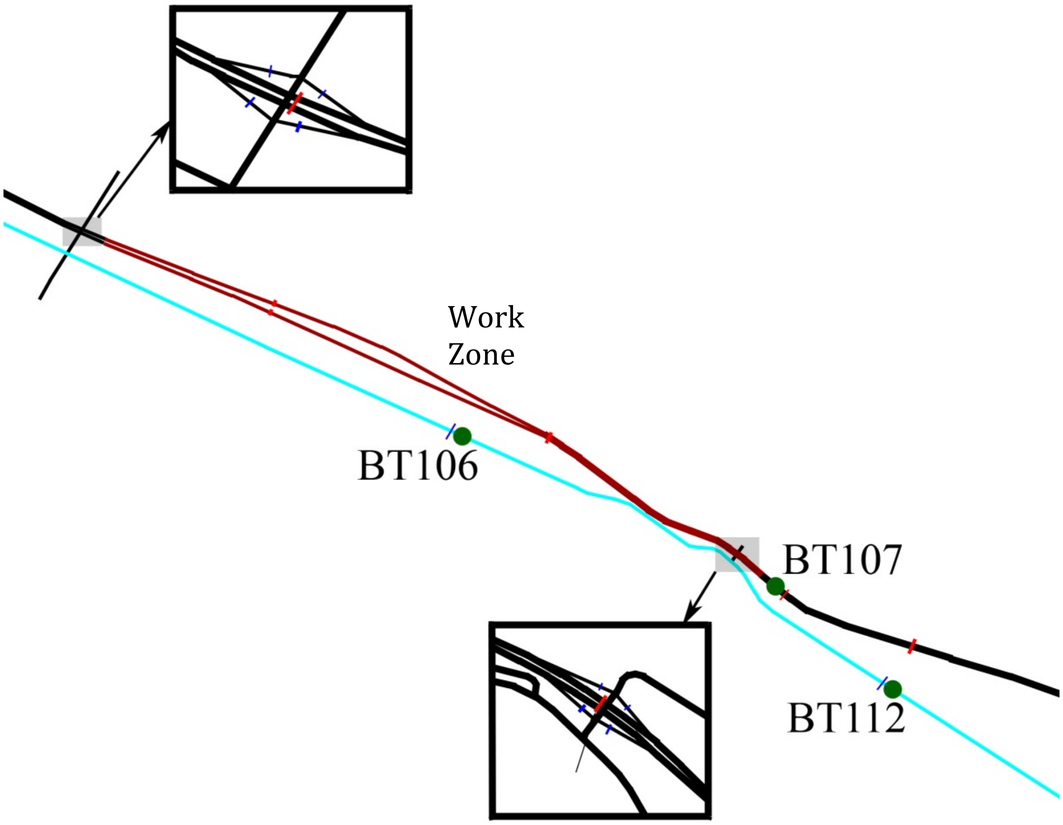
B.3 Tomah Work Zone



B.4 Tomah Work Zone Location (West Work Zone)



B.5 Tomah Work Zone Location (East Work Zone)



APPENDIX C

BLUETOOTH PAIRS, TRIPLES, AND QUADRUPLES

C.1 Portage Work Zone

NB (WB)

Pairs		Triples					Quadruples
		Queue	Diversion	Mainline	Long Distance	Other*	
BT2 – BT3	BT2 – BT12	BT3 – BT12 – BT5	BT12 – BT6 – BT13	BT12 – BT5 – BT13	BT1 – BT5 – BT10	BT1 – BT3 – BT12	BT1 – BT12 – BT5 – BT13
BT1 – BT3	BT12 – BT13	BT4 – BT12 – BT5	BT3 – BT6 – BT13	BT1 – BT5 – BT13	BT1 – BT5 – BT11	BT2 – BT3 – BT12	BT1 To BT12 To BT5 To BT13
BT1 – BT9	BT13 – BT11	BT1 – BT12 – BT5	BT4 – BT6 – BT13	BT2 – BT5 – BT13	BT1 – BT5 – BT7	BT3 – BT5 – BT13	BT2 To BT12 To BT5 To BT13
BT2 – BT9	BT13 – BT10	BT2 – BT12 – BT5	BT12 – BT6 – BT8	BT3 – BT12 – BT13	BT2 – BT5 – BT10	BT4 – BT5 – BT13	BT1 To BT12 To BT6 To BT13
BT3 – BT12	BT3 – BT5		BT12 – BT6 – BT7		BT2 – BT5 – BT11	BT5 – BT13 – BT7	BT2 To BT12 To BT6 To BT13
BT4 – BT12	BT1 – BT5		BT1 – BT9 – BT10		BT2 – BT5 – BT7	BT5 – BT13 – BT10	BT1 To BT3 To BT6 To BT13 (via STH 51)
BT3 – BT6 (via US 51)	BT4 – BT5		BT1 – BT9 – BT11		BT1 – BT6 – BT10	BT6 – BT13 – BT10	BT2 To BT3 To BT6 To BT13 (via STH 51)
BT4 – BT6 (via US 51)	BT2 – BT5		BT2 – BT9 – BT10		BT1 – BT6 – BT11	BT5 – BT13 – BT11	BT4 To BT12 To BT5 To BT13
BT12 – BT5	BT1 – BT6		BT2 – BT9 – BT11		BT1 – BT6 – BT7	BT6 – BT13 – BT11	BT4 To BT12 To BT6 To BT13
BT12 – BT6	BT2 – BT6		BT4 – BT12 – BT6		BT2 – BT6 – BT10	BT6 – BT13 – BT7	BT3 To BT12 To BT5 To BT13
BT5 – BT13	BT5 – BT10		BT4 – BT6 – BT8		BT2 – BT6 – BT11	BT1 – BT3 – BT12	BT3 To BT12 To BT6 To BT13
BT6 – BT13	BT5 – BT7		BT1 – BT6 – BT13		BT2 – BT6 – BT7	BT1 – BT3 – BT12	BT1 To BT3 To BT6 To BT13 (via STH 51)
BT6 – BT7	BT5 – BT11		BT3 – BT6 – BT8			BT1 – BT3 – BT12	BT2 To BT3 To BT6 To BT13 (via STH 51)
BT6 – BT8	BT6 – BT10		BT2 – BT6 – BT13			BT1 – BT3 – BT12	BT12 To BT6 To BT13 To BT10
BT13 – BT7	BT6 – BT11		BT1 – BT6 – BT7				BT12 To BT5 To BT13 To BT10
BT9 – BT10			BT2 – BT6 – BT7				BT12 To BT6 To BT13 To BT11
BT9 – BT11			BT1 – BT6 – BT8				BT12 To BT5 To BT13 To BT11
BT1 – BT12			BT2 – BT6 – BT8				BT12 To BT6 To BT13 To BT7

Quadruples (continued)				
BT12 To BT5 To BT13 To BT11	BT1 To BT5 To BT13 To BT7	BT1 To BT5 To BT13 To BT11	BT1 To BT6 To BT13 To BT7	
BT4 To BT6 To BT13 To BT10	BT2 To BT5 To BT13 To BT11	BT4 To BT5 To BT13 To BT7	BT2 To BT6 To BT13 To BT10	
BT4 To BT6 To BT13 To BT11	BT2 To BT5 To BT13 To BT7	BT4 To BT12 To BT6 To BT7	BT2 To BT6 To BT13 To BT11	
BT4 To BT5 To BT13 To BT10	BT1 To BT5 To BT13 To BT10	BT1 To BT6 To BT13 To BT10	BT2 To BT6 To BT13 To BT7	
BT4 To BT5 To BT13 To BT11	BT1 To BT5 To BT13 To BT11	BT1 To BT6 To BT13 To BT11		

SB (EB)

Pairs		Triples					Quadruples
		Queue	Diversion	Mainline	Long Distance	Other*	
BT11 To BT13	BT12 To BT2	(BT11 – BT13 – BT5)	BT11 – BT9 – BT1	BT11 – BT13 – BT5	BT10 – BT5 – BT1	BT11 – BT13 – BT6	BT11 To BT13 To BT5 To BT12
BT10 To BT13	BT13 To BT6	(BT10 – BT13 – BT5)	BT11 – BT9 – BT2	BT10 – BT13 – BT5	BT11 – BT5 – BT1	BT6 – BT12 – BT4	BT10 To BT13 To BT5 To BT12
BT11 To BT9	BT5 To BT4	(BT11 – BT13 – BT6)	BT10 – BT9 – BT1	BT7 – BT13 – BT5	BT7 – BT5 – BT1	BT10 – BT13 – BT6	BT11 To BT13 To BT6 To BT12
BT10 To BT9	BT12 To BT4	(BT10 – BT13 – BT6)	BT10 – BT9 – BT2	BT13 – BT5 – BT12	BT10 – BT5 – BT2	BT7 – BT13 – BT6	BT10 To BT13 To BT6 To BT12
BT8 To BT6	BT5 To BT1	(BT7 – BT13 – BT5)	BT8 – BT6 – BT12	BT10 – BT5 – BT12	BT11 – BT5 – BT2	B11 – BT5 – BT4	BT7 To BT13 To BT5 To BT12
BT7 To BT6	BT10 To BT5		BT7 – BT6 – BT12	BT11 – BT5 – BT12	BT7 – BT5 – BT2	BT11 – BT5 – BT3	BT7 To BT13 To BT6 To BT12
BT7 To BT13	BT11 To BT5		BT11 – BT9 – BT1	BT7 – BT5 – BT12	BT10 – BT6 – BT1	BT10 – BT5 – BT4	BT13 To BT5 To BT12 To BT1
BT13 To BT5	BT7 To BT5		BT13 – BT6 – BT12		BT11 – BT6 – BT1	BT10 – BT5 – BT3	BT13 To BT6 To BT3 To BT1 (via STH 51)
BT5 To BT12	BT10 To BT6		BT8 – BT6 – BT4		BT7 – BT6 – BT1	BT7 – BT5 – BT4	BT13 To BT5 To BT12 To BT2
BT6 To BT12	BT11 To BT6		BT8 – BT6 – BT3		BT10 – BT6 – BT2	BT7 – BT5 – BT3	BT13 To BT6 To BT3 To BT2 (via STH 51)
BT6 To BT4 (via STH 51)	BT5 To BT3		BT7 – BT6 – BT4		BT11 – BT6 – BT2		BT13 To BT6 To BT12 To BT1
BT6 To BT3 (via STH 51)	BT5 To BT2		BT7 – BT6 – BT3		BT7 – BT6 – BT2		BT13 To BT6 To BT12 To BT2
BT12 To BT3	BT6 To BT1		BT10 – BT6 – BT4				BT13 To BT5 To BT12 To BT4 (via STH 51)
BT3 To BT1	BT6 To BT2		BT10 – BT6 – BT3				BT13 To BT6 To BT12 To BT4 (via STH 51)
BT3 To BT2			BT11 – BT6 – BT3				BT11 To BT5 To BT3 To BT1
BT9 To BT1			BT13 – BT6 – BT4				BT10 To BT5 To BT3 To BT1
BT9 To BT2			BT13 – BT6 – BT3				BT11 To BT5 To BT3 To BT2
BT12 To BT1			BT10 – BT6 – BT12				BT10 To BT5 To BT3 To BT2
BT13 To BT12			BT11 – BT6 – BT12				BT7 To BT5 To BT3 To BT1
			BT7 – BT6 – BT12				BT11 To BT6 To BT12 To BT1

Quadruples (continued)				
BT11 To BT6 To BT12 To BT2	BT7 To BT6 To BT12 To BT1	BT10 To BT6 To BT3 To BT1		
BT10 To BT6 To BT12 To BT1	BT7 To BT6 To BT12 To BT2	BT10 To BT6 To BT3 To BT2		
BT10 To BT6 To BT12 To BT2	BT11 To BT6 To BT3 To BT1	BT7 To BT6 To BT3 To BT1		
BT7 To BT5 To BT3 To BT2	BT11 To BT6 To BT3 To BT2	BT7 To BT6 To BT3 To BT2		

C.2 Tomah Work Zone

SB (EB)

Pairs		Triples: Queue	Triples: Diversion	Triples: Mainline	Triples: Long Distance
BT101 To BT110	BT102 To BT106	BT109 – BT104 – BT107	BT110 – BT102 – BT105	BT111 – BT109 – BT104	BT110 – BT102 – BT112
BT101 To BT109	BT105 To BT112	BT101 – BT109 – BT104	BT101 – BT110 – BT102	BT101 – BT104 – BT107	BT111 – BT102 – BT112
BT101 To BT102	BT101 To BT104		BT111 – BT109 – BT105	BT103 – BT106 – BT107	BT101 – BT109 – BT108
BT102 To BT105	BT103 To BT106		BT103 – BT102 – BT111	BT103 – BT105 – BT107	BT101 – BT105 – BT108
BT103 To BT105	BT109 To BT103		BT103 – BT102 – BT110	BT101 – BT109 – BT103	
BT103 To BT102	BT102 To BT112		BT102 – BT106 – BT107		
BT103 To BT104	BT109 To BT106		BT102 – BT105 – BT107		
BT104 To BT107	BT102 To BT104		BT105 – BT112 – BT108		
BT105 To BT106	BT110 To BT103		BT105 – BT106 – BT112		
BT105 To BT107	BT102 To BT103		BT101 – BT102 – BT105		
BT106 To BT107	BT101 To BT104		BT109 – BT105 – BT107		
BT106 To BT112	BT104 To BT106		BT103 – BT104 – BT107		
BT109 To BT105	BT107 To BT108		BT102 – BT106 – BT112		
BT109 To BT104	BT109 To BT107		BT101 – BT110 – BT103		
BT110 To BT111	BT104 To BT108		BT104 – BT106 – BT107		
BT110 To BT102			BT105 – BT106 – BT107		
BT111 To BT109			BT102 – BT105 – BT106		
BT112 To BT108			BT103 – BT109 – BT101		

Quadruples			
BT103 To BT106 To BT112 To BT108	BT101 To BT110 To BT102 To BT105	BT101 To BT110 To BT104 To BT104	
BT101 To BT102 To BT106 To BT107	BT110 To BT102 To BT105 To BT112	BT103 To BT102 To BT111 To BT101	
BT101 To BT102 To BT112 To BT108	BT102 To BT105 To BT106 To BT112		
BT101 To BT109 To BT104 To BT107	BT103 To BT104 To BT106 To BT107		
BT109 To BT106 To BT112 To BT108	BT103 To BT105 To BT106 To BT107		

NB (WB)

Pairs		Triples			
		Queue	Diversion	Mainline	Long Distance
BT102 To BT111	BT108 To BT104	BT107 – BT104 – BT109	BT108 – BT112 – BT105	BT108 – BT107 – BT104	BT112 – BT102 – BT110
BT102 To BT110	BT109 To BT111	BT104 – BT109 – BT101	BT112 – BT106 – BT105	BT107 – BT104 – BT103	BT112 – BT102 – BT111
BT102 To BT101	BT109 To BT101		BT107 – BT106 – BT105	BT104 – BT109 – BT101	BT108 – BT109 – BT101
BT102 To BT103	BT110 To BT101		BT112 – BT105 – BT102		BT108 – BT104 – BT103
BT104 To Bt109	BT112 To BT106		BT107 – BT106 – BT103		BT108 – BT106 – BT104
BT104 To BT102	BT112 To BT105		BT107 – BT106 – BT102		BT104 – BT102 – BT101
BT104 To BT105	BT112 To BT102		BT107 – BT106 – BT109		
BT105 To BT103	BT104 To BT103		BT105 – BT102 – BT111		
BT105 To BT102	BT104 To BT101		BT105 – BT109 – BT101		
BT105 To BT109	BT107 To BT105		BT106 – BT102 – BT111		
BT106 To BT105	BT106 To BT104		BT106 – BT109 – BT101		
BT106 To BT103	BT103 To BT102		BT105 – BT102 – BT110		
BT106 To BT102	BT103 To BT109		BT102 – BT110 – BT101		
BT106 To BT109			BT106 – BT102 – BT110		
BT107 To BT106			BT112 – BT106 – BT102		
BT107 To BT104			BT107 – BT104 – BT102		
BT108 To BT107			BT104 – BT102 – BT111		
BT108 To BT112			BT104 – BT102 – BT110		
			BT112 – BT102 – BT111		

Quadruples			
BT108 To BT112 To BT105 To BT103	BT108 To BT112 To BT102 To BT111	BT108 To BT112 To BT102 To BT110	BT107 To BT106 To BT105 To BT109
BT108 To BT112 To BT105 To BT102	BT107 To BT106 To BT109 To BT101	BT108 To BT112 To BT106 To BT104	BT108 To BT107 To BT106 To BT103
BT108 To BT112 To BT105 To BT109	BT108 To BT104 To BT109 To BT101	BT108 To BT107 To BT106 To BT104	BT107 To BT106 To BT105 To BT103
BT107 To BT106 To BT102 To BT110	BT112 To BT106 To BT105 To BT102	BT108 To BT112 To BT105 To BT109	
BT107 To BT106 To BT102 To BT111	BT112 To BT105 To BT109 To BT101	BT108 To BT107 To BT105 To BT109	