QUANTIFYING TRAVELER DIVERSION AND ITS IMPACT DURING A WEEKEND FULL FREEWAY CLOSURE: A CASE STUDY WITH I-43/I-894 IN MILWAUKEE

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ABSTRACT

Short-term full freeway closure is a work zone strategy that is attracting more consideration by DOTs in order to allow for accelerated construction time and shorter duration of traveler impacts. Such closures are very often limited to weekends or night times. Because of the potential for large impacts on adjacent arterials, there is a need for a good understanding of traveler's diversion patterns in response to detour guidance. Although studies have shown that many drivers will choose alternate routes when they are aware of work zone delays, quantifying such patterns has not been sufficiently addressed, either in the professional literature or in practice.

This paper presents a case study on quantifying driver diversion and impacts during the I-43/I-894 full freeway closure event in October 2010 in Milwaukee. Analysis of the target study region is based on integrating many data sources, including the Volume, Speed, and Occupancy Application Suite (V-SPOC) loop detectors, I-94 N/S Corridor microwave detectors, Statewide Traffic Operations Center (STOC) video surveillance, the TRAffic DAbase System (TRADAS), automatic traffic recorder (ATR) stations, and the Traffic Responsive Signal System (TRSS). This combined dataset offered a good look at the diversion impacts of the full freeway closure along with an assessment of the contributing factors to diversion. From this research, state DOT engineers will have a better understanding on how to create rules, assumptions and guidelines for implementing full freeway closures specifically for their jurisdictions.

Traffic conditions at the intersection of W. Loomis Rd. & W. Layton Ave.

Pre-Closure Conditions

Closure Conditions

INTRODUCTION

Short-term full freeway closure is a work zone strategy that is attracting more consideration by state DOTs in order to allow for accelerated work zone duration that result in a shorter duration of traveler impacts. Normally closures of this magnitude are limited to either weekends or at night. Because all traffic has detoured, a full freeway closure creates a safe environment for the construction workers, who may work around the clock to ensure a faster completion date for the project.

Due to an expansion of I-43/I-894, the Wisconsin Department of Transportation (WisDOT) replaced a box culvert that crosses Villa Mann Creek, which took place on October 1-3, 2010. The expansion of I-43/I-894 is part of the I-94 N/S Corridor reconstruction project, which is adding capacity to I-94 from Milwaukee to Chicago. Figure 1 shows a skeleton of the Milwaukee freeway network with the location of the full freeway closure. A major event that took place during the weekend of the closure at Miller Park (Brewers baseball stadium) was Farm Aid, which showcased well known acts such as Willie Nelson, John Mellencamp, Neil Young, and Dave Matthews, and was expected to draw 34,000 patrons.

In order to compare conditions of a non-closure weekend to the closure weekend, multiple weekends were considered. The comparison weekend should not have a Milwaukee Brewers' home stand, and the comparison weekend had to be after the northbound (NB) W. Layton Ave. on-ramp and W. Layton Ave. bridge construction had been completed, because NB I-94 drivers would be more susceptible to exit there due to a ramp closure on the Mitchell Interchange, as explained in the TMP section of this report. The non-closure weekend with most of the criteria was September 17-20, 2010.

LITERATURE REVIEW

From a traffic operations standpoint, there have not been many studies on full freeway closures. The Federal Highway Administration (FHWA) has published some case studies (1) that briefly talk about planning measures that need to be taken and the benefits and impacts of a full freeway closure. In the cities of Detroit, MI and Portland, OR, the cost of construction was reduced, and the duration of construction was dramatically reduced. Also, the state DOTs received phone calls and emails from the public that were pleased about the project, but a formal survey was not conducted.

Washington State DOT did a more extensive study (2) when they used weekend full freeway closures to complete a rehabilitation project on a 5.5 mile section of I-405 from Coal Creek to Sunset Boulevard. Their paper goes into the quality of paving during nighttime conditions, public feedback, and traffic operational impacts. The travel time, total vehicle miles traveled, and average congestion was increased, but they were not increased by more than 14%. Most drivers (84.62%) were in the Seattle area during the weekends of the closure, and most of the drivers (77.78%) did not arrange their weekend to be out of town because of the closure. More than half of the drivers (53.45%) had their travel plans affected by the I-405 closure, and 69.11% of drivers used a trip route that was different than normal during the closure weekend. The results showed a large number of drivers did not cancel their trip, shop at different places, or spend less money because of the closure. Of the cancelled trips, most were visiting trips (37%) and shopping trips (24%).

There were also reports on 30 area business that were surveyed on a scale of 1 to 5, 1 being a strong negative impact, and 5 being a strong positive impact. The average was a 3.0, which would indicate no impact. There were also 11 trucking firms surveyed as to whether their operations were impacted or not. The results showed that most (64%) had very small or no impact due to the closure.

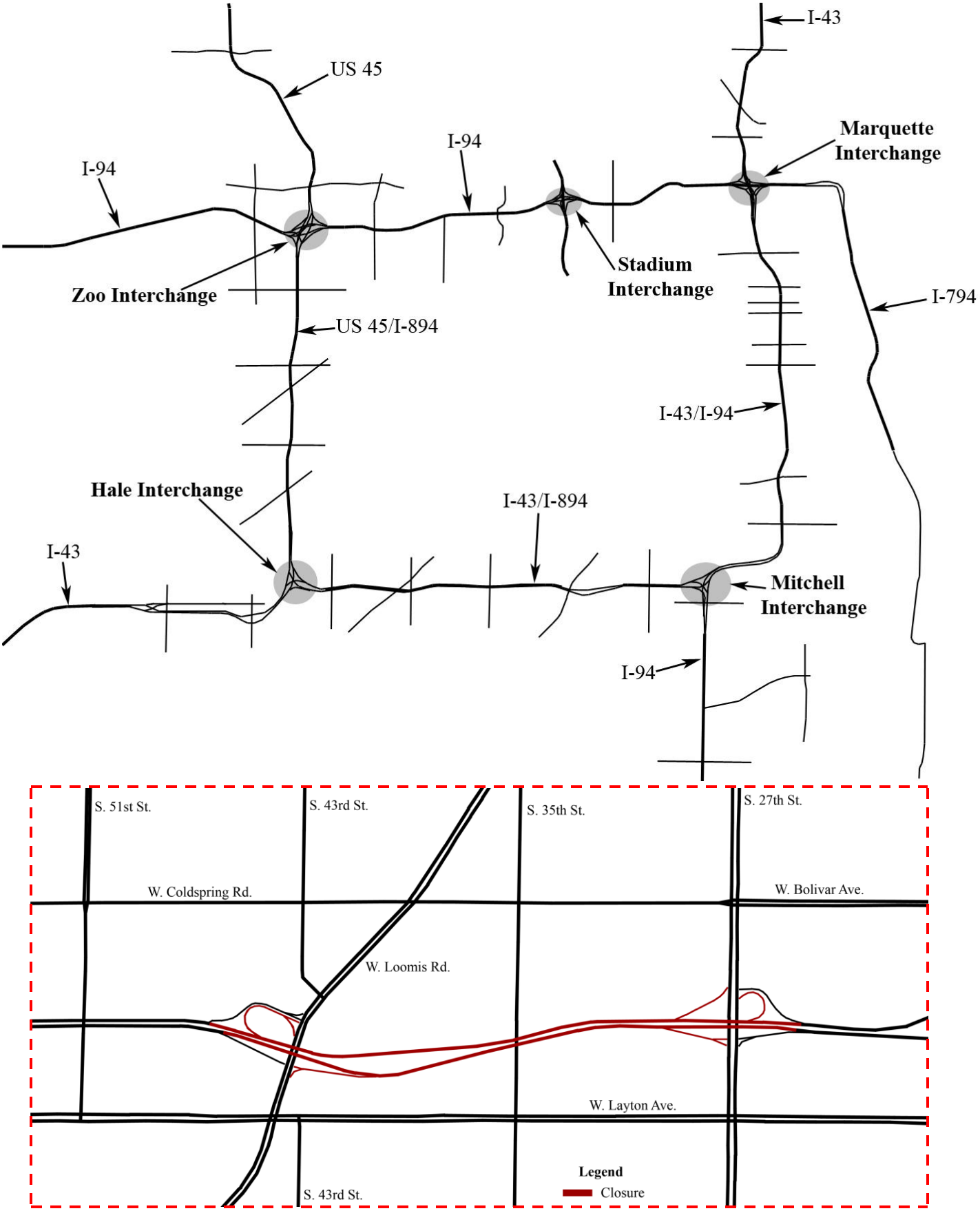


Figure 1: Milwaukee freeway network with closure location

The California Department of Transportation did a study (3) on weekend full freeway closures on I-15 in Devore, CA. The project was completed in six weekends, in which a TMP was conducted, and traffic impacts were reported. The stretch of freeway has less average daily traffic (ADT) than the I-43/I-894 study in Milwaukee. The maximum decrease encountered in ADT was 41%, but the maximum delay encountered was 201 minutes, which occurred at 3:00 PM on a Saturday.

TRANSPORTATION MANAGEMENT PLAN (TMP)

A transportation management plan (TMP) documents impacts expected from work zone projects and how they meet the policies and standards of the Wisconsin Department of Transportation (WisDOT). The TMP documents and explains the closures necessary for closing down the freeway, other construction zones in the area, and mitigation techniques to minimize delays. The TMP team chose to close down certain ramps in the area, and the software package SYNCHRO was used to develop optimized signal timing schemes and to estimate delay times that will be encountered on intersections with on/off ramps based on different diversion percentages. Other signalized intersections in the immediate area of the closure were retimed to account for the increase in traffic, and local police were scheduled to be on site during most of the Saturday in case traffic congestion reached a serious level.

The necessary closures to construct the box culvert are shown visually in Figure 1. Below are additional closures necessary for mitigation efforts:

- WB Airport Spur (including the NB entrance ramp to I-94 West)
- W. Howard Ave. entrance ramp to I-43/94 SB
- S. 76th St. entrance ramp to I-43/894 EB
- W. Forest Home Ave. entrance ramp to I-43/894 EB
- S. 60th St. entrance ramp to I-43/894 EB
- Hale Interchange S-E ramp to I-43/894 EB (added after the TMP was finalized)

Other natural closures due to the I-94 N/S Construction Project Include:

- W. Howard Ave. CD-ramp (off-ramp to W. Howard Ave.)
- S. 20th St./W. Layton Ave. exit ramp from I-94 SB
- S. 20th St. entrance ramp to I-94 SB (near W. Layton Ave.)
- W. Layton Ave. entrance ramp to I-94 NB (near Mitchell Interchange)

Other projects adjacent to the project include:

- I-94 N-S Freeway Project from W. College Ave. to W. Howard Ave. (WisDOT)
- W. Loomis Rd. resurfacing from STH 100 to S. 27th St. (WisDOT)
- S. 27th St. resurfacing from W. College Ave. to W. Howard Ave. (WisDOT)
- W. Howard Ave. resurfacing from S. 6th St. to S. 13th St. (WisDOT)
- W. Layton Ave. resurfacing from S. 27th St. to W. Loomis Rd. (WisDOT)
- S. 6th St., W. Holt Ave., W. Bolivar Ave. resurfacing (City of Milwaukee)
- S. 13th St. resurfacing W. Rawson Ave. to W. College Ave. (Milwaukee County)
- W. Howell Ave. Intersection Improvements (WisDOT)
- W. Loomis Rd., W. Howard Ave. pipeline installation (Milwaukee Metropolitan Sewerage District)

WisDOT's Southeast Region has the following policies:

- No weekday off-peak two-lane closures are allowed
- No weekday peak hour lane closures are allowed
- No work will be allowed on Labor Day/Thanksgiving/Columbus Day weekend
- No work will be allowed over Summerfest week, State Fair week, or 2 hours before/after Milwaukee Brewers games vs. the Chicago Cubs or Chicago White Sox

Traffic mitigation contracts were developed with the following agencies to assist incident management:

- Milwaukee County Sheriff Department
- Greenfield, City of Milwaukee, and Oak Creek Police Department
- Greenfield, City of Milwaukee, and Oak Creek Fire Department
- City of Milwaukee and Milwaukee County DPW
- Milwaukee County Transit System
- AGBA
- General Mitchell International Airport

By developing contracts with these agencies, WisDOT would be better equipped to respond quickly to incidents in and around the corridor. These agencies were involved in weekly traffic meetings.

Some of the other strategies included:

- Ongoing participation in the regional Traffic Incident Management Enhancement (TIME) Program
- Updating the lane closure system to provide traveler information
- Coordination the State Traffic Operations Center (STOC) to provide traveler information

The TMP team had a theory that keeping the STOC informed of the project status would result in public travelers having a better understanding of the project. Thus, the public would have the ability to avoid congested areas, find detour routes, and travel through the construction zone more efficiently. Experienced public drivers would also have the knowledge to create their personalized diversion route to reduce congestion.

DATA COLLECTION

The data collection plan utilizes multiple sources already in place by WisDOT. Extensive data was available through the Volume, Speed, and Occupancy Application Suite (V-SPOC), which include loop detectors on most ramps and mainline counts on the freeway. In addition to the V-SPOC detectors, WisDOT has automatic traffic recorder (ATR) stations that are operated continuously across the Southeast Region, and are considered more reliable than loop detectors.

Since the I-94 N/S Corridor project is a major reconstruction, WisDOT installed microwave detectors to monitor traffic conditions. At the Statewide Traffic Operations Center (STOC), they monitor traffic conditions and travel times using detectors and video surveillance. Those cameras were used to view the traffic conditions, and measure queues. To determine the queues generated, a reference point was chosen, and GIS or GoogleMaps was used to get a distance for each time interval chosen. Due to the experimental use of STOC cameras, the short queues on Saturday could not be easily determined, and were disregarded. The short queues were more easily determined on Sunday utilizing two cameras instead of one.

Another byproduct of the I-94 N/S Corridor Project is the implementation of the Traffic Responsive Signal System (TRSS), with the collaboration of the cities in the area and Milwaukee County. TRSS intersections (Figure 2) utilize a different way of determining green time for a single direction, which consists of three different alternative intervals. The first alternative interval is the default setting, and corresponds to normal conditions. If the first threshold is reached, then the second alternative interval is chosen, which has a greater green time. If the second threshold is reached, then the third alternative interval is chosen and results in a greater green time than the second alternative interval. There are algorithms in place to ensure the signalized intersections are responsive, but not “too

responsive", meaning that the green time is not fluctuating too often. The thresholds are based on traffic counts, occupancy, and speed data which are being utilized in this study.

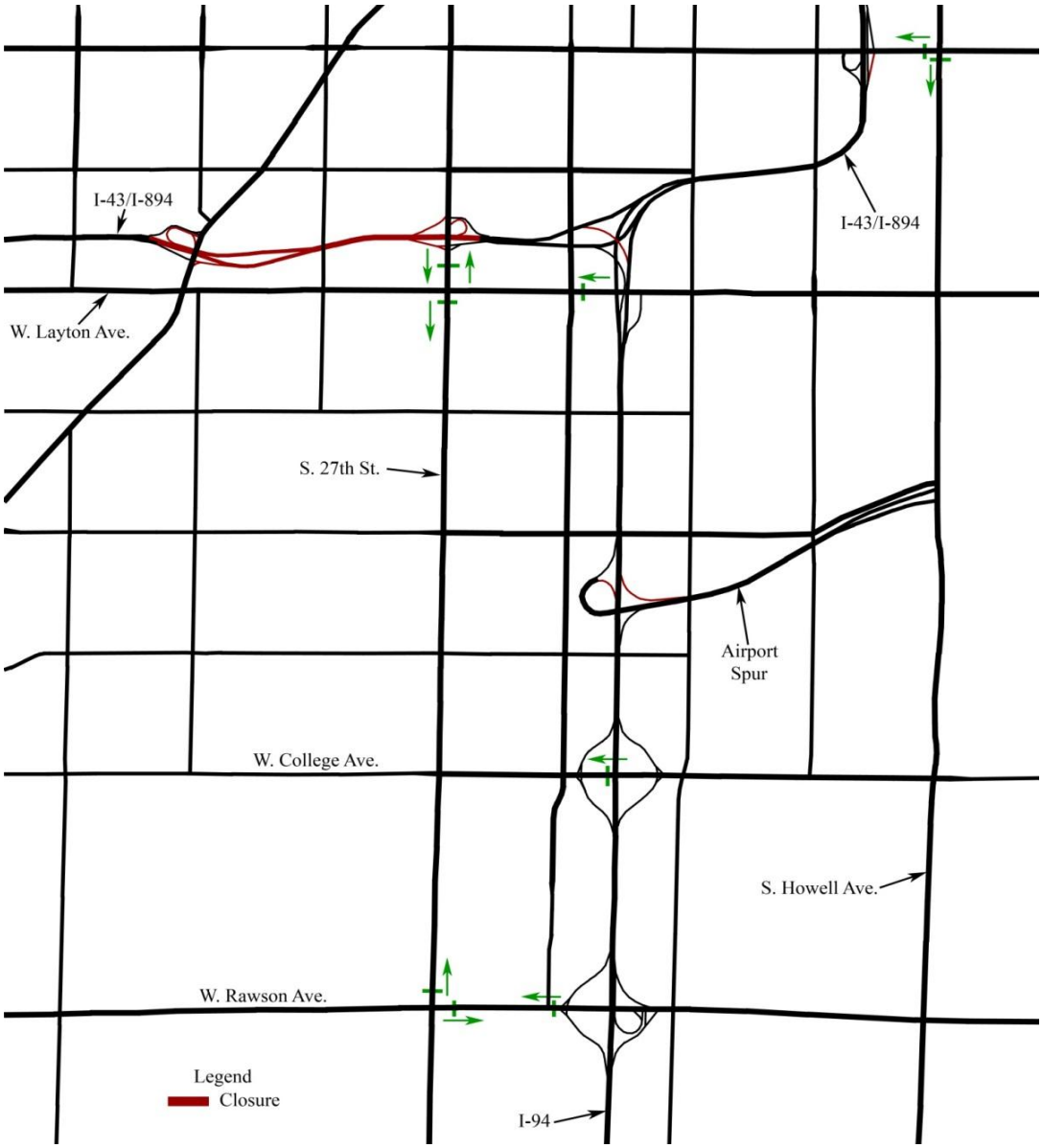


Figure 2: Map of TRSS intersections (The arrow indicates the direction that is affected)

The en route information consisted of messages displayed on the fixed changeable message signs, 511 messages, radio broadcasts, and posted construction signs. The fixed changeable message signs normally post travel times for two different locations. During the closure the fixed changeable message signs displayed the closure information and in some cases, guidance on a location to divert.

Using the data on V-SPOC required a closer look at the data to further validate the dataset. There were occasional data compiling errors at the 5 minute count level, which means that some of the 15 minute counts were affected, too. All 5 minute ramp counts were corrected by hand using averaging and interpolation techniques to generate accurate 15 minute counts. The V-SPOC historical counts (dating back over 10 years) were consulted in determining whether a detector was operating correctly during the pre-closure weekend. Since the counts didn't produce a proper flow balance, a linear programing model

was created, and the GEH formula (shown below) was consulted. Corridors of data were analyzed, with continuous data stations as the extent of each corridor, and the result with the lowest sum of GEHs for the corridor was chosen.

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

M: New Count (Balanced)

C: Old Count (Raw Count)

In order to determine whether the change in volume is significant or just noise, a t-test was conducted. Since all mainline volumes were balanced using TRADAS ATR station data, the hourly volumes were used in the t-test. All other volumes, including TRSS intersections, had 15 minutes counts used in the t-test.

TRAFFIC OPERATIONS RESULTS

Regional Impacts

The major regional traffic, which consists of drivers only going through Milwaukee to get to another destination, was expected to cause elevated counts on certain road segments. An example would be drivers from the south (such as Racine, Kenosha, or Chicago) going to western destinations (such as Madison or Minneapolis). Instead of taking the bypass, which does not involve going through the highest traveled area in Milwaukee, drivers will take I-94, which should produce an increase in drivers going westbound (WB) through the Zoo Interchange. When comparing the traffic volumes, there is a significant increase in traffic on WB I-94 east of the Zoo Interchange. The time intervals that incorporate Farm Aid traffic leaving Miller Park were neglected. There was not an increase in traffic entering or leaving the Milwaukee network as a whole, indicating that the increases in volumes are due to drivers taking the regional routes. The sum of the mainline traffic volumes on the outer edge of the Milwaukee network (Detectors on I-94 at Oakwood Rd., I-43 at 124th St., I-94 at 124th St., US 45 at Wisconsin Ave., and I-43 at Wisconsin Ave.) showed daily volumes with less than 1% difference from the non-closure weekend to the closure weekend.

Another indication of drivers taking a regional route is the significant increase in volume of the W. Ryan Rd. off-ramp. The suggested route was to take W. Ryan Rd. to STH 100 to I-94. However, it is unclear if these drivers are taking the regional route or if they found different destinations on S. 27th St.

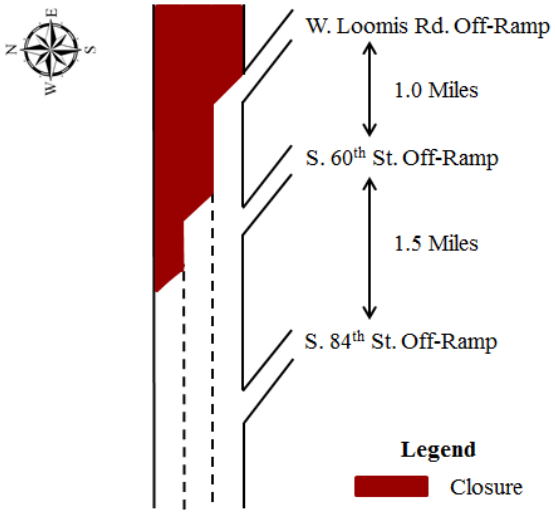
Local Impacts

Traffic heading NB on I-94 and using I-43/I-894 or shopping at one of the many businesses in the area had the following ramps for diversion (starting from the south and working north); W. Rawson Ave. off-ramp, W. College Ave. off-ramp, and W. Layton Ave. off-ramp. The W. Rawson Ave. off-ramp had a significant increase in volume, indicating that people diverted at that point. However, W. College Ave. did not show any statistical difference in volume, showing that drivers weren't taking that route. The W. Layton Ave. off-ramp did not have any detectors, but there was a TRSS detector on W. Layton Ave. west of the off-ramp, which picks up all of the traffic exiting at W. Layton Ave. The volumes at that location were significantly increased, but the data also captured airport traffic going into the area or cities southwest of Milwaukee.

Traffic using the Hale Interchange, and heading eastbound (EB) towards the work zone had three possible off-ramps they could take and include; S. 84th St. off-ramp, S. 60th St. off-ramp, and W. Loomis Rd. off-ramp. S. 84th St. did not show a statistical difference in volume, but S. 60th St. and

W. Loomis Rd. off-ramps had major statistical increases. The mainline volumes were drastically reduced, which could provide indication that drivers normally taking S. 84th St. off-ramp either cancelled their trip or took a different route. Figure 3 shows the distance between the intersections and the volume increases on S. 60th St. off-ramp and W. Loomis Rd. off-ramp.

The analysis of the TRSS intersections in the study area, along with EB S. 27th St. on-ramp showed surprising results. The on-ramp from S. 27th St. onto EB I-43/I-894 did not have a statistical difference on Saturday from the non-closure weekend. However, volumes on S. 27th St. from W. Layton Ave. (going NB and SB) had significant increases in volume, showing that there still is much traffic in the area. Drivers choose not to get back onto the freeway at that point, which raises concerns about drivers' knowledge about the project and drivers' distrust that there is not another closure up ahead.



	Increase in Daily Volume (EB I-43/I-894) between Pre-Closure Weekend & Closure Weekend			
	S. 60th St. off-ramp		W. Loomis Rd. off-ramp	
Day	Closure Volume (Veh)	% Change	Closure Volume (Veh)	% Change
Saturday	8785	79.0	15363	225.8
Sunday	4077*	59.0*	10560*	313.8*

*Only includes the time the freeway was closed

Figure 3: EB I-43/I-894 during closure conditions with volume increases on off-ramps

Traffic getting back onto WB I-43/I-894 had three logical on-ramps to enter and include; W. Loomis Rd. on-ramp, S. 60th St. on-ramp, and S. 84th St. on-ramp. All three on-ramps had statistical increases in volume, with the highest intensity at W. Loomis Rd. and decreasing westerly away from the closure.

Queue Length & Diversion Percentage

The queue length for EB I-43/I-894 on Saturday, October, 2, 2010 is shown in Figure 4. Due to the experimental use of traffic cameras as a method for determining queue length, the queue could not be determined for a distance of 0.4 miles or less. The queue length is measured in 5 minute intervals. The distance of the queue length is measured from the stop line at the intersection of EB W. Loomis Rd. off-ramp and W. Loomis Rd. to the last car traveling at a speed of less than 30 MPH. The queue lengths were reported to the nearest 0.1 miles to account for possible errors in the reading of queue lengths on the traffic cameras.

On Saturday, October 2, 2010, the queue length had expected spikes during the day, which would result from normal Saturday traffic. The maximum queue sustained was 1.2 miles, which is approximately 0.1 miles past the S. 60th St. off-ramp shown in Figure 5. This proves the S. 60th St. off-ramp could handle the excess traffic for the entire weekend. Also, the queue length stabilized like a

normal short-term work zone taking place on a weekday during non-peak hour times. On Sunday, October 3, 2010, the queue length took longer to increase in length, and was shorter in total length and average length. This could be a sign of either stabilization of the construction zone or natural reductions in volume because it is a Sunday rather than Saturday. The queues on WB S. 27th St. off-ramp were negligible and in most cases did not reach the end of the ramp. The one case when it did reach the end of the ramp was due to an incident. This is a direct result of compliance of southbound I-43/I-94 traffic and the closing of NB I-94 to WB I-43/I-894 ramp (Mitchell Interchange).

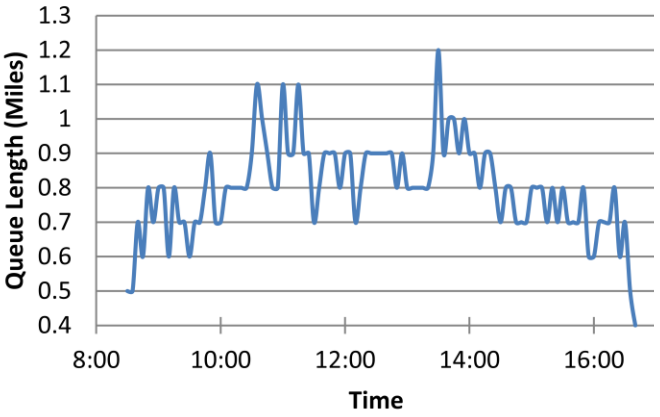


Figure 4: Queue length on EB I-43/I-894 (Saturday, October 2, 2010)

Figure 5: Maximum queue length on EB I-43/I-894 (Saturday, October 2, 2010)

The queue length for this project can be compared to other construction projects in the Milwaukee metropolitan area that were analyzed (4). The other construction projects were done on a weekday from 9 AM to 2 PM, and the locations include; WB I-94 between S. 108th St. and S. 121 St. (WZ 1), EB I-94 between S. 68th St. and S. Hawley Rd. (WZ 2), and NB I-94 at W. College Ave. (WZ 3). All of the construction zones involved lane closures, not a full freeway closure. WZ 2 and WZ 3 had queues that stabilized within the first half hour and WZ 1 stabilized at 12:00 (Noon). The I-43/I-894 full freeway closure had more fluctuation at the start of the queues, but during peak hours had an overall increase in queue length, then it stabilized. Once the queue stabilized, WZ 1 had an average queue length of 2.3 miles, WZ 2 had an average queue length of 1.3 miles, and WZ 3 had an average queue length of 2.1 miles. The maximum queue for EB I-43/I-894 had a lower average queue length than all of those other work zones. There were also four construction zones on the I-410 corridor in San Antonio, TX (5), which involved lane closures during the day (9 AM to 4 PM) that yielded higher maximum queues except one, which was near a major interchange.

The diversion percentage was analyzed for EB I-43/I-894 to get a better sense of the driver's decision process. The diversion percentage equation is listed below.

$$Diversion\ \% = \frac{Exiting\ Volume}{Mainline\ Volume}$$

The mainline volume is in reference to the volume of I-43/I-894 west of the off-ramp being analyzed. Figure 6 shows the diversion percentage and how it varies with time on Saturday, October 2, 2010. A diversion rate of over 0.3 is considered high by most state DOT's, and the S. 84th St. off-ramp and S. 60th St. off-ramp are above 0.3 for a long period of time. A diversion rate of over 0.5, which

happens at the S. 60th St. off-ramp, indicates more drivers are diverting at S. 60th. St. rather than taking the force-off option at W. Loomis Rd.

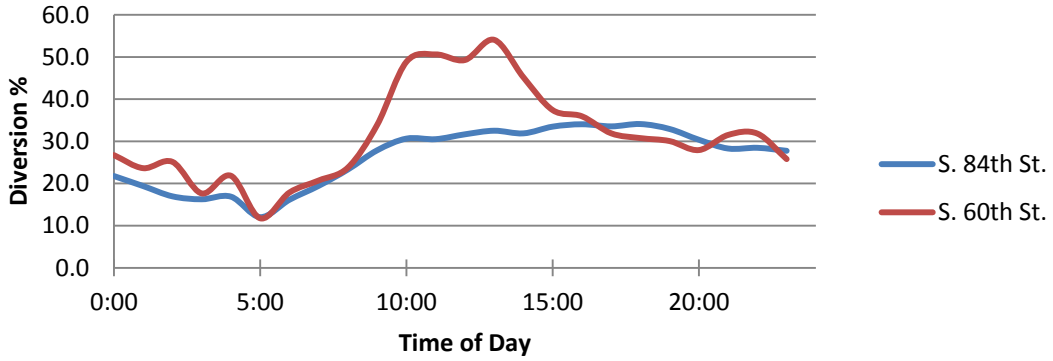


Figure 6: Diversion percentage of EB I-43/I-894 traffic (Saturday, October 2, 2010)

There were other normal and abnormal queues in the study area. On Saturday, there was queuing on the NB I-43/I-94 to WB I-94 ramp (Marquette Interchange). It is unclear whether this was due to regional traffic, Farm Aid traffic, or a combination of the two. This is still a topic that has to be investigated further by analyzing the Marquette Interchange traffic along with the Stadium Interchange traffic. There was also queuing on Sunday for traffic on SB I-43/I-94 near the Mitchell Interchange, but is important to note that the traffic engineers involved in the I-94 N/S Corridor project see queuing on regular basis on Sunday due to a lane drop occurring on the southbound (SB) I-43/I-94 to SB I-94 ramp (Mitchell Interchange), which goes from two lanes to one.

En Route Information

The method of the messages displayed was to give as much information to the driver without overloading the driver with too much information. Traveler responses to changeable message signs are usually analyzed using driver surveys, but no surveys were collected on this weekend. A possible explanation for drivers not taking W. College Ave. could be the lack of information in the changeable message sign. Foo, Abdulhai, and Hall (6) proved that the diversion rate can increase or decrease by 6% with the following messages, "Express moving Well / Moving Slowly / Very Slowly". In Foo, Abdulhai, and Hall's study, the changeable message sign was constantly changing with change in speeds, and traffic was adapting to the changes. The issue with the I-43/I-894 closure would be the lack of congestion on I-94 because the closure itself was not on I-94.

The synced HAR system is the WisDOT radio broadcast. They used the term, "severe delays", which could have caused drivers to divert more than normal, and account for some of the drivers deciding not to get back on I-43/I-894 going into the Mitchell Interchange. It is important to note that the radio broadcast did not give alternate routes.

Pre-Closure Simulation Comparison

The results of the anticipated travel delay and queue length during peak travel periods came from a simulation from SYNCHRO. The TMP team created multiple simulation files for multiple locations and multiple diversion scenarios. The simulation files that include over congestion on NB I-94 near the Mitchell Interchange (traffic exiting at W. Layton Ave.) and WB I-43/I-894 traffic being forced off at S. 27th St. were not considered in this analysis because the queues were not considered significant.

However, the simulation that includes EB I-43/I-894 being forced off at W. Loomis Rd. was different than the numbers encountered in the field. Table 1 shows the queue lengths the SYNCHRO simulation and Table 2 shows the queue lengths encountered in the field.

Table 1: Estimated queue lengths (SYNCHRO simulation) for EB I-43/I-894 traffic being forced off at W. Loomis Rd.

TMP (SYNCHRO Analysis)

Diversion %	Volume (Vol)	95th Percentile Queue	Peak Hour Factor (PHF)
10	2481	2.1	0.95
30	1930	1.1	0.95
50	1379	0.03	0.95

Table 2: Queue lengths encountered in the field for EB I-43/I-894 traffic being forced off at W. Loomis Rd.

Closure Conditions (Saturday, October 2, 2010)

Time	Volume (Vol)	95th Percentile Queue	Peak Hour Factor (PHF)	Diversion % (compared to Pre-Closure Weekend)	Diversion % (Vehicles Entering I-894)
8:00 AM	917	0.7	0.72	62.1	41.6
9:00 AM	891	0.8	0.62	67.9	52.3
10:00 AM	779	1.0	0.86	75.0	64.5
11:00 AM	855	1.1	0.77	75.6	65.7
12:00 (Noon)	914	0.9	0.85	76.9	65.3
1:00 PM	797	1.0	0.89	79.5	69.0
2:00 PM	938	0.9	0.91	76.2	62.7
3:00 PM	1026	0.8	0.85	73.7	58.4
4:00 PM	1025	0.7	0.91	72.3	57.7
5:00 PM	1059	0.8	0.97	69.6	54.7
Averaged % (Compared to Pre-Closure Weekend)				72.9	59.2

The diversion percentages encountered during the full freeway closures were higher than the highest diversion percentage scenario used in the simulation, which should yield a negligible queue, but the queue length was over 0.7 miles. The simulation model used a smaller starting volume than was encountered during the pre-closure weekend, which would result in minor decreases in diversion percentage.

The main errors in the SYNCHRO simulation files include lane channelization and not using multiple intersections. At the intersection of the EB I-43/I-894 off-ramp and W. Loomis Rd., there is another intersection (W. Loomis Rd. & W. Layton Rd.) less than 0.1 mile away, which was not included in the simulation model. The intersection of W. Loomis Rd. & W. Layton Ave. carries traffic that diverted at S. 84th St. and S. 60th St. In order to properly model all corresponding intersections, traffic diversion is an important aspect to signalization timing schemes. The other major error was lane

channelization. SB W. Layton Ave. goes from two lanes to three lanes, in which the simulation file created a protected right turn for traffic exiting from I-43/I-894, which helped in traffic flow and resulted in negligible queues for the 50 percent diversion scenario.

TRAFFIC DIVERSION ESTIMATION

Regression Analysis Theory

The regression analysis allows the development of models to estimate the influences certain traffic attributes have on the diversion. The multivariable linear regression model can be expressed below:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \epsilon$$

In the equation above, y is the dependant variable, $x_1, x_2, \ldots, x_k$ are independent variables, $\beta_0, \beta_1, \ldots, \beta_k$ are coefficients, and ϵ is the residual (error term). Since multivariable regression analysis is being utilized, the R^2_{adj} along with tests of each independent variable are used to determine if an independent variable contributes significantly to the model. Two models were developed to identify the influencing factors, with consideration of a single location or multiple locations.

S. 60th St. Diversion

In this model, the dependent variable is volume on the S. 60th St. off-ramp. There were multiple factors considered for diversion at S. 60th St, but only the following equation passed all of the variable tests:

$$y = 19.6 + 10.4x_1 + 0.257x_2 + 199.2x_3 - 0.444x_4$$

Where,

$x_1 =$ Queue Length

$x_2 =$ Mainline Volume before S. 60th St. (Arrival Rate)

$x_3 =$ S. 60th St. off-ramp Occupancy

$x_4 =$ Mainline Speed at S. 60th St.

Figure 7 illustrates where the independent variables are located for variables $x_2, x_3,$ and x_4. The results produce a good understanding to the factors that cause drivers to divert. As the queue length increases, the diversion at S. 60th St. increases. Also, as the mainline volume before S. 60th St. increases, the diversion at S. 60th St. increases, and as stated earlier, the diversion percentage was higher than 0.5 at certain time intervals. As the occupancy on the S. 60th St. off-ramp increased, the diversion at S. 60th St. increased too. At first glance, this doesn't agree with intuition, because more drivers are diverting even though the congestion on the off-ramp is increasing. This could be a new factor in full freeway closures, because if the drivers see the queue length, they know the force-off option will take them longer. This concept also makes sense with the STOC video surveillance, which is shown in Figure 5. Drivers are using the shoulder to divert onto S. 60th St. Finally, as the speed at S. 60th St. increases, it has a larger negative impact on the diversion, meaning that fewer drivers will divert at S. 60th St.

In the model, 155 data points were chosen and 2 outliers were taken out due to bad data. The coefficient of determination, $R^2 = 0.844$, and the adjusted coefficient of determination, $R^2_{adj} = 0.840$, indicates a good fit of the data. The R^2 value is high, which indicates most of the variability can be explained in the model. To show that each individual variable contributes significantly to the model, a significance of variable test was conducted and is shown in Table 3. Since the p-value is very low, we are more than 99% confident that the variables contribute significantly to the model. In Table 3, the constant has a high p-value, which would indicate that it may not contribute significantly to the model.

In order to draw better conclusions on the constant, more data points are needed from different full freeway closures.

Table 3: S. 60th St. significance of variable test

Model	Unstandardized Coefficients		Standardized Coefficients	t_0	p-value
	β	Std. Error	Beta		
(Constant)	12.694	9.896		1.283	0.202
Queue Length	14.605	4.670	0.165	3.127	0.002
Mainline Volume before S. 60th St.	0.330	0.044	0.305	7.472	0.000
S. 60th St. Exit Occupancy	120.691	21.248	0.344	5.680	0.000
Speed of Drivers at 60th St.	-0.463	0.109	-0.299	-4.233	0.000

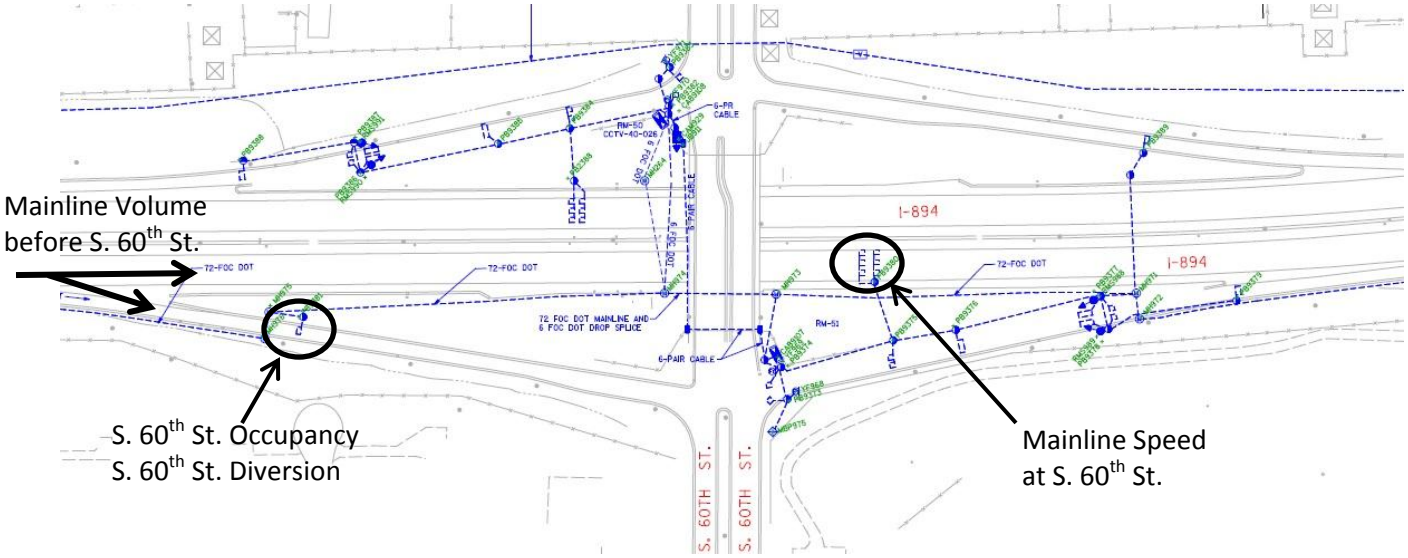


Figure 7: Locations of independent variables of the S. 60th St. diversion model (Source: WisDOT)

S. 60th St. & S. 84th St. Diversion

In this diversion model, the dependent variable is volume on both the S. 60th St. off-ramp and the S. 84th St. off-ramp. This diversion model will predict traffic diverting at both S. 60th St. off-ramp and S. 84th St. off-ramp. There were multiple factors considered for diversion at S.60th St. & S. 84th St., but only the following equation passed all of the variable tests:

$$y = 67.77 + 0.361x_1 - 1.09x_2 - 6.07x_3$$

Where,

x_1 = Arrival Rate (Volume before off-ramp)

x_2 = Speed near the off-ramp

x_3 = Distance of the Alternate Route

The results produce a good understanding to the factors that cause drivers to divert in a corridor setting. As the arrival rate increases, the diversion at the off-ramp will increase. As the speed near the off-ramp increases, it has a larger negative impact on the model, which indicated less diversion. Finally, as the distance of the alternate route increases, drivers will be less likely to divert.

In the model, 926 data points were chosen with no data points taken out of the model. The coefficient of determination, $R^2 = 0.940$, and the adjusted coefficient of determination, $R^2_{adj} = 0.940$, indicates a good fit of the data. Similar to the S. 60th St. regression model, a significance of variable test was conducted and is shown in Table 4. Since the p-value is very low, we are more than 99% confident that the variables contribute significantly to the model. Since a significant number of data points were used, the standardized regression coefficients can be used to draw conclusions to see which variables are more important. The arrival rate is approximately 3.6 times more important than speed near the off-ramp, and approximately 5.1 times more important than distance of the alternate route. The speed near the off-ramp is approximately 1.4 times more important than distance of the alternate route.

Table 4: S. 60th St. & S. 84th St. significance of variable test results

Model	Unstandardized Coefficients		Standardized Coefficients	t_0	p-value
	β	Std. Error	Beta		
(Constant)	67.765	2.124		31.911	0.000
Arrival Rate (Volume before off-ramp)	0.361	0.003	0.963	116.060	0.000
Speed near the off-ramp	-1.087	0.034	-0.268	-31.906	0.000
Distance of the alternate route	-6.069	0.282	-0.187	-21.542	0.000

These results go better with a driver survey. The study of the I-43/I-894 full freeway closure did not include a driver survey, but the I-94 E/W Corridor research project (currently being analyzed by UW-Milwaukee) includes a driver survey.

DRIVER PERCEPTION OF FULL FREEWAY CLOSURES

To determine the driver perception of full freeway closures, a ranking question was asked in the I-94 E/W Corridor research project, in which drivers were asked to rank their preferred construction method (1 being the most preferred, and 7 being the least preferred). The survey was conducted online. In order to obtain the best possible results, a comprehensive plan was conducted, which includes the sending of the survey link to employees of the biggest companies of Milwaukee and people signed up for updates on repave94.org, utilization of social media websites like Facebook and Twitter, leaving flyers at all of the cities/villages in the Milwaukee area, and the posting of the link to the driver survey on repave94.org and local media websites. A total of 756 drivers filled out the survey, and the results are shown in Table 5. Table 5 includes surveys filled out prior to May 16, 2011. The online survey ends on June 10, 2011.

Table 5: Ranking of construction methods

Construction Method	Average Rank (1 being the best, 7 the worst)	Standard Deviation
Single lane closures around the clock (24 hours)	2.81	1.93
Single lane closures around the clock (24 hours) with nighttime (9:30 PM - 5:30 AM) multiple lane closures	2.61	1.66
Single lane closures around the clock (24 hours) with nighttime (11 PM - 4:30 AM) full freeway closures	3.28	1.40
Multiple lane closures around the clock (24 hours)	4.63	1.56
Multiple lane closures around the clock (24 hours) with nighttime (11 PM - 4:30 AM) full freeway closures	4.75	1.35
Full freeway closures (weekends only)	5.18	1.83
Full freeway closures during nighttime (weekdays 11:30 PM - 4:30 AM) and on weekends	4.75	2.28

The results show a lack of acceptance to full freeway closures. Some of the lack of acceptance can come in the form of fear of the unknown. Even though drivers know the project will end earlier, they do not want to be forced off the freeway, because of the potential for getting lost in a major urban area, especially drivers not familiar with Milwaukee. Also, the standard deviation is highest with full freeway closures, which indicated that drivers either rank full freeway closures high or low (less drivers ranked them in the middle). Finally, the results show that drivers have the same attitude towards multiple lane closures around the clock as full freeway closures.

CONCLUSIONS AND FUTURE RESEARCH

Based on the case study of the full freeway closure of I-43/I-894 in Milwaukee, state DOTs can get a better understanding of how traffic behaves during a full freeway closure in an urban setting. The queue lengths did not reach the levels WisDOT traffic engineers planned for. The driver perception of full freeway closures can change in the future, especially if state DOT's publicize rules that each regions must abide by, like not having full freeway closures on I-94 (east/west direction) during Milwaukee Brewers home stands.

The research of the I-43/I-894 full freeway closure is still on-going. In the near future, there will be an attempt to create more regression models to get a better understanding of the diversion characteristics. This research will also be compared to the impacts of the I-94 E/W Corridor research project (I-94 E/W Corridor rehabilitation project: repave94.org), which consists of analyzing diversion patterns and impacts on arterial streets. In that study, Bluetooth technology will be used to acquire accurate travel times on I-94 and the immediate arterial streets chosen.

Both the I-43/I-894 full freeway closure and the I-94 E/W Corridor research project will be used in a bigger research project, called the RADIUS Project. The RADIUS Project consists of creating a travel forecasting model that can estimate traffic patterns due to work zones in Southeast Wisconsin.

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REFERENCES

1. *Full Road Closure for Work Zone Operations: A Cross-Cutting Study*. Federal Highway Administration Work Zone Program, Federal Highway Administration, Washington, DC, 2003.

2. Dunston, Phillip S., Mannering, Fred L. *Evaluation of the Full Weekend Closure Strategy for Highway Reconstruction Projects: I-405 Tukwila to Factoria*. Washington State Transportation Center, Washington State Department of Transportation, Olympia, WA, 1998.

3. Kim, C., Lee, E.B., Monismith C.L. Construction and Traffic Analysis of Interstate 15 (Devore II) Concrete Pavement Reconstruction Project. Caltrans District 8, California Department of Transportation, San Bernardino, CA, 2008.

4. Chen, Yali, Xiao Qin, David A. Noyce, and Chanyoung Lee. *A Hybrid Process for Micro-Simulation and Logistic Regression for Short-Term Work Zone Traffic Diversion*. In *Transportation Research Board 2008 Annual Meeting* CD-ROM, Transportation Research Board, 2008.

5. Ullman, Gerald L. *Queuing and Natural Diversion at Short-Term Freeway Work Zone Lane Closures*. In *Transportation Research Record 1529*. Texas Transportation Institute, Texas A&M University, College Station, pp. 19-26.

6. Foo, Simon, Abdulhai, Baher, Hall, Fred L. Impacts on Traffic Diversion Rates of Changed Message on Changeable Message Sign. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2047*, Transportation Research Board of the National Academies, Washington, DC, 2008,

7. Fricker, Jon D., Whitford, Robert K. *Fundamentals of Transportation Engineering: A Multimodal Systems Approach*. Pearson Education Inc., Upper Saddle River, NJ, 2004.