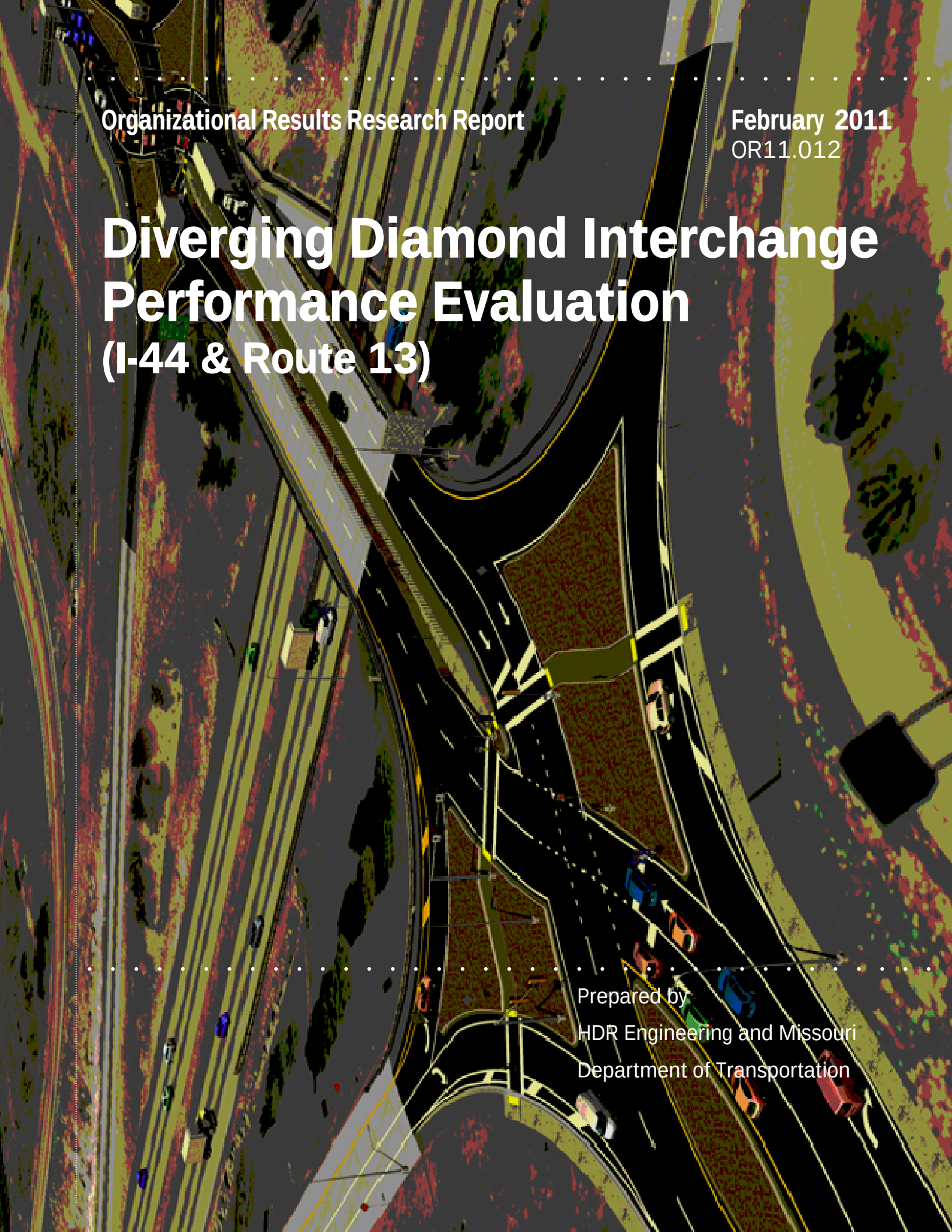

Organizational Results Research Report

February 2011
OR11.012

Diverging Diamond Interchange Performance Evaluation
(I-44 & Route 13)

Prepared by
HDR Engineering and Missouri
Department of Transportation

Final Report

TRyy1013

Diverging Diamond Interchange Performance Evaluation (I-44 & Route 13)

Prepared for
Missouri Department of Transportation
Organizational Results

by

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Executive Summary

This DDI Performance Evaluation was directed towards assessing:

- **Traffic Operations** – Pre-construction, post-construction and future traffic conditions
- **Safety** – Pre-construction and post-construction crash conditions
- **Public Perceptions**
    - General Public
    - Pedestrians and Bikes
    - Larger Vehicles (Trucks, Recreational vehicles – mobile homes, boats, etc.)

Traffic operation conclusion included the following:

- Left turn movements within the DDI experienced a noticeable decrease in traffic delay and traffic queuing;
- Through movements within the DDI experienced a slight increase in travel time because in part due to the slow speed through the crossover areas during off peak periods;
- The DDI, in the future, will handle increased traffic volumes when compared to a diamond interchange. The 2035 traffic model demonstrated this fact. It was also observed on several occasions during peak travel periods or when an over-dimension load negotiated the DDI. The recovery from traffic back-ups created by these conditions were normally eliminated within one to two signal cycle lengths;
- Over-dimension loads up to 18 foot wide and 200 foot long have successful moved through the DDI
- The overall the traffic flow through DDI is better

Safety conclusion included the following:

- Total crashes were down by 46% in the first year of operation;
- Left turn type crashes were eliminated and left turn right angle type crashes were down 72% because of how left turns are handled within the DDI (free flow movements or yield control);
- Rear-end type crashes were down slightly that might also be the results of how left turns are handled not under traffic signal control
- DDI's post-construction crash types are similar to any other signalized intersection and no definite crash pattern was noticed in the review that could lead to stating that within a DDI a certain type of crash increased;

Public Perception conclusions included the following:

- A very high percentage (80% plus) expressed that traffic flow had improved and traffic delay had decreased;
- A very high percentage (87%) expressed that crash were more likely to occur within a standard diamond when compared to a DDI;
- A very high percentage (around 80%) expressed that larger vehicles and pedestrian/bike movements through the DDI were better or similar to a standard diamond interchange;
- A very high percentage (91%) expressed good understanding on how the interchange operated with the current design of islands, signing, signals and pavement markings.

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Introduction

The Missouri Department of Transportation (MoDOT) working with the Federal Highway Administration (FHWA) to find the right transportation solution that would address freeway interchange improvement needs; explored an innovative interchange solution called the Diverging Diamond Interchange (DDI) or Double Crossover Diamond (DCD). Extensive research, traffic modeling and outreach efforts were performed to determine if this solution would work in the United States.

Based on this joint preliminary evaluation effort, the decision was made to allow the construction of the DDI solution. MoDOT and other State DOT's started planning and designing DDI's. Interstate 44 and Missouri Route 13 was the first constructed in the United States. This post-construction MoDOT performance evaluation was initiated to confirm results found in the preliminary evaluation and to answer questions on traffic operations, safety and public perceptions.

This literature review covers websites, papers and presentations, and publications relating to diverging diamond interchanges (DDIs) other than the subject DDI in Springfield, Missouri. All of the material found during the literature search originates in the United States, even though the interchange concept was originally developed in France. Little information is available about the design and history of the three DDIs in operation in France.

Much of the available literature is in the form of media stories or public outreach efforts and is therefore very general in-nature and meant as an introduction to the concept (1-10). DDIs are being considered in a dozen or more states, with five DDI's constructed and operating by late 2010 (11). As part of this evaluation, a representative sample of media stories and public outreach were collected and reviewed. "*Time*" magazine's February 7, 2011 edition included an article called "*Traffic Gem*" that highlighted the DDI's potential operational and safety benefits (12).

Many of the technical conference papers and presentations found are also of a general conceptual nature with some notable exceptions at the TRB and ITE conferences (13-15). FHWA has published two technical documents (16-17) covering safety and operations as well as an informational report released in April 2010 that covers a far greater breadth of topics related to the DDI (16). The Utah Department of Transportation has also published a DDI Guidelines document that is not currently available to the public (18).

In May 2010, MoDOT released a document entitled *Missouri's Experience with a Diverging Diamond Interchange: Lessons Learned* (19). This document provides both an overview as well as guidance on specific topics based on designs already complete or underway within the State of Missouri. Topics covered include design elements, constructions issues, operations and signal timing, as well as public involvement. The report also notes that MoDOT's Engineering Policy Guide has been updated to include detail information on Diverging Diamond Interchanges (20) on their knowledge gained and experiences with deployment of the DDI solution.

Public Perception

Public perception of the DDI has been positive, in general, with one notable exception being Brooklyn, Ohio, where opposition has been unrelated to driver expectancy or engineering aspects of the project, but rather to the cost of the project (21). The remainder of the literature indicates some public skepticism, but more are impressed with the innovation and cost efficiencies being demonstrated by the respective agencies. Popular Science magazine named the DDI to their "Best of What's New" list in 2009 (22).

Driver Perception

Driver perception is mentioned explicitly or alluded to in almost every source, including news articles. None of the media reports imply that this is a safety risk. All of the technical articles stress that signing, striping, and proper design are needed to mitigate this risk.

FHWA performed an experiment to test driver behavior, navigation errors, and red light running at a DDI versus a standard diamond interchange. Two variations of signing and striping were used for the DDI creating two DDI alternatives and one standard diamond alternative. The results of this study showed that fewer navigation errors, wrong way movements, and red light violations occurred with the DDI scenarios. Also of note was the significant decrease in average vehicular speed at the signalized intersections in these scenarios (16). As a result of this speed decrease a DDI is likely to decrease accident severity, though the report does not specifically make that conclusion.

Safety

The sources that discuss safety all point to the theoretical safety improvements that should result from the significantly reduced number of vehicular conflict points within the DDI when compared to other interchange concepts. Most of the sources do not mention pedestrian safety explicitly. Those that do discuss the shorter crossings points required in the DDI, but also the fact that the number of crossings points increase with the DDI compared to other interchange concepts, though each of the crossings can be signal protected without significant impacts to vehicular flow. The FHWA tech brief on pedestrians at a DDI is focused on the operational aspects where the number of average stops a pedestrian makes is the key measure of effectiveness. The DDI does not operate as well as other interchanges using this measure.

FHWA performed an accident analysis at the French DDI in Versailles and compared it to a similar location in the United States. The report found a significant decrease in accident rate and severity (1), a result to be expected given the lower speeds found at a DDI when compared to other interchange concepts (16).

Bicycle and Pedestrian Accommodation

Though one source (6) implied that the DDI is not the best interchange for accommodating pedestrians, most other sources concur that the DDI is among the better interchange concepts in this regard. A majority of sources point to the fact that where pedestrians and bicyclists are moved to the center of the interchange, as they are in the Springfield design, they are barrier-protected as a major improvement in safety and accommodation for bicycles and pedestrians.

Oregon, notably, would still require bicycle lanes next to travel lanes even when the crosswalk is in the center of the interchange[1] (23).

Construction Cost

All sources point to the potential for significant savings in construction cost for a DDI when compared to other interchanges (1-3, 7, 18, 22, 24), though some sources indicated that costs will not always be lower for every situation based on the project site (5-6).

Signalization and Operations

All of the technical sources point to the two-phase signals within the DDI as a significant contributor to the DDI's operational benefits. The FHWA's 2010 AIIR has a section dedicated to the discussion of signal phasing with regard to controllers (25). Chlewicki published a paper on the theoretical aspects of signal timing and coordination at a DDI (12). A number of published sources compared the DDI to other interchange concepts (5, 8, 14, 17-18), while one also pointed out the potential operational impacts of a DDI on freeway operations as well (14).

In general, the literature indicates that the DDI offers a substantial improvement in operations over other interchange types when turning volumes are high. The DDI does not perform as well when ramp traffic is low and through volumes are high, a direct result of the fact that conflicting volumes in a DDI are the opposing through movements. While some sources provide hard numbers, or ratios, beyond which turning movement volumes would cause a DDI to fail, other sources directly contradict this idea.

DDIs also have an impact on freeway operations by the nature of the way traffic from a DDI enters the freeway when compared to other diamond interchange configurations. They are less tightly spaced and do not merge into traffic in the denser platoons found with traditional diamond interchanges. This behavior was found to have the greatest difference when the freeway is at or near capacity (14).

Design Guidelines

There are two agency-published (18, 25) and one other (15) comprehensive sources for DDI design guidelines that go into any level of detail regarding multiple aspects of geometric design for a DDI. The FHWA AIIR provides far more detail than the others with regard to signing and striping, though most of it is based on MoDOT practice. FHWA made the conscious decision to make this an "informational report" as opposed to more formal "guidelines"[2].

UDOT guidelines are the sole source for certain specifics, such as minimum terminal separation distance and maximum volume thresholds for DDI implementation. It is important to note that other sources contradict the limits in the UDOT guidelines. For example, the document states that "observations have found that a minimum [ramp terminal separation distance] of 850 feet" is required for proper operation. All existing DDIs (French and American) are below this distance as are almost all DDIs currently in design.

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[1] Conversations with ODOT's bicycle liaison indicated that a primary reason for this is the risk of head on bicycle collisions within the ped/bike corridor at the center of the interchange.

[2] Information gained based on a phone conversation with Joe Bared, FHWA, in late April 2010.

Signal warrants are included in two documents (15, 18) as there is the anticipation that future DDIs may be constructed with such unbalanced movements that signalization of one or both terminals may not be necessary.

Objectives

This performance evaluation was directed towards assessing:

- **Traffic Operations** – Pre-construction, post-construction and future traffic conditions
- **Safety** – Pre-construction and post-construction conditions
- **Public Perceptions**
    - General Public
    - Pedestrians and Bikes
    - Larger Vehicles (Trucks, Recreational vehicles – mobile homes, boats, etc.)

Present Conditions

The preliminary evaluation provided very good information on what could be anticipated or expected, but the reality of deploying a DDI solution in the real transportation world would complete the story on whether or not the DDI would work and be publicly accepted. This post-construction evaluation does help answer the questions does it work; how does it compare to the previous interchange; and is it acceptable by the traveling public.

Technical Approach

Performance measurements (PMs) will set the stage on how the evaluation of the Diverging Diamond Interchange (DDI) will be conducted and presented to potential audiences. These audiences will vary from a DOT executive staff member making a decision on whether or not a DDI solution should be considered in their state or local community to that of a Internet user wanting to know more about a DDI because it has surfaced as a potential solution in their community.

PMs must be understandable and applicable to the potential readers' needs so they can learn from the first DDI improvement made in the United States. The DDI evaluation report focused on these PMs, so their selection was important in producing well respected evaluation reports.

PM's were obtained from various sources of information. Information provided by MoDOT, data collected in the field, opinions from various transportation users, operational observations, etc. The following provides a description of PMs, their source or collection method and "why" they are used in this final report.

Traffic Operation

Traffic Volumes were based on traffic counts conducted by MoDOT for both the "*pre-construction*" and "*post-construction*" of the DDI improvements[3]. These turning traffic movement counts will serve as the base information for the development of "*pre-construction*"

[3] **DDI improvements or interchange refers to the roadway section from Norton Road to Evergreen Street along Route 13**

and "*post-construction*" traffic simulation models Understanding the before and after traffic flow conditions will allow for comparison of a typical diamond interchange to that of the DDI.

These comparisons also included a future (2035) traffic conditions to provide additional insight on how the DDI will work in the future.

Default Traffic Simulation Parameters were summarized based on changes required during the calibration process. Viewing of the recorded videos was used to determine if drivers appear to maneuver differently through the DDI. Default parameters were adjusted and are discussed in the operational report.

Travel Times have been collected by MoDOT (*pre-construction*) and HDR (*post-construction).* Knowing the *pre-construction* and *post-construction* travel times was used by the evaluators to calibrate the traffic simulation models to augment better results. *Pre-construction* and *post-construction* improvements conditions were compared and analyzed.

Total Network Delays were calculated from results obtained from the traffic simulation models. Total network delay estimates the delay based on all the vehicles traveling through the network. This can be expressed as average delay per vehicle or as a cumulative delay experienced by all the vehicles. *Pre-construction* and *post-construction* conditions were compared and analyzed.

Vehicle Stops were calculated from the results obtained from the traffic simulation models. Vehicle stops are the estimated number of stops that would occur while traveling through the DDI improvements. Vehicle stops can be calculated for the network and/or each intersection movement. *Pre-construction* and *post*-construction improvement conditions were compared and analyzed.

Percentage of Trucks was obtained from MoDOT and was used as data input into the traffic simulation models. Trucks' movement and flow through the interchange were observed during various field data collection periods and were included in the traffic operations report.

Route 13 is a major North-South corridor in Missouri and serves many tourists coming to Southwest Missouri for various recreational and entertainment activities. Many tourists arrive driving their motor-homes, trucks with fifth wheel trailers, truck or auto pulling a boat, etc. These large vehicle combinations present similar concerns to that of 18 wheeler heavy trucks when traveling through the DDI. Tourists are more of an occasional driver when operating these larger vehicle combinations, thus, presented an opportunity to observe less experienced drivers than the professional truck driver as they travel through the DDI. A Friday afternoons and evenings were observed.

Pedestrians and Bicycles were obtained from traffic counts from MoDOT and were used as data input into the traffic simulation models. Pedestrian and bicycle movements were observed as they traveled through the DDI.

Safety

Traffic crash information obtained from MoDOT and the City of Springfield was analyzed for the following:

- Severity – fatal, serious injury, minor injury and property damage only
- Type of crash – right angle, rear-end, sideswipe, etc.

Crash data was evaluated for a five-year period before the improvements and one-year after improvements. Roadway segment crash rates were and compared to determine any changes in the *pre-construction* and *post-construction* periods. Summary of results in charts and graphs were developed to investigate changes in the two (2) time periods (*pre-construction* and *post-construction*).

Public Perception

On-line survey information was collected from the general public by an on-line survey. This survey of the general public focused on the operation of the DDI and their perspective on the overall safety of the DDI. The survey instrument was 18 multiple choice questions long with 3 opened ended questions where the respondent could provide more detail comments. Results are delivered in charts and graphs with the 3 opened ended questions' responses contained with a summary document in this report's Appendix.

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Trucking Industry survey information was collected in telephone conversations with two truck drivers and one trucking firm. A similar survey was developed and used in conducting these interviews.

Pedestrians' and bikes' perspectives were obtained through a conversation with a local pedestrian and bike community representative and a national experienced pedestrian and bike planner and designer.

Results and Discussion (Evaluation)

Traffic Operation

This section focuses on the traffic operational aspects of the existing I-44/Route 13 Diverging Diamond Interchange (DDI) compared with those of the Diamond Interchange that previously existed at this location. The existing DDI was opened to traffic on June 21, 2009.

In addition to comparing actual "*pre-construction*" and "*post-construction*" travel time data, VISSIM traffic simulation models were developed to assess and compare additional operational characteristics of these two types of interchanges. This traffic operation section provides a summary of the following areas:

- Study Intersection Improvements – Although the main focus of this analysis is the evaluation of I-44/Route 13 interchange, two additional intersections were also included due to their proximity to the interchange ramps. As part of the interchange construction project, additional capacity improvements (described later in this report) were also constructed to further reduce driver delay. Understanding these improvements is critical to interpreting the analysis results.

- Data Collection Tasks – Travel time runs were conducted in April 2010 during both the AM and PM peak hours between Evergreen Street and Norton Road along Route 13. Video recordings of the travel time runs were also completed for purposes of reviewing driver behavior traveling through the DDI.
- Development of Peak Hour Traffic Volumes – MoDOT provided Year 2008 AM and PM peak hour traffic volumes at the four study intersections. Year 2010 average daily traffic volumes along the I-44 Ramps were also provided by MoDOT. Based on the traffic volume data provided along with historical ADT volumes along Route 13, Opening Year 2010 and Year 2035 AM and PM peak hour traffic volumes were developed.
- Traffic Simulation Models – VISSIM models were developed for both the "*pre-construction*" and "*post-construction*" conditions. MoDOT provided a partial VISSIM model of the DDI concept that was used as a starting point in developing the DDI model. A VISSIM model of the "*pre-construction*" diamond interchange was also developed based on Synchro models of the Route 13 corridor.
- Comparison of Operational Characteristics – Based on the "*pre-construction*" and "*post-construction*" data and the results from the VISSIM models, a series of performance measures were developed for the two interchange types.

Study Intersection Improvements

The purpose of this sub-section is to provide an understanding of the various improvements that were completed at each of the four study intersections. A clear understanding of these improvements is critical when comparing the results of the "*pre-construction*" and "*post-construction*" conditions. In some instances, due to the additional improvements beyond those improvements that were completed as part of the interchange project; a positive change in a specific performance measure may be partially due to those additional improvements and not the DDI solution. The following points highlight the key improvements at the study intersections:

- Norton Road – An exclusive right turn lane from the I-44 WB Off-Ramp was constructed. This improvement effectively removed the right-turn traffic from the Route 13/Norton Road intersection, thus leading to an overall reduction in average intersection delay. In addition, a previous project, increased capacity and relocated the intersection further away from the westbound I-44 ramps.
- I-44 WB On/Off Ramp – A short time after the opening of the DDI concept, a traffic signal was added to the westbound-to-northbound right turn lane. This would typically lead to an increase in average intersection delay. The original design signed this movement as a Yield-controlled movement. This signal was added to improve safety for the right-turning ramp traffic to address potential safety concerns of unexpected northbound traffic flow from the opposite side of the roadway.
- I-44 EB On/Off Ramp – Similar to the WB Ramp, a traffic signal was added to the eastbound-to-southbound right-turn lane.
- Evergreen Street– This crossroad was moved approximately 500 feet south from its original location. The total distance from the I-44 EB On/Off Ramp to Evergreen is approximately 800 feet.

Data Collection Tasks

For purposes of this sub-section, MoDOT provided travel time runs in the "*pre-construction*" conditions (i.e. prior to the conversion of the interchange to a diverging diamond). MoDOT conducted a total of seven to eight AM/PM peak hour travel time runs on October 23, 2008 and October 28, 2008. For the "*post-construction*" condition, HDR conducted a series of seven (7) - AM/PM peak hour travel time runs through the four study intersections on 4/22/2010 and 4/27/2010. It should be noted that cycle lengths of 120 seconds during the AM peak hour and 140 seconds during PM peak hour were observed for each interchange configuration. In the Appendix, a series of graphs summarizing the travel time runs were developed.

- Diamond Interchange
    - In general, average travel speeds between 35 and 40 mph were observed during both the NB and SB AM peak hour travel time runs.
    - Travel speeds during the NB PM were significantly less and ranged from 9 to 18 mph.
    - Travel speeds during the SB PM ranged between 24 and 34 mph.
- Diverging Diamond Interchange
    - In general, average travel speeds between 9 and 21 mph were observed during both the NB AM and PM peak hour travel time runs.
    - Travel speeds during the SB AM and PM peak hours were generally higher and ranged from 9.5 to 29.5 mph.
    - The design speed of the double crossover areas at each ramp terminal will somewhat impact speeds as motorists travel through the DDI.

Video recordings of the DDI travel time runs were also produced. Project team members viewed these recordings to observe drivers traveling through the study intersections. In general, no major driver behavior issues were observed as drivers traversed the DDI.

Development of Peak Hour Traffic Volumes

MoDOT provided Year 2008 AM/PM peak hour traffic volumes at each of the four study intersections. In 2008, the I-44/Route 13 interchange consisted of a typical diamond interchange configuration. The intersection of Route 13/Evergreen Street was located 300 feet south of the Route 13/ I-44 EB On/Off Ramp intersection. The east approach of the Route 13/Evergreen Street intersection accessed very few businesses and therefore had low turning volumes.

Figure TO-1 depicts the balanced Year 2008 AM/PM peak hour volumes used for purposes of this project. These volumes were used in the development of the Year 2010 and Year 2035 peak hour traffic volumes.

In developing the future year traffic volumes, a review of historical Route 13 ADT volumes was completed. Since 2001, ADT volumes to the north and south of the I-44/Route 13 interchange have remained steady or have slightly decreased. A noticeable decrease was observed since US Route 160, located approximately two miles west of (and roughly parallel to) Route 13, was widened from two to four lanes.

Based on the available information a conservative growth rate of 1% per year was applied to the Year 2008 turning movement volumes to estimate the base Year 2010 and Year 2035 AM/PM peak hour volumes.

It should be noted that because the intersection of Evergreen Street/Route 13 was relocated further to the south of its original location in conjunction with the DDI construction, the analysis included additional traffic at the appropriate turning movements based on the higher development intensity east of the intersection. Figure TO-2 depicts the balanced Year 2010 AM/PM peak hour volumes used for the opening scenario of the DDI. Figure TO-3 depicts the balanced Year 2035 AM/PM peak hour volumes based on the 1% per year growth rate.

Traffic Simulation Models

A key element of this study was the development of traffic simulation models to assess the operational characteristics of the diverging diamond interchange in comparison to those of a typical diamond interchange. VISSIM was selected as the traffic simulation model due to MoDOT's familiarity with the simulation software, along with VISSIM's flexibility in coding non-traditional geometric features. A VISSIM screen capture of both interchange configurations in contain in the Appendix.

VISSIM models were developed for both the "*pre-construction*" and "*post-construction*" conditions. MoDOT provided a pre-construction model of the DDI that was used as a starting point. As noted above, the changes in the geometric configurations of the four study intersections don't allow for a complete "*apples to apples*" comparison. This report, however, will highlight a few of the operational characteristics of the interchange ramp junctions themselves.

Once the geometric and traffic control characteristics were coded, the VISSIM models were calibrated. In addition to travel time data, observations of traffic flow and vehicle queuing were used in the calibration process. Since the focus of this project was the operational analysis of the at-grade intersections along Route 13, VISSIM's urban driver behavior model was used along each of the roadway links. Based on the available data, the default settings for both the "Following" (*Look ahead (0-820.21 feet) and back distances (0-492.13 feet*)) and "Lane Change" (*Minimum headway (1.64 feet) and safety distance reduction factor (0.6)*) parameters were utilized.

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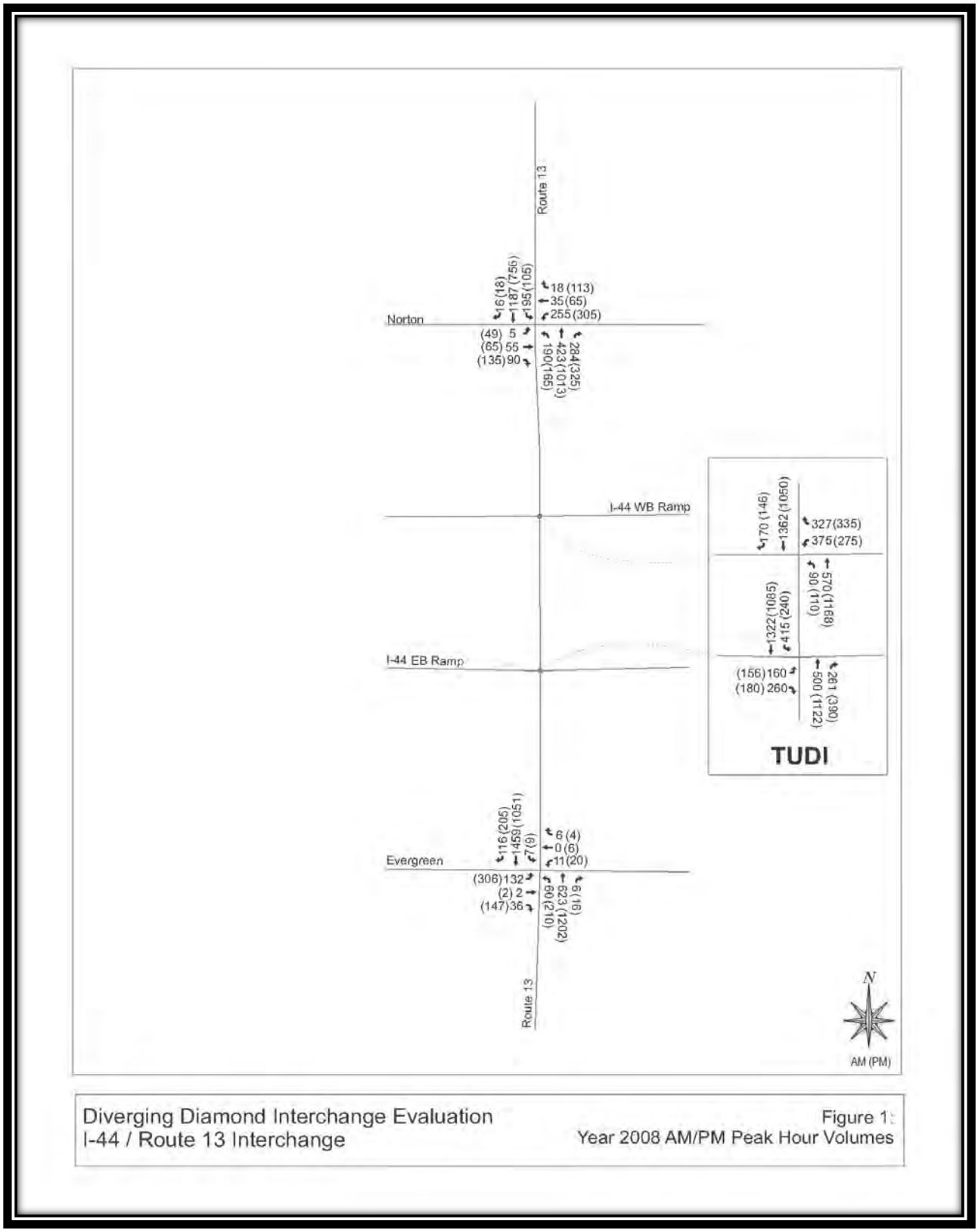
Figure TO-1 – Year 2008 Traffic Volumes



Diverging Diamond Interchange Evaluation
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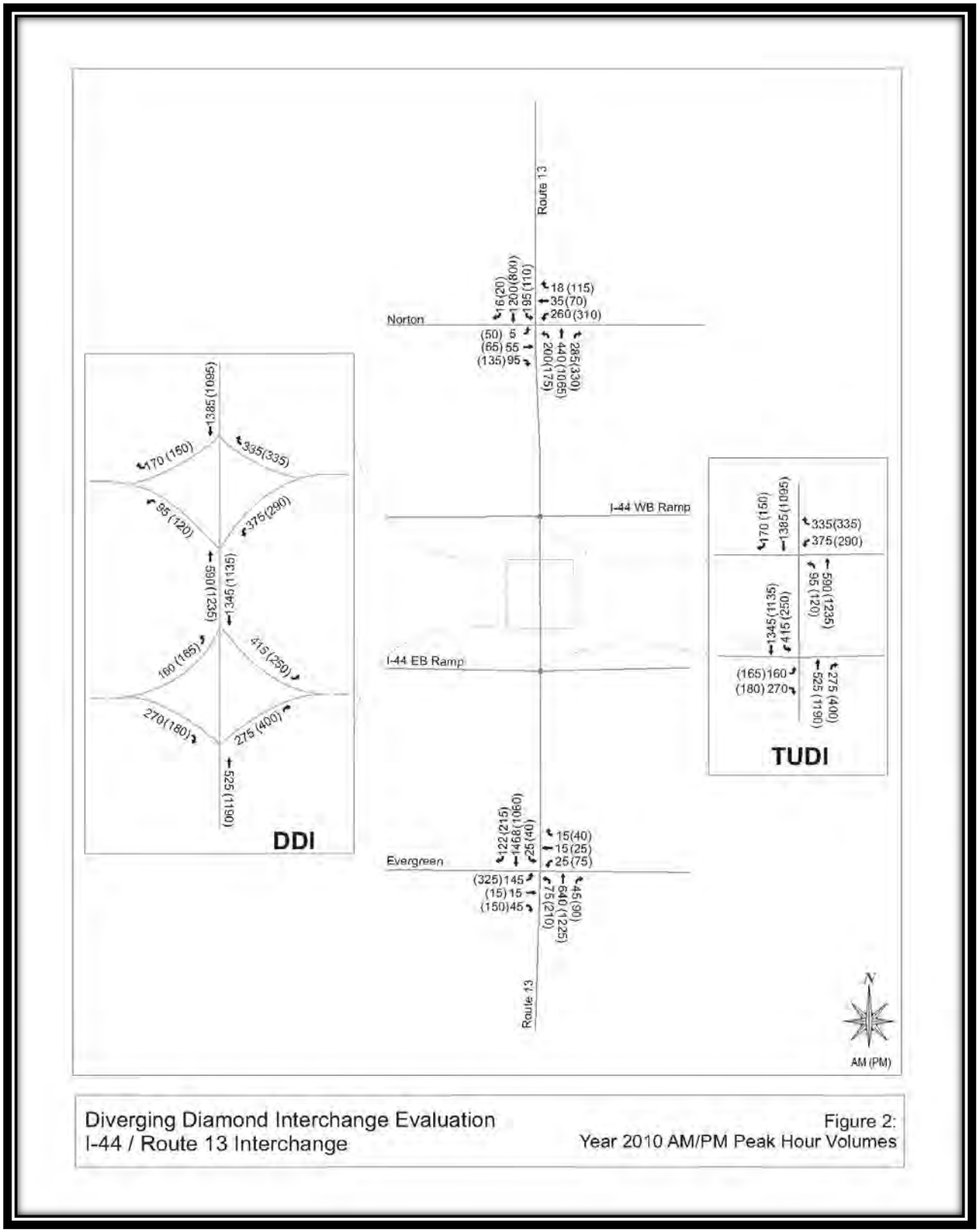
Figure 1:
Year 2008 AM/PM Peak Hour Volumes

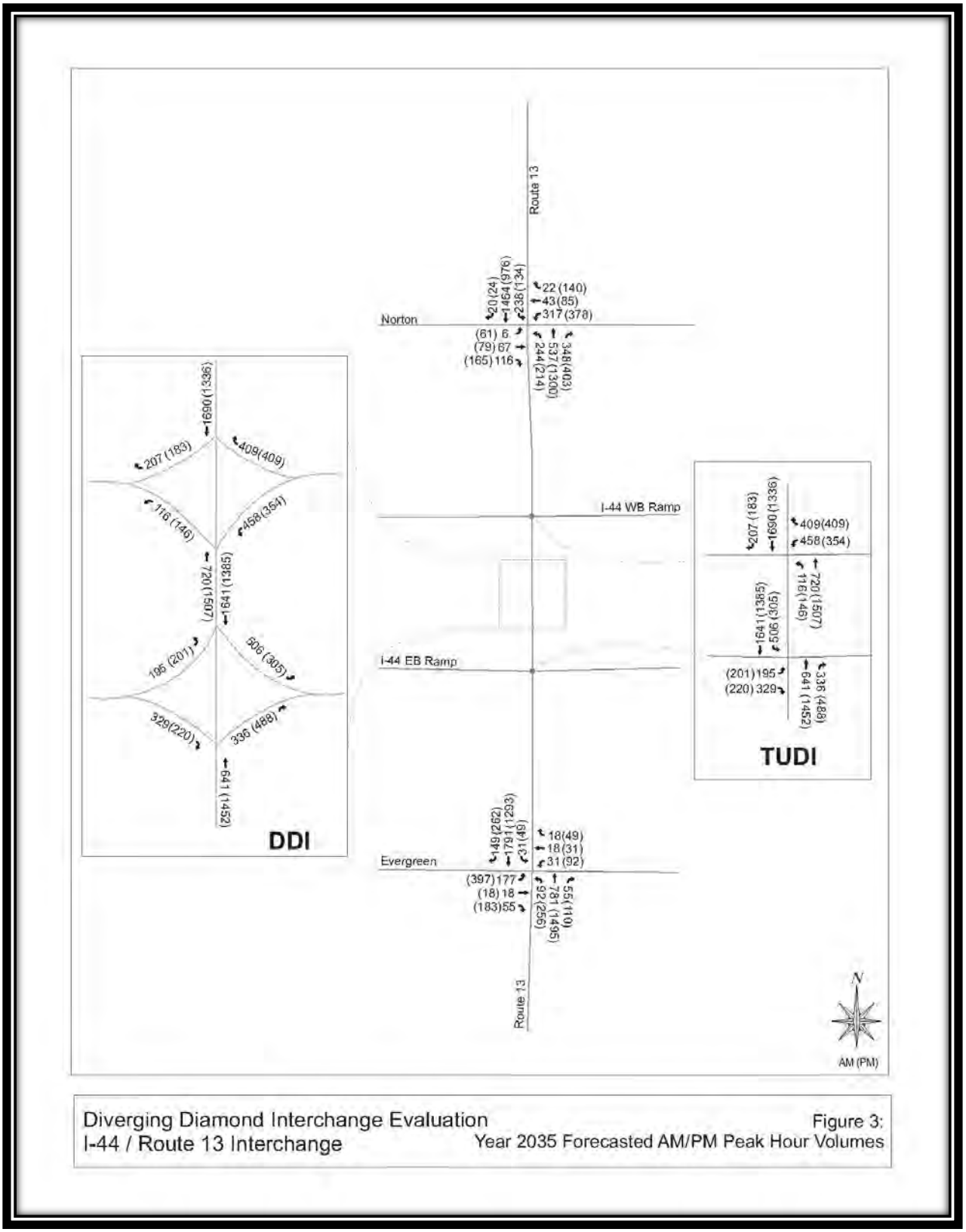
Figure TO-2 – Year 2010 Traffic Volumes



Diverging Diamond Interchange Evaluation
I-44 / Route 13 Interchange

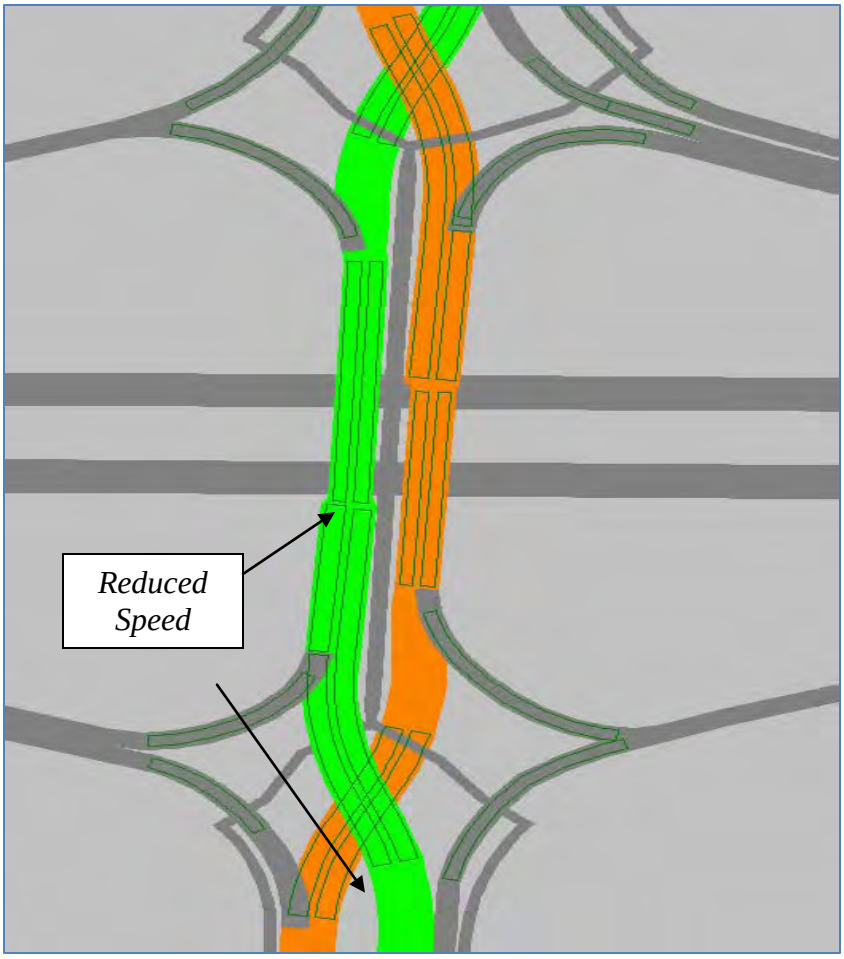
Figure 2:
Year 2010 AM/PM Peak Hour Volumes

Figure TO-3 – Year 2035 Traffic Volumes



Travel speeds were also reviewed as part of the VISSIM calibration. Travel speeds within VISSIM can be coded in several ways. As vehicles enter the network, they are assigned a travel speed based on a user-coded speed distribution. They will continue to travel at that speed, regardless of geometric features, until they approach a *desired speed zone* or a *reduced speed zone*. These zones were coded based on speed limits as well as turning radii. Within the DDI model, additional reduced speed zones (18 to 30 mph) were coded through the curves and across the bridge to account for the configuration's inherent geometric constraints of the crossover areas. Figure TO-4 depicts a screen capture of the reduced speed zones within the DDI VISSIM models.

Figure TO-4 – Reduced Speed Zones within VISSIM Model



Included in Appendix is a summary of the field collected travel time runs versus those produced by the VISSIM model. In general, VISSIM speeds were within 10 mph of the field measured travel speeds for the DDI models. VISSIM-related travel speeds for the diamond interchange models were higher than those measured in the field. It should be noted, however, the field travel time results reflect only 7 to 8 runs. The VISSIM results reflect several hundred to as many as a thousand vehicles traveling through the corridor and therefore include vehicles that may have been stopped at a red light. Travel time runs along arterials (especially short sections such as this study area) are highly sensitive to signal timing and phasing.

Comparison of Operational Characteristics

Several performance measures were extracted from VISSIM to compare the operations of the Typical Diamond Interchange to those of the Diverging Diamond Interchange. As noted above, due to some of the geometric differences at the study area intersections, an "*apples to apples*" comparison is not completely feasible. However, an isolated comparison between the ramp junctions of the two interchange configurations is reasonable. The following provides a highlight of the model results.

Travel Time Results – In general, during lower traffic-flow periods, longer travel times through the DDI were observed (and simulated). During the Year 2035, however, two of the DDI models had slightly lower corridor travel times than those of the typical diamond interchange. Overall, a higher travel time run for the DDI configuration is reasonable since all traffic traveling through the interchange uses only two travel lanes versus a typical diamond interchange at which left turning traffic is allowed to queue in storage bays. In addition, all traffic at the DDI must traverse two low-speed horizontal curves (crossover areas) in the DDI configuration.

Table TO-1 – Network-Wide *Results*

		Average delay time per vehicle (Seconds)	Total delay time (Hours)	Total Stops
2008 Diamond	AM	32.9	74.0	6,290
	PM	39.4	95.7	7,095
2010 DDI	AM	29.6	68.2	5,853
	PM	42.4	107.5	7,896
2035 Diamond	AM	74.4	184.2	13,908
	PM	103.5	269.6	19,701
2035 DDI	AM	93.0	202.2	11,112
	PM	95.6	250.7	16,881

Network-Wide Results – Table TO-1 depicts a summary of three performance measures related to the entire study area included within the VISSIM model. Total modeled network delay is summarized based on average delay time per vehicle as well as total delay time and total stops. During higher-volume periods, the DDI configuration results in a lower delay/vehicle. The DDI configuration resulted in a lower number of total stops in each of the models except for the PM Peak hour model. This could be due to the higher traffic volumes at the relocated Evergreen Street/Route 13 intersection.

Average Intersection Delay – Table TO-2 depicts a summary of the average delay per vehicle for each of the VISSIM models. The results in this table highlight the benefits of the DDI alternative more clearly. Both of the I-44 ramp junction intersections exhibited lower intersection delays than the typical diamond interchange. These results highlight the negative impact that closely spaced intersections can have on overall delay. If the DDI were isolated (no adjacent intersection signals), the DDI would be expected to significantly reduce driver delays.

TableTO- 2 – Average Intersection Delay

	Average Delay per Vehicle (seconds)							
	Diamond (2008)		DDI (2010)		Diamond(2035)		DDI(2035)	
	AM	PM	AM	PM	AM	PM	AM	PM
Norton	25.7	25.2	28.0	30.0	47.4	66.6	49.5	79.4
44 WB Ramp	28.1	22.9	17.6	19.6	46.4	66.8	37.5	53.8
44 EB Ramp	21.1	25.5	17.1	22.6	33.9	42.5	26.1	34.7
Evergreen	12.7	26.5	15.4	28.3	20.0	40.7	18.5	41.3

Observations
Several observations were conducted during the study period to assess peak hour operations and potential impacts to traffic operations. The following is a summary of these observations:

- Friday evening tourist traffic and PM peak traffic periods were observed and found only minor back-ups compared to pre-construction when traffic backed-up for a mile or greater. These Friday evenings were previously impacted in part due to the heavy southbound left turn movement onto I-44. With this left turn movement now being free flow in the DDI solution, the mixture of large vehicles (trucks, mobile homes, vehicles towing boats, etc.) made the southbound movement in more efficient manner leading to a reduction traffic delays.
- Friday evenings during the annual Ozark Empire Fair (fairgrounds located just northeast of the DDI) were observed during the arrival periods for the major evening events. Northbound traffic and both Eastbound and Westbound ramp traffic were found to be heavy, but they normally cleared within one to two signal cycles. This interchange and adjacent signalized intersections in previous years were controlled by law enforcement staff based on the heavy traffic demand and safety concerns.
- An oversized load was observed during an off peak period. The movement of 14 foot plus wide load did take a complete signal cycle to clear causing some minor back-ups in traffic. However, this backed-up traffic cleared within one signal cycle after the load cleared.
- Observations were also made at the second DDI in Springfield at US Route 60 and National. This interchange operates similar in nature to I-44 and Route 13 with a couple different distinctions. A dual right off ramp and dual left off ramp were constructed based on traffic demands and they have eliminated the daily morning commute back-up onto US Route 60. Signal spacing lengths between the interchange ramps and adjacent signalized intersections is greater. This additional signal spacing appears to have improved traffic flow along the National corridor when compared to traffic flow along Route 13.
- A complete power outage was observed after a summer thunderstorm at US Route 60 and National. Motorists adjusted to darken signals and treated the crossover area like a two-way stop condition while exiting traffic from the off ramps went to a yielding condition. This power outage happened late in the PM peak when traffic was still somewhat heavy and only minor delays were observed.

Safety

This section provides the results of a two-level safety analysis performed on crash data provided by MoDOT and the City of Springfield. It will identify potential changes in roadway safety based the evaluation of pre-construction and post-construction crash data and will do a more in-depth crash analysis of the post-construction crash reports to better answer the question - does the DDI increase or decrease crashes when compared with standard diamond interchange?

The first-level analysis compares the five (5) years of pre-construction crash data (2004 through 2008) to one (1) year of post-construction (2009/2010) crash data. This comparison of crash data will provide a good initial indicator on the safety of the DDI solution. Additional post-construction crash data beyond the initial year will help confirm initial findings and provide

additional insight to any potential changes in trends over time (i.e. motorists becoming more accustomed to the interchange).

The post-construction crash data period included crash data from August 26, 2009 through August 26, 2010 were used, since the project's final construction completion on August 26, 2009.

The second-level analysis included the investigation of crash reports for all crashes occurring within the operational area of the interchange. The interchange operational area is defined for this analysis as the roadway segment between I-44 Westbound ramps and I-44 Eastbound ramps. This investigation included the review of actual field crash reports to determine if crash patterns were different than previously experienced within the standard diamond interchange and/or different than what would be normally expected along similar corridor.

First-Level Safety Analysis – Crash Severity
In first-level safety analysis, crash data was evaluated based on total crash numbers, crash severity, crash rates and crash types. The pre-construction crash data covered five years (baseline information 2004 through 2008) and an average was calculated across the five-year period. This average shows the crash variation by year of the baseline period that can be used to provide a slightly different comparison perspective on how the post-construction period performed. The following figures (S-1 through S-5) are presented to depict the first-level safety analysis on crash numbers, crash severity and crash rates:

Figure S-1 – Total Crash

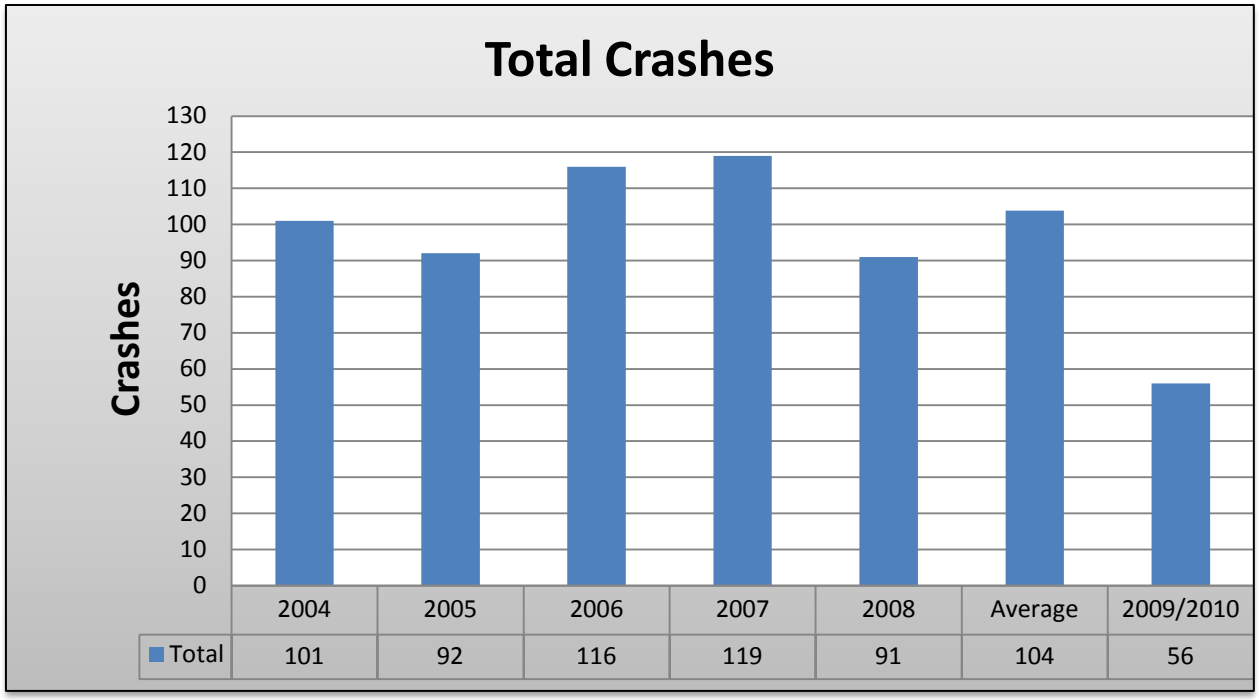


Figure S-2 - Disabling Injury Crash

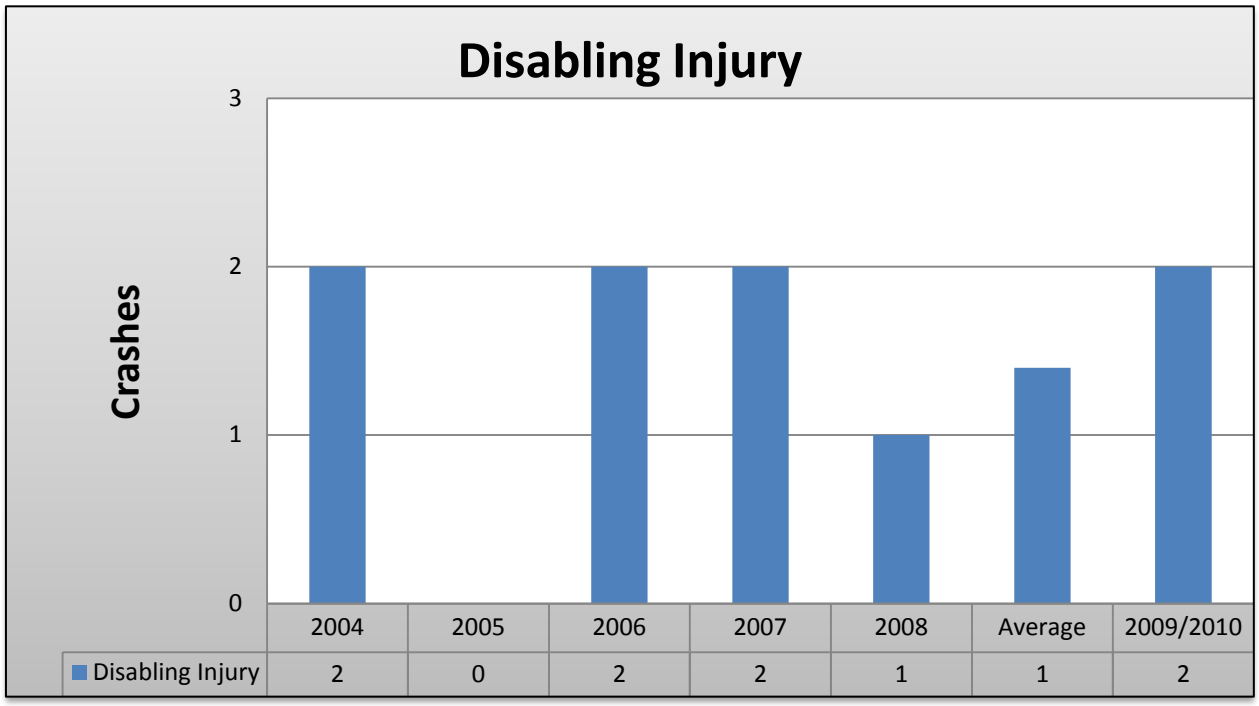


Figure S-3 - Minor Injury Crash

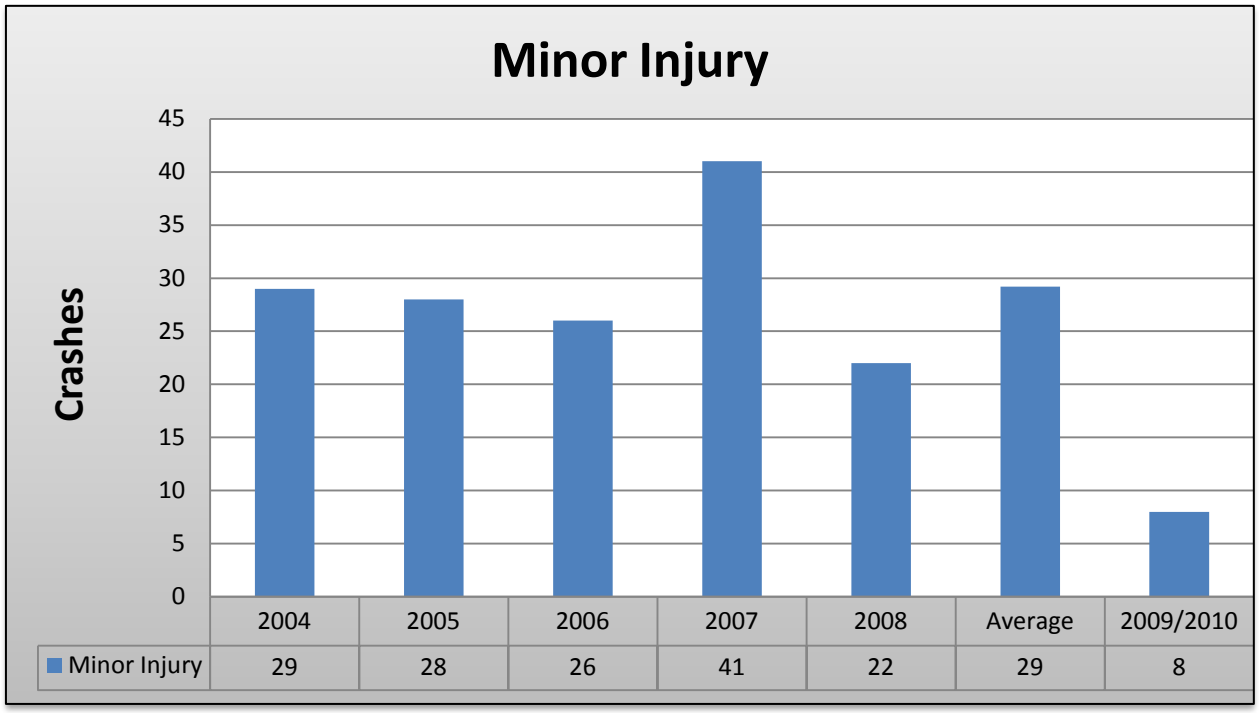


Figure S-4 - Property Damage Only Crash

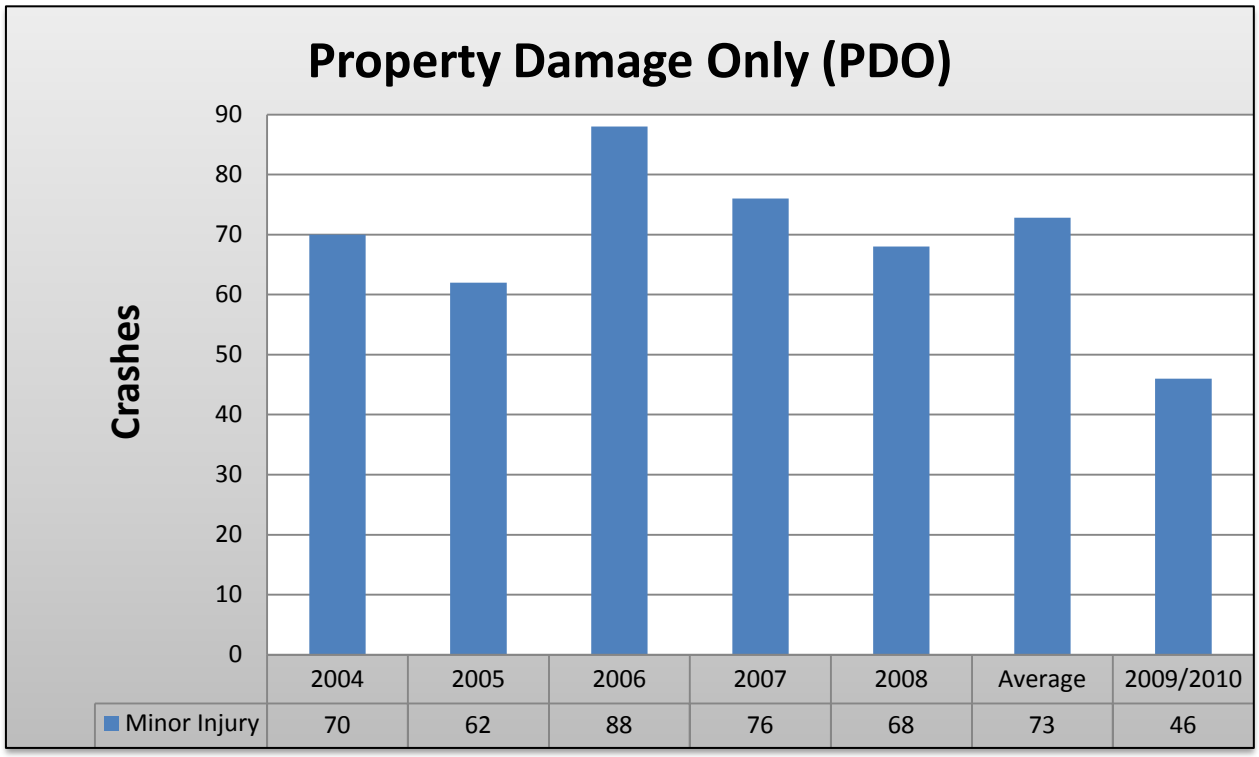
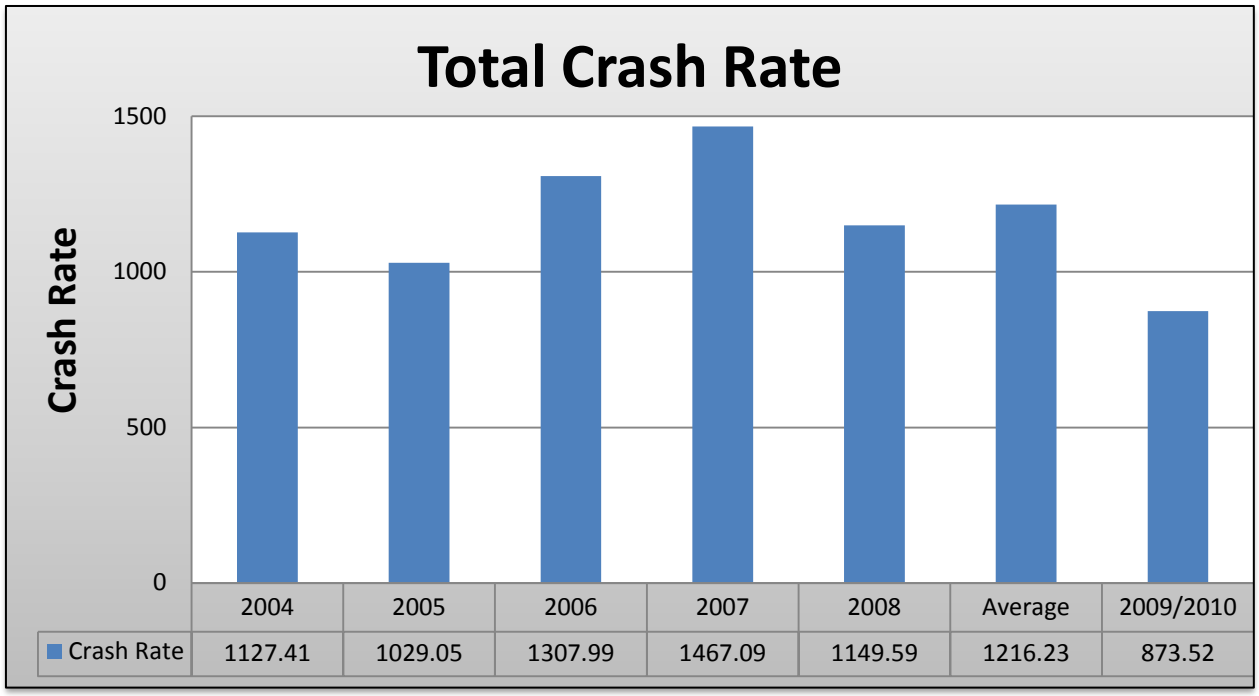


Figure S-5 – Total Crash Rates



Results of the first-level severity analysis:

- Total Crashes were down when comparing the average across the 5-year baseline to the one-year post-construction period by 46% ;
- No Fatal Crashes occurred in the both 5-year baseline and the initial year after the DDI was constructed;
- Disabling Injury crashes were up when comparing the average across the 5-year baseline to the one-year post-construction period by 1 crash. Based the frequency of these more serious crashes, it is difficult to compare it alone. It should be reviewed in the future when more long-term crash information is available;
- Minor Injury crashes were down when comparing the average across the 5-year baseline and the one-year post-construction 72%;
- Property Damage Only were down when comparing the average across the 5-year baseline and the one-year by 37%;
- Crash Rates were down when comparing the average across the 5-year baseline and the one-year post-construction by 28%.

First-Level Safety Analysis – Crash Type

The second part of the first-level safety analysis investigated the type of crashes to determine if there was any difference in pre-construction and post-construction types of crashes or if the DDI construction introduced any noticeable changes in types of crashes. The following figures (S-6 through S-9) are presented to depict the first-level safety analysis on crash types. Since there are almost 30 different crash type categories, the study team selected the 3 highest types (representing almost 74% of the crashes) and combined the remaining into a single category labeled as "Others" types.

Figure S-6 – Rear-end Type Crashes

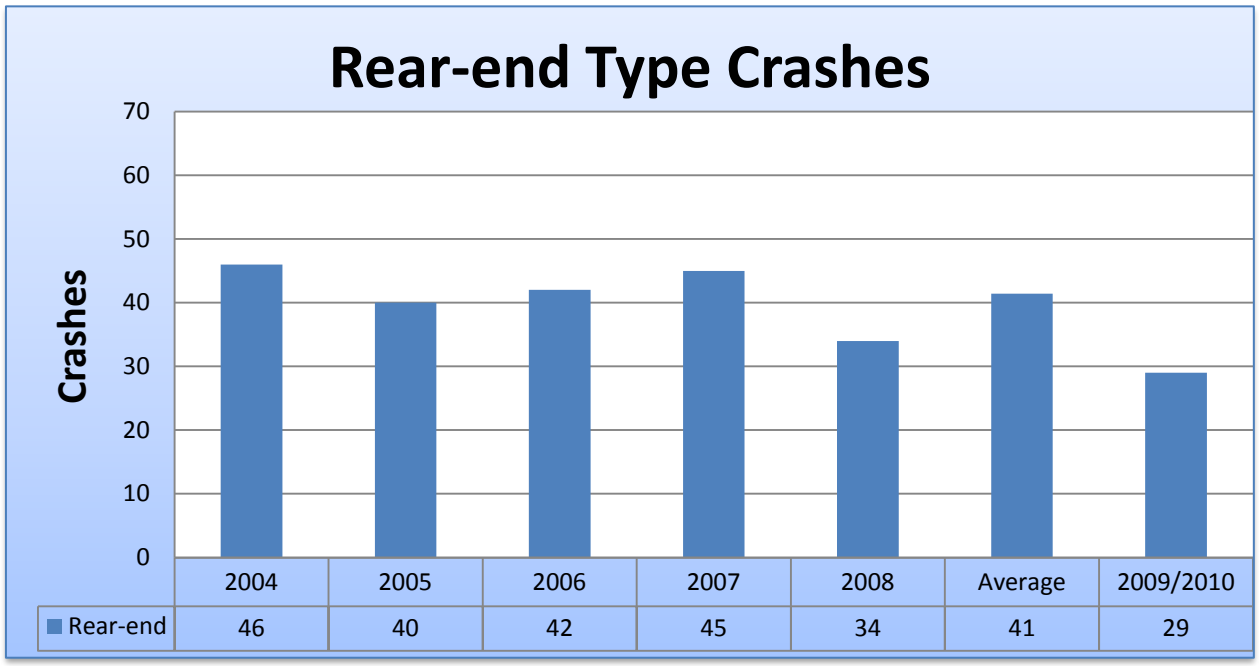


Figure S-7 – Left Turn Right Angle Type Crashes

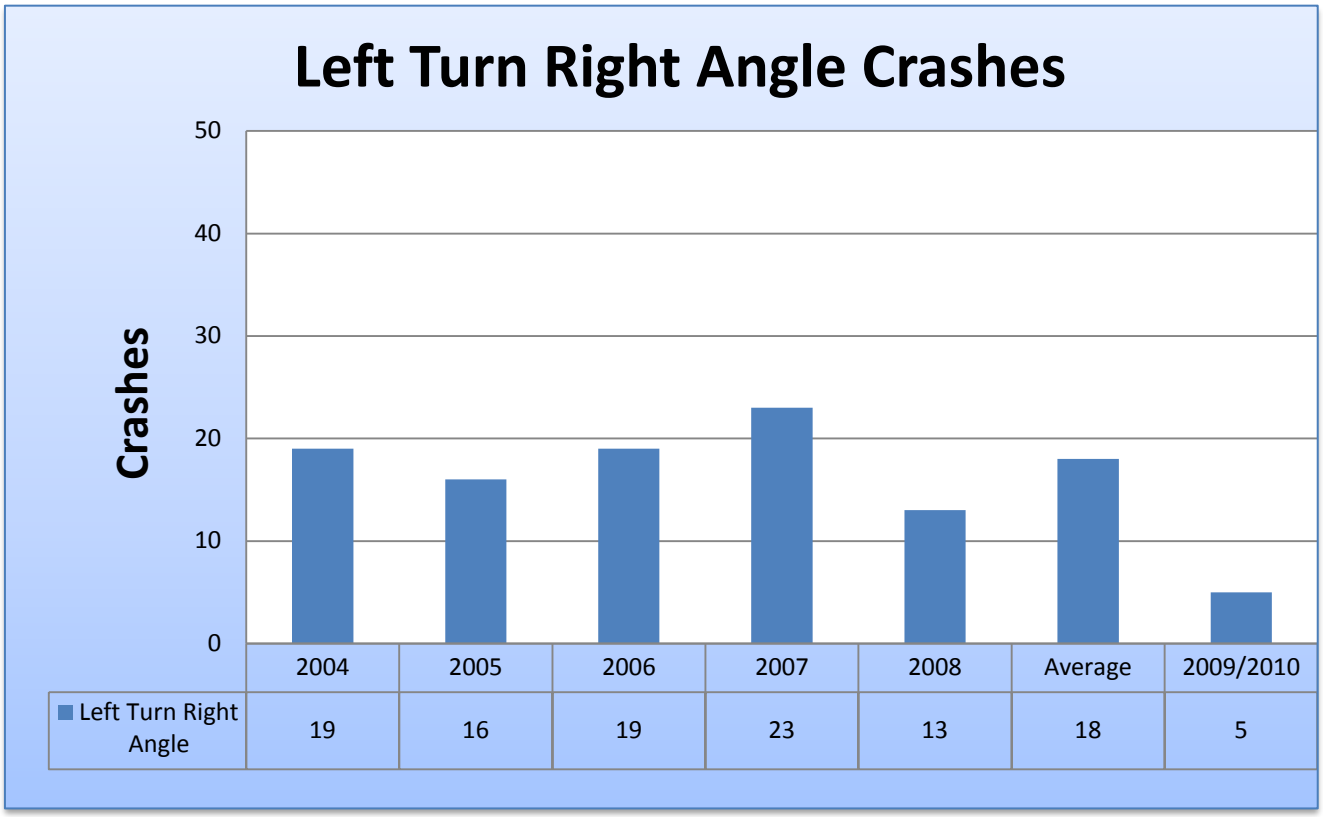


Figure S-8 – Left Turn Type Crashes

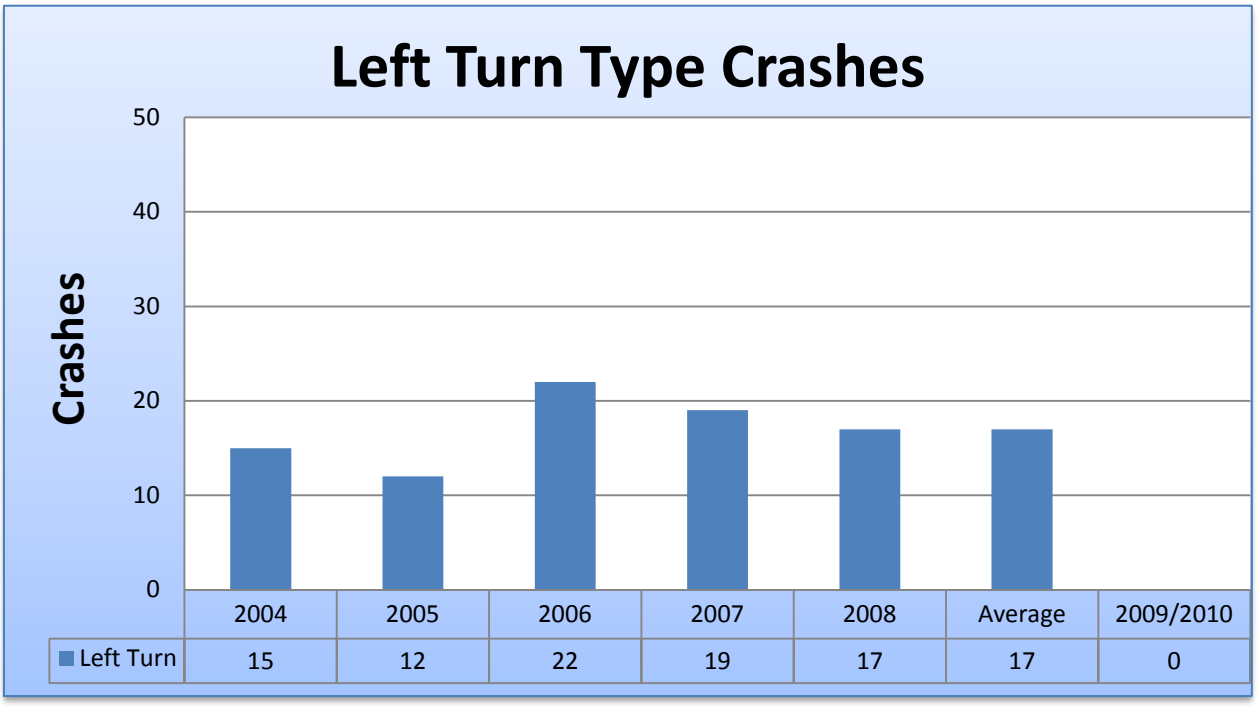
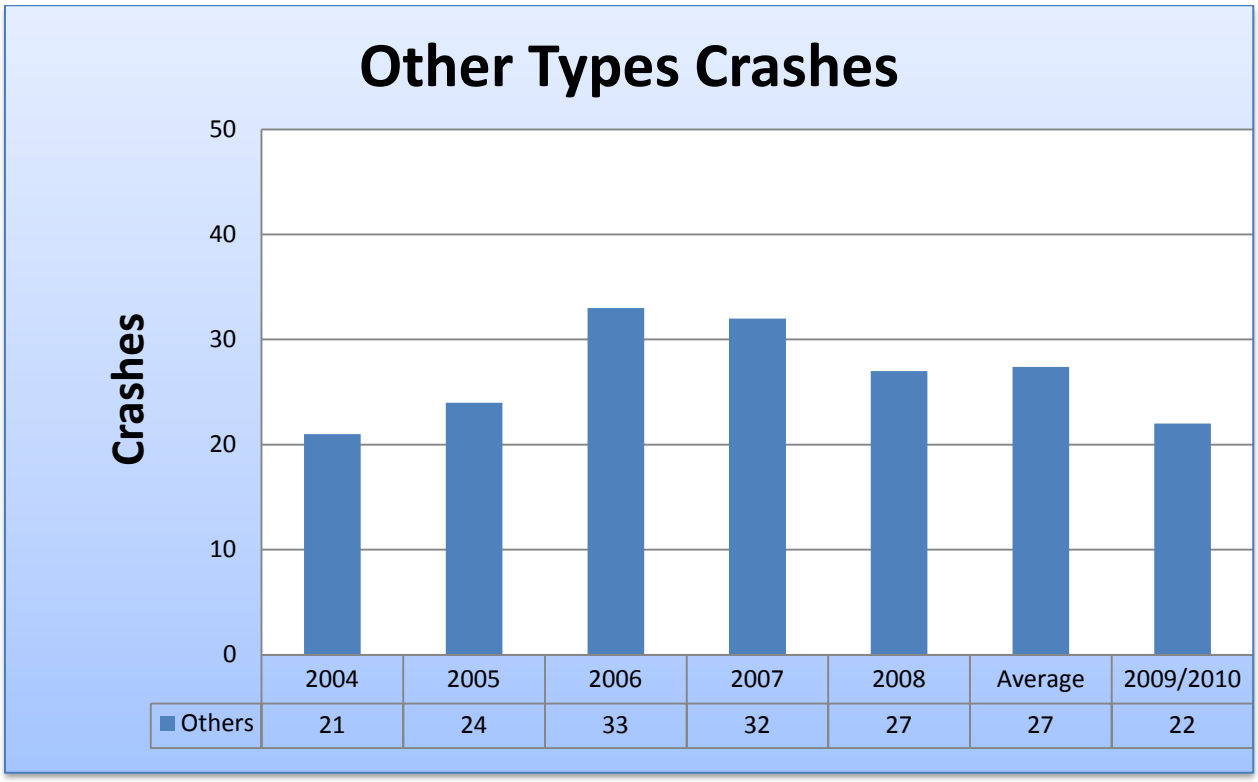


Figure S-9 – Other Type Crashes



Results of the first-level crash type analysis:

- Rear-end Crashes were down when comparing the 5-year pre-construction average to the first post-construction year by 29%;
- Left Turn Right Angle Crashes were down when comparing the 5-year pre-construction average to the first post-construction year by 72%;
- Left Turn Crashes in the pre-construction period were eliminated completely;
- Other Crashes were down when comparing the 5-year pre-construction average to the first post-construction year by 19%

Second-Level Safety Analysis

The second-level safety analysis reviewed actual field crash reports for all crashes occurring in the post-construction period (August 26, 2009 through August 26, 2010) within the DDI. There were 9 crashes in last 4 months of 2009 and 16 crashes in first 8 months of 2010 at or near DDI. The following describes the general location, severity, direction of travel and type of crash:

<u>Eastbound Ramp</u>

3 – Property Damage Only - Northbound – Rear-end
4 - Property Damage Only - Southbound – Rear-end
2 – Property Damage Only – Eastbound and Southbound – Right Turn Right Angle
1 – Minor Injury - Southbound – Sideswipe
1 – Property Damage Only - Southbound – Sideswipe
1 - Property Damage Only - Northbound – Sideswipe

Westbound Ramp
5 - Property Damage Only - Northbound – Rear-end
1 – Disabling Injury - Southbound – Rear-end
2 - Property Damage Only - Eastbound – Rear-end
1 - Property Damage Only - Westbound – Rear-end
1 - Property Damage Only - Southbound – Out of Control
1 – Disabling Injury - Northbound – Out of Control
1 - Property Damage Only - Northbound – Sideswipe
1 – Property Damage Only – Southbound – Fixed Object

There were 26 additional crashes at or near Norton Road and 5 additional crashes at Evergreen or the South Commercial entrance.

Approximately 64% of the crashes were Rear-end type crashes which is a common crash type at signalized intersections. Sideswipe and Right Turn Right Angle are also common crash types at signalized intersections. The two right turn off ramps are now under signal control. Signals were added based on early operational observations of the DDI. These traffic signals were in placed during this post-construction safety evaluation period.

The out of control were further investigated – one may have been caused by medical condition and the other accelerated when the signal changed to yellow and lost control. The fixed object crash apparently hit the island curb while making a free left turn onto the I-44 on ramp and struck a sign.

The following Table S-1 displays the comparison between crashes within the interchange's operational area for the 5-year pre-construction to 1-year post-construction.

Table S-1 Crash Data Comparison

Severity	5-Year Pre-Construction Average	1-Year Post-Construction	Change in Crash Numbers
Disabling Injury	**1**	**2**	**1**
Minor Injury	**14**	**1**	**(13)**
Property Damage Only	**38**	**22**	**(16)**
Total	**53**	**25**	**(28)**
Crash Type			
Rear-end	**21**	**16**	**(5)**
Left Turn Right Angle	**11**	**0**	**(11)**
Left Turn	**9**	**0**	**(9)**
Others	**12**	**9**	**(3)**
Total	**53**	**25**	**(28)**

Note: A red number represents a reduction in the number of crashes

Public Perception

Public opinions on innovative solutions like the DDI provide valuable information that can help to enhance both safety and traffic operations. This Public Perception section covers information gained through three different public users of the DDI. The following provides a general overview on how this information was gained from each user group:

- Motorists – an on-line survey was developed that requested their opinion on how the DDI operates, the DDI's safety aspects, interaction with larger vehicles within the DDI, pedestrian and bicycle facilities, and the traffic control devices used (signing, pavement marking and signals). The on-line survey and results are contained within the Appendix.
- Larger Vehicle Drivers – interviews with two drivers who travel through the DDI almost daily and their perspective on similar questions asked in on-line survey mentioned above. Also, a company that hauls frequent over-dimension loads was interviewed to gain their perspective on how the DDI performed in the movement over-dimension loads through it.
- Pedestrians and Bicyclists – interview with professionals who are involved in planning, designing and operating pedestrian/bike facilities. This interview was more directed towards pedestrian and bicycle facilities within the DDI and a general discussion on what is needed to further address access, mobility and safety for pedestrians and bicyclists.

Motorists On-line Survey

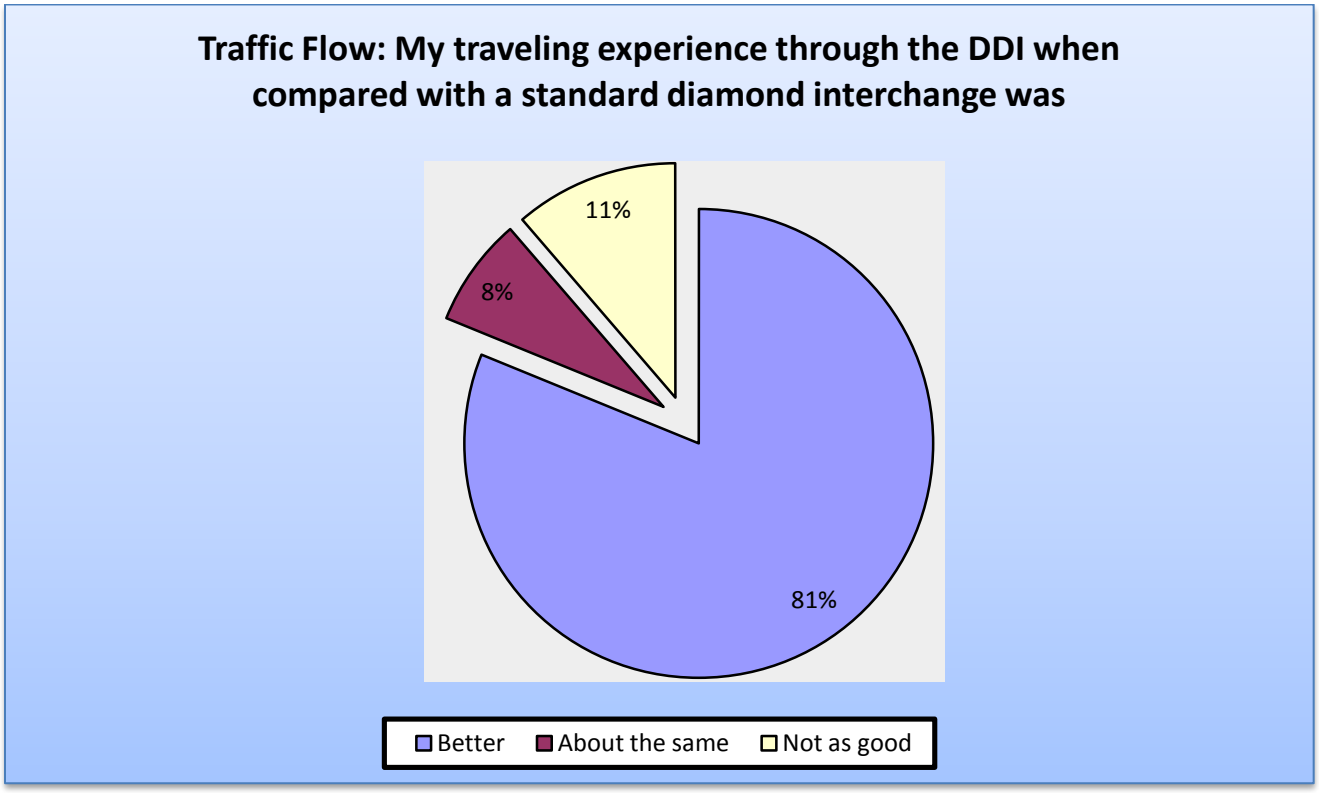
There were 21 questions with 3 questions being open-ended in this survey. The survey and results are contained within the appendix of this report. These questions were developed to gain responses on traffic flow, traffic safety, access and understanding of the interchange. These groupings will be used to convey the results of the survey.

There were a total of 53 people who responded to the survey. A survey web link was promoted on the MoDOT District 8 Homepage and was conducted through the Survey Monkey application.

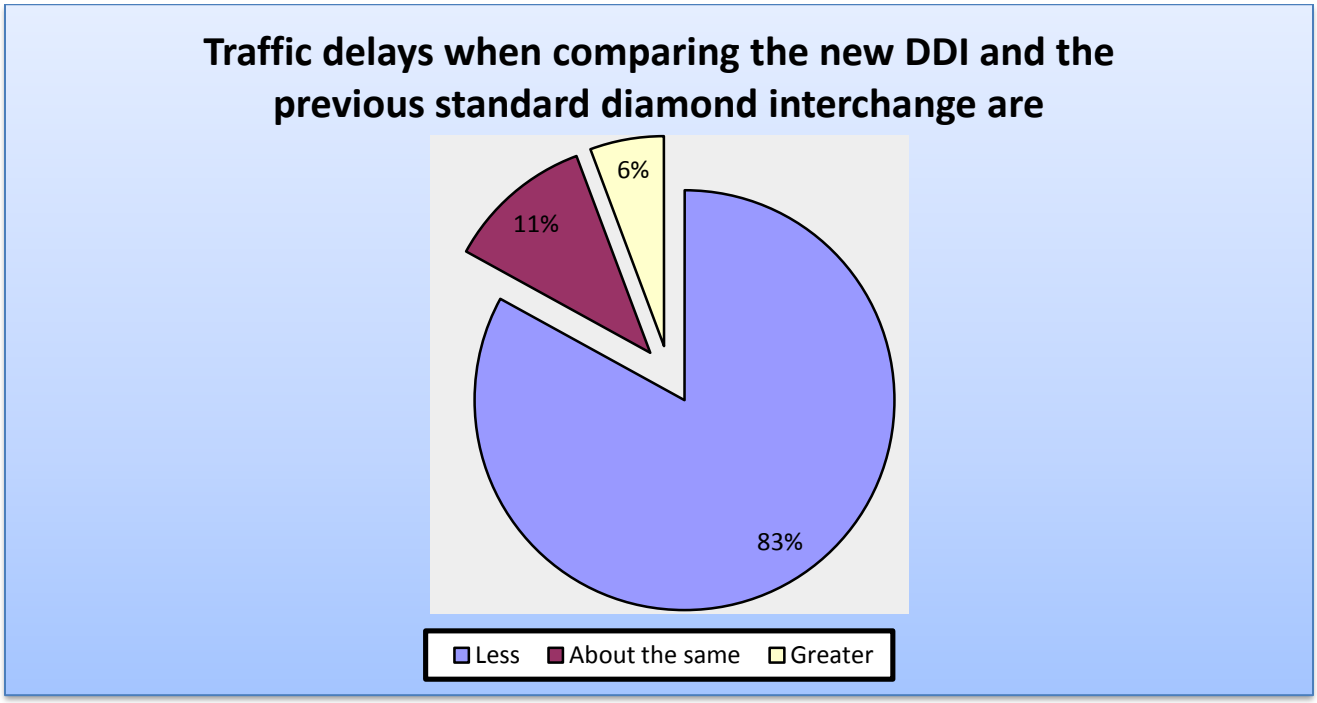
Traffic Flow

Figures (PO-1 through PO-3) display the results from the survey when the participant was asked questions to compare traffic flow through the DDI. PO-1 asked about travel experience when compared between the DDI and a standard diamond interchange. PO-2 asked about traffic delay when compared between the DDI and the previous standard diamond interchange. PO-3 asked about traffic back-ups when compared between the DDI and the previous standard diamond interchange.

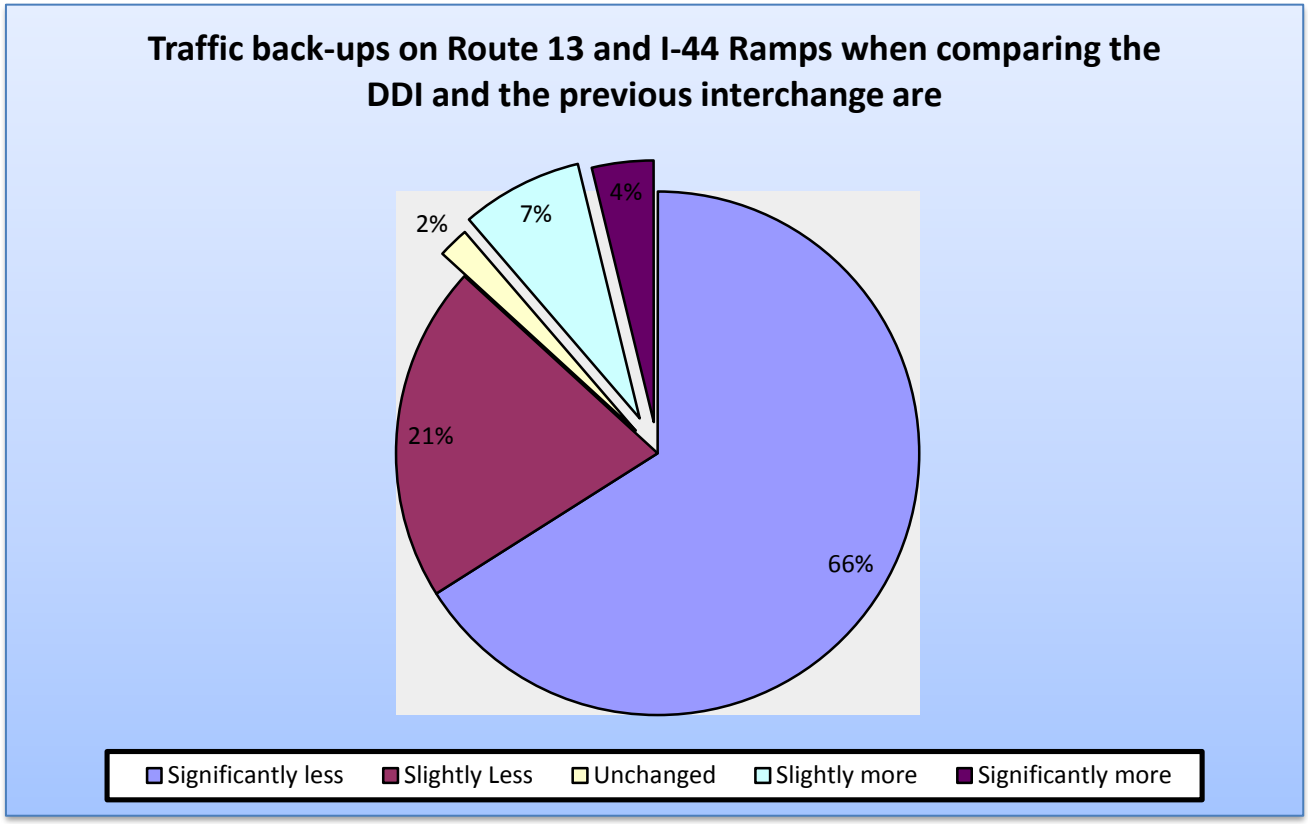
PO-1 Traffic Flow – Travel Experienced Comparison



PO-2 Traffic Flow – Traffic Delay Comparison



PO-3 Traffic Flow – Traffic Back-up Comparison



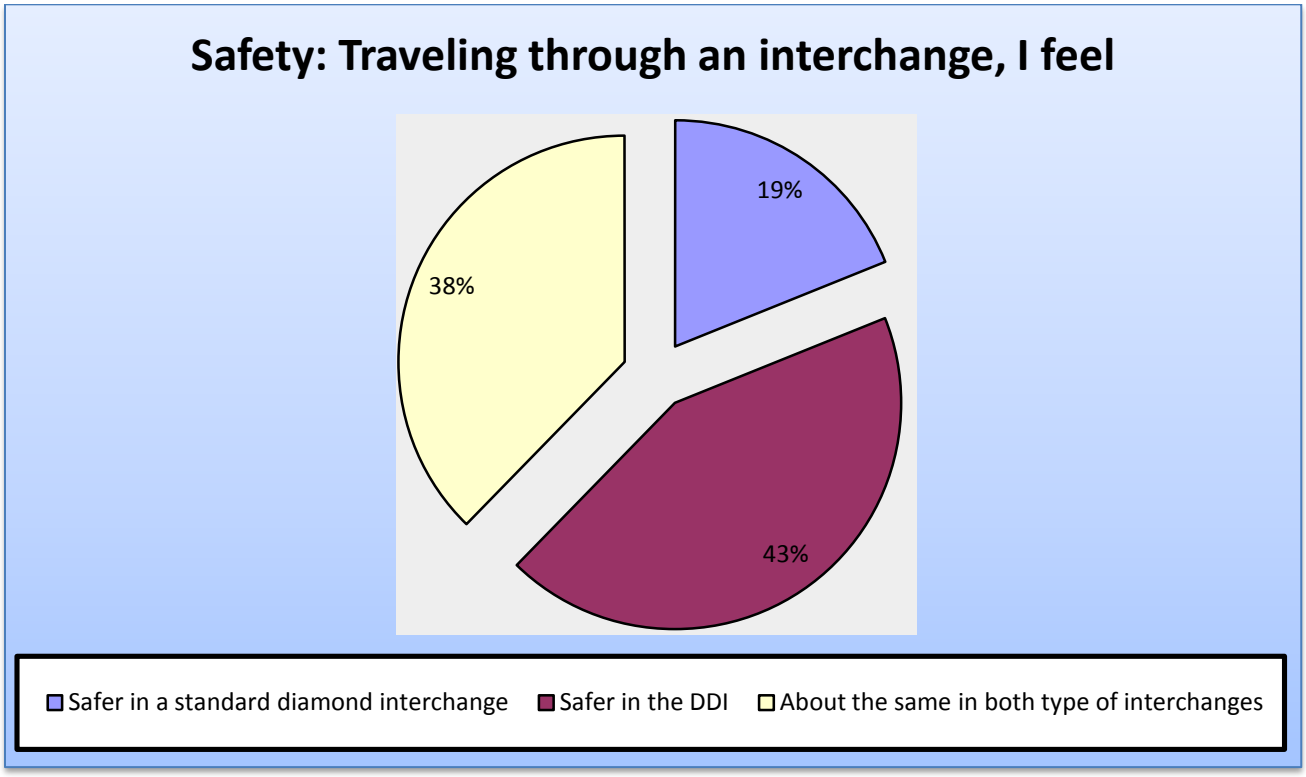
Results – Traffic Flow

- A very high percentage expressed that traffic flow was better (81%), traffic delays were less (83%) and traffic back-ups were significantly or slightly less (86%).
- Based on this survey, it is apparent that the motorists have experienced improved traffic flow through the DDI.

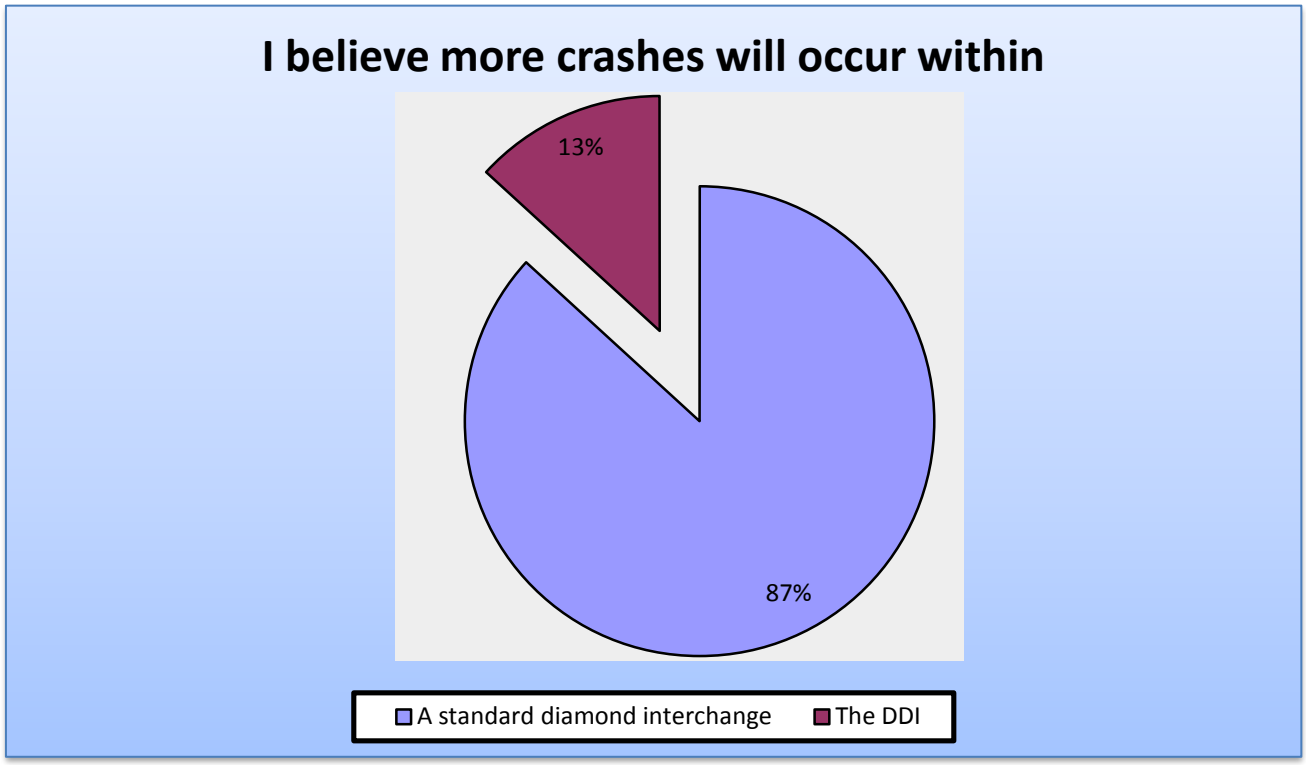
Traffic Safety

Figures (PO-4 through PO-6) display the results from the survey when the participant was asked questions to compare traffic safety through the DDI. PO-4 asked about traffic safety when compared between the DDI and the standard diamond interchange. PO-5 asked about the likelihood of more crashes when compared between the DDI and the previous standard diamond interchange. PO-6 asked about safe travel next to larger trucks when compared between traveling through the DDI and the previous standard diamond interchange.

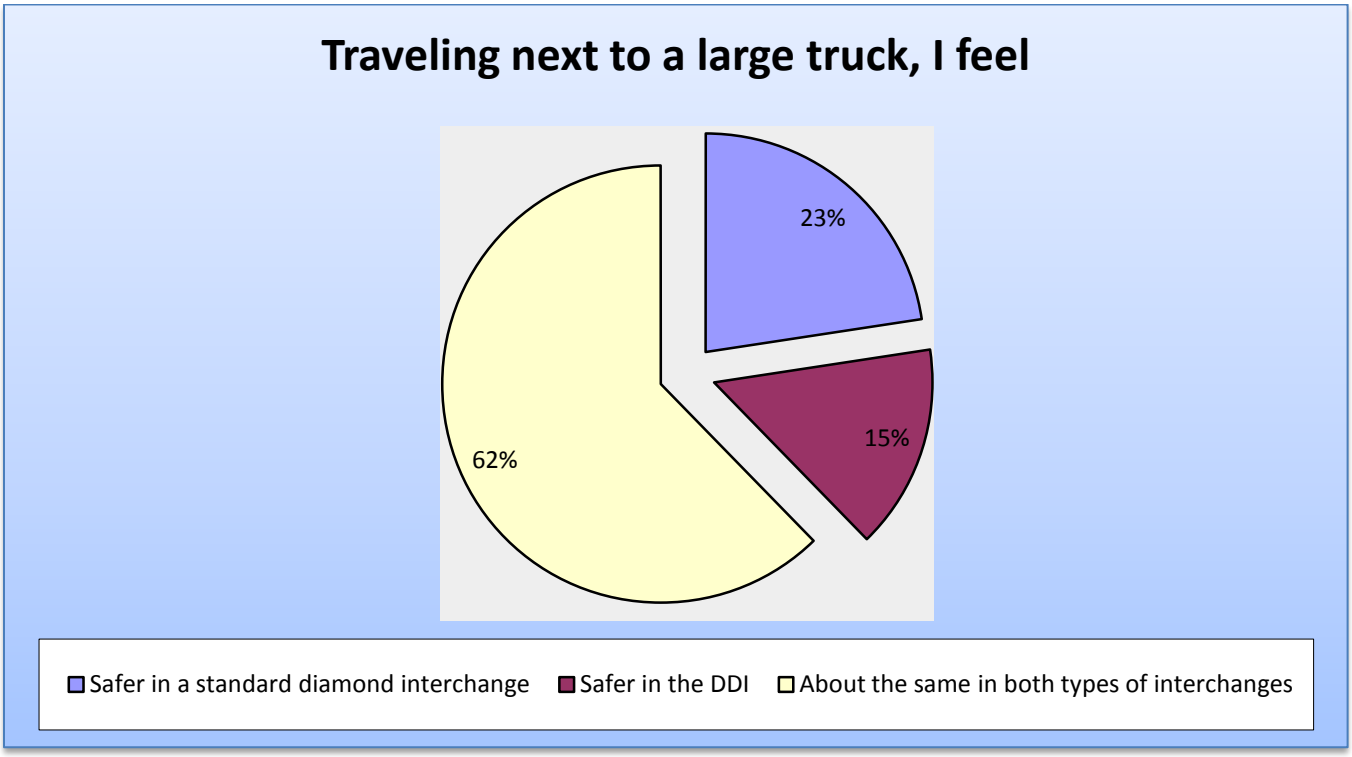
PO-4 Traffic Safety – Safe Travel through Comparison



PO-5 Traffic Safety – Likelihood of More Crashes Comparison



PO-6 Traffic Safety – Traveling Next to Large Truck Comparison



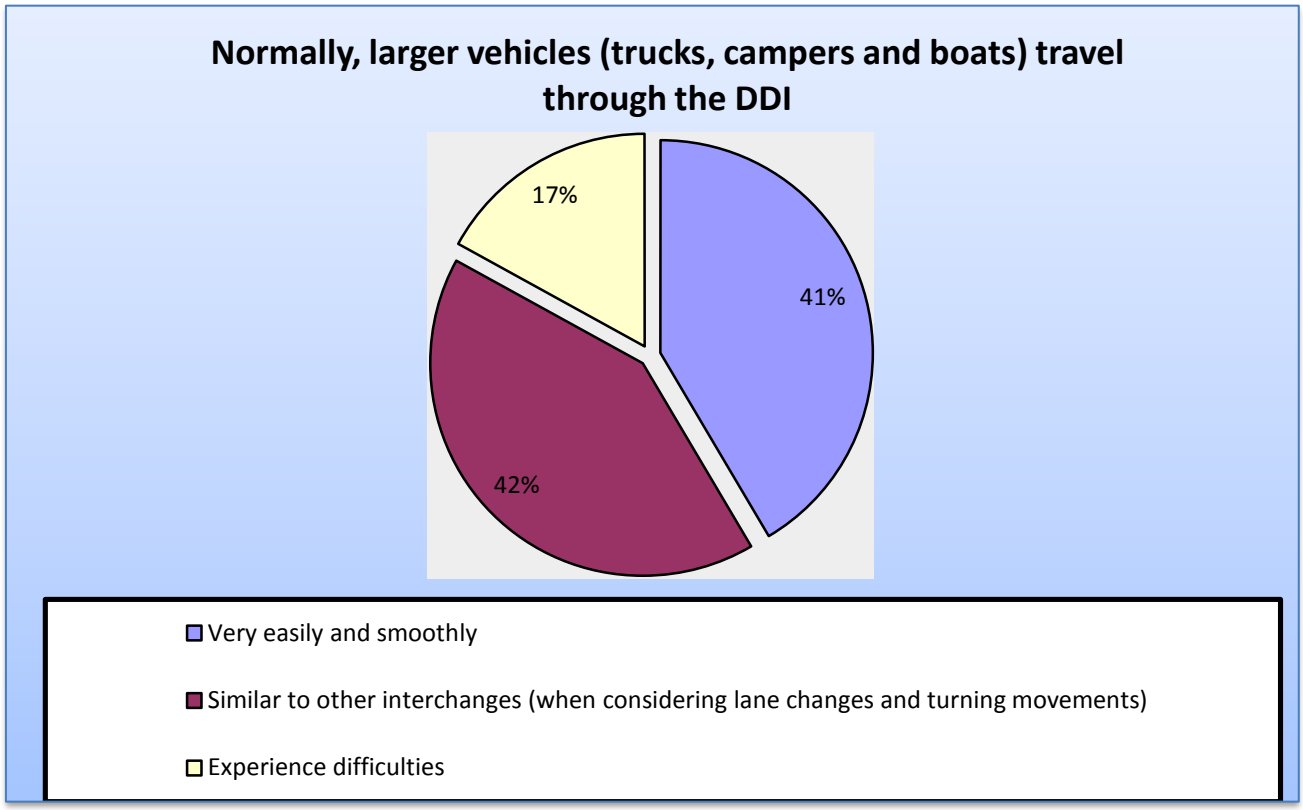
Results – Traffic Safety

- When asked about safe travel through an interchange, 43% expressed feeling safer in the DDI, and 19% expressed feeling safer in the standard diamond interchange while the remaining 38% expressed there was no difference in either interchange type.
- Nearly 87% expressed that more crashes would occur in the standard diamond interchange.
- Traveling next to a large truck – most participants expressed feeling safe in both interchange types with the standard diamond interchange having a slightly higher percentage than the DDI.
- Based on this survey, it appears that the motorists expressed feeling as safe or safer in the DDI. They have expressed a very high percentage that more crashes would occur in a standard diamond interchange

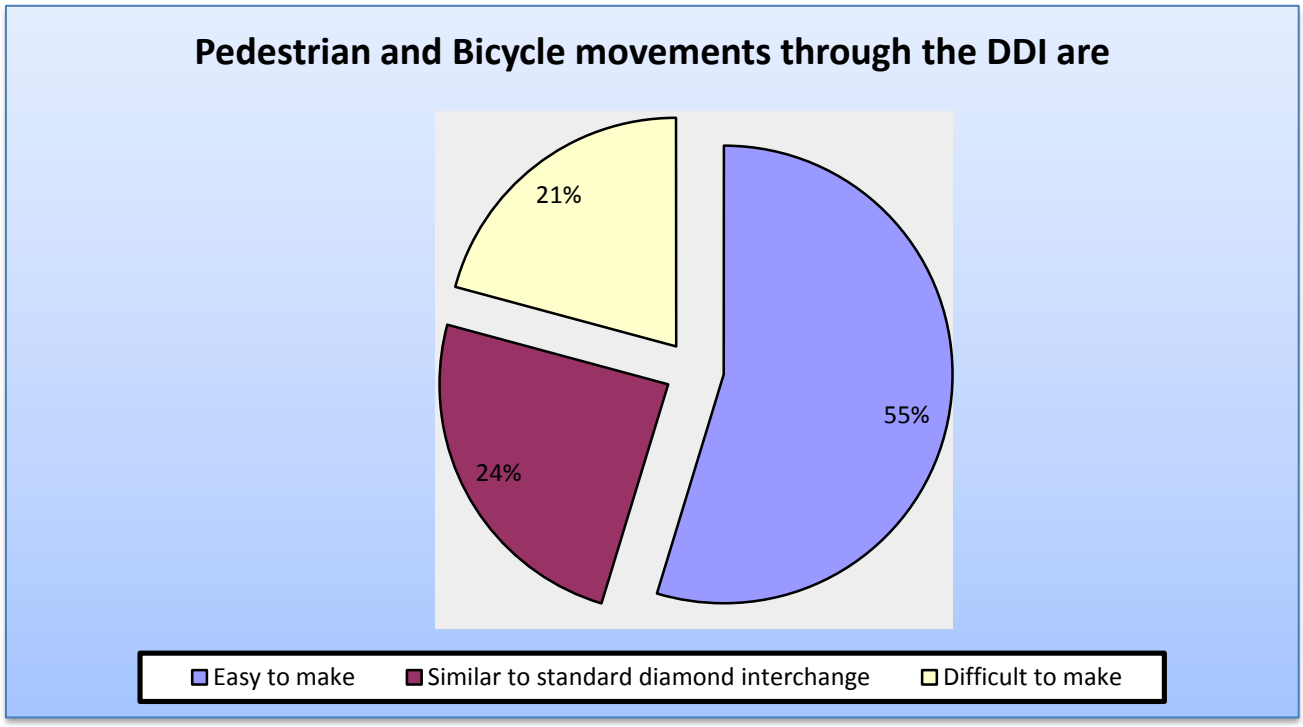
Access

Figures (PO-7 through PO-9) display the results from the survey when the survey participant was asked questions to compare access for non-motorized users and larger vehicles through the DDI. This interchange is part of a major commerce corridor between Kansas City and Springfield; experiences significant tourism traffic into Southern Missouri; and it provides a connection across I-44 to major generators like the zoo and a major fairground. PO-7 asked about access for larger vehicles (trucks, campers and boats) traveling through the DDI. PO-8 asked about pedestrian and bike movements through the DDI. PO-9 asked about the pedestrian and bike access across the bridge in a center separated walk/path with regards to its safety.

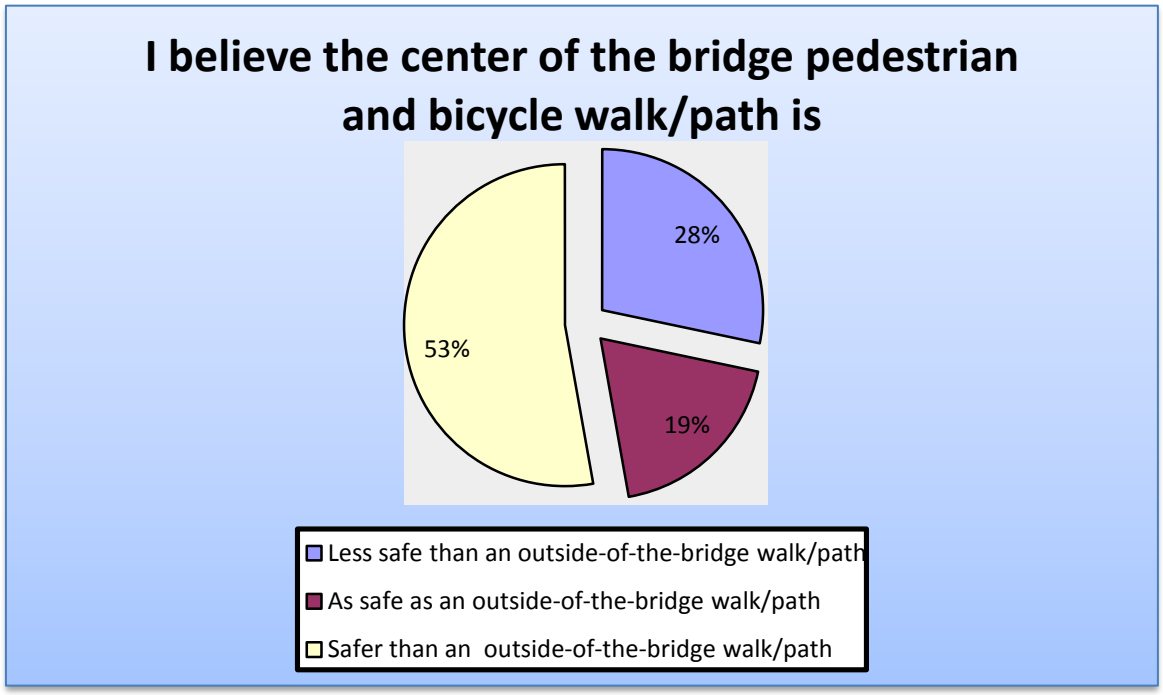
PO-7 Access – Larger Vehicles Travel through the DDI



PO-8 Access – Pedestrian and Bike Travel through the DDI



PO-9 Access – Pedestrian and Bike Center Walk/Path through the DDI



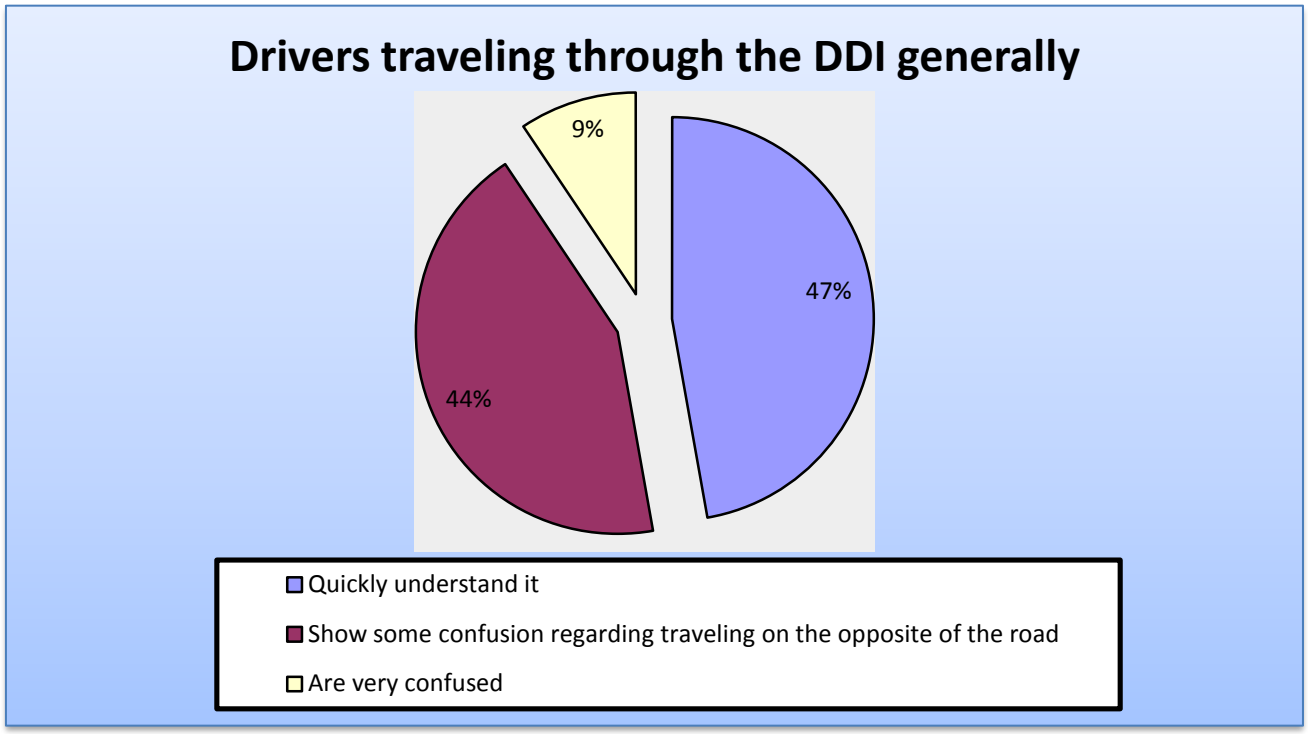
Results - Access

- When asked about how well larger vehicles travel through the DDI, only 17% expressed that these larger vehicles experience any difficulties while 83% expressed their movement can be made easily and smoothly (41%) or no different that other type of interchanges (42%).
- Nearly 79% felt that pedestrian and bike travel through the DDI was easy to make or similar to other interchange types with 21% expressing it was more difficult.
- Nearly 53% felt the center pedestrian and bike walk/path was safer than outside pedestrian and bike facilities while 28% expressing the outside facilities were safer.
- Based on this survey, it appears that access for larger vehicles and pedestrian and bike traffic is provided in a very reasonable manner through the DDI.

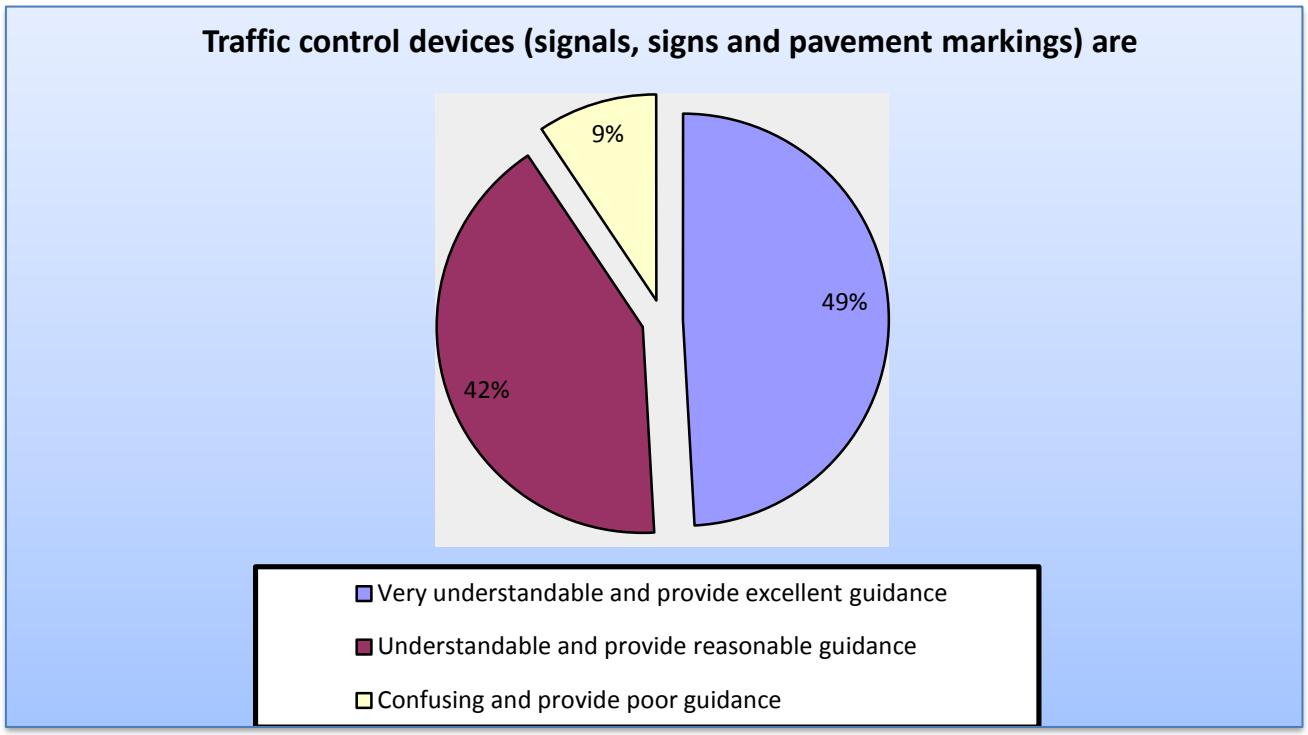
Understanding

Figures (PO-10 through PO-12) display the results from the survey when the participant was asked questions to comment on understanding the DDI. This interchange introduces a new innovative interchange that requires motorists to travel on the opposite side of the roadway through the interchange area. Understanding of the interchange's operations is very important. PO-10 asked about motorists' understanding regarding travel through the DDI. PO-11 asked how well the traffic control devices guide motorists through the DDI. PO-12 asked how well the larger traffic islands guide motorists through the DDI.

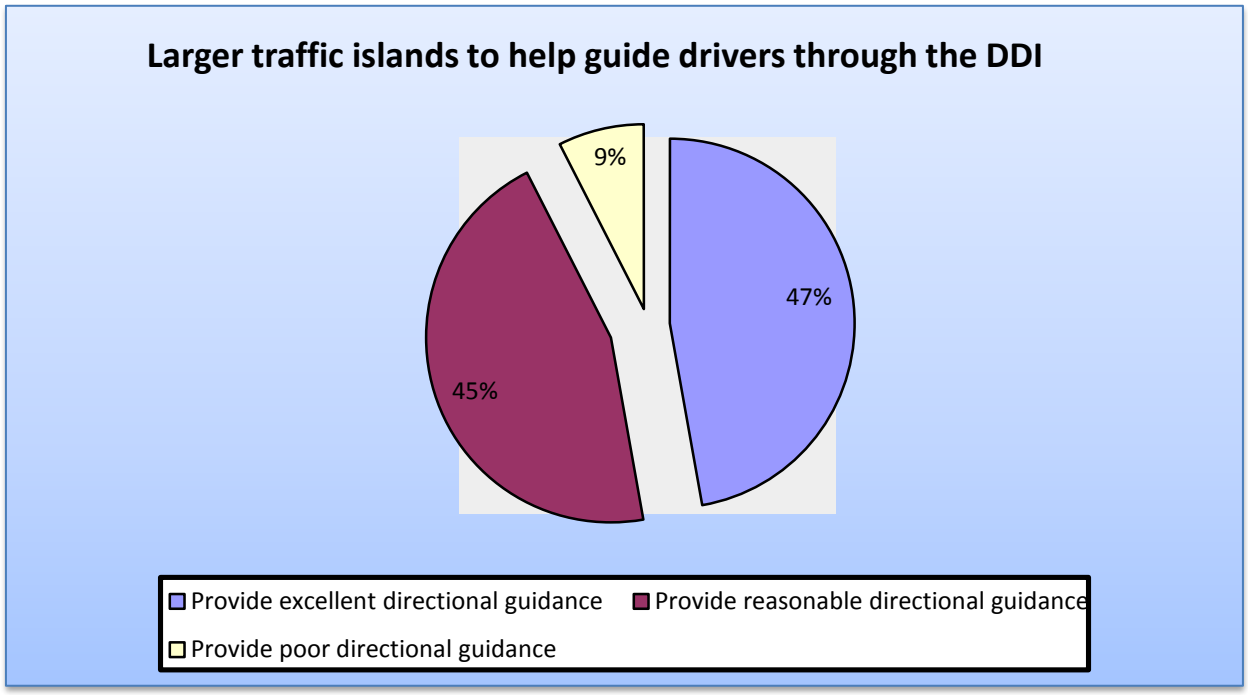
PO-10 Understanding – Motorists' Understanding regarding travel through the DDI



PO-11 Understanding – Traffic Control Devices Understanding



PO-12 Understanding – Larger Traffic Islands to help provide Guidance



Results - Understanding

- When asked about understanding, regarding travel through the DDI, 47% expressed it was quickly understood, 43% expressed some confusion, and 9% expressed they were very confused.
- Nearly 91% expressed that traffic control devices provided excellent (49%) or reasonable (42%) guidance and only 9% expressed poor guidance.
- Nearly 93% expressed that the larger traffic islands provided excellent (47%) or reasonable (45%) directional guidance and only 7% expressed poor directional guidance.
- Based on this survey, it appears that the understanding of how the DDI operates is fairly high and that the traffic control devices and the larger traffic islands provide good guidance through the DDI.

Comments on Opened Questions

Comments on the three opened questions were varied and most expressed positive support of the DDI. They expressed improved traffic flow, less traffic delay, no left turns (referencing that all left turns are no longer controlled by signals) and easier truck movements when asked about what they like. They expressed sharpness of the crossover areas, the height of the center barrier wall, larger trucks using both lanes in the crossover area, and first-time motorists' confusion when asked about what they dislike. They expressed less "curvy" in the crossover area, lower barrier walls, adding additional lanes like the National DDI, adding lighting, and accelerating the US 65 and Chestnut DDI as other comments. Over 60% of the survey participants added comments with most being positive in nature.

Survey Participant Information

- 80% of participants were male
- 12% were 16 to 25 years old
- 45% were 26 to 40 years old
- 39% were 41to 65 years old
- 4% were over 65 years old
- Most participants were from Missouri (Springfield, Southwest Missouri, Kansas City and St. Louis areas) with one outstate based on zip code information provided.

Larger Vehicle Driver Interview

A survey was developed with similar questions to the on-line survey to gain insight based on a truck drivers' opinion. After discussion with a local trucking firm on the survey distribution and the prospect of a low return of surveys with limited information, it was discussed that it might be a better approach to interview a couple of drivers. An opportunity was presented to discuss over-dimension loads with a local trucking firm.

This approach did provide a better opportunity to actually speak with and get additional feedback from drivers who travel through the interchange, sometimes several times a day. The survey was used as a guide for the interview with their completed survey contained within the Appendix to this report. The following Table PO-1 provides an overview of the two interviews conducted. It was also observed that at least one online survey participant was a truck driver from information provided in the survey.

Table PO-1 Interview Questions – Large Vehicle Drivers

Question	Driver #1	Driver #2
Travel experience DDI versus Diamond	Better	Better
Traffic delay DDI versus Diamond	Less	Less
Traffic back-ups DDI versus Diamond	Slightly less	Significantly less
Drivers traveling through the DDI	Show some confusion	Show some confusion
Traffic control devices	Very understandable	Very understandable
Pedestrian and Bike movements	Easy to make	Easy to make
Large traffic island	Provides excellent guidance	Provides excellent guidance
Navigating through crossover areas	Similar to dual left turn lanes	Similar to dual left turn lanes
Larger vehicles travel through the DDI	Similar to other types of interchanges	Similar to other types of interchanges
Left turn movements onto ramps	Easy to make	East to make
Safer travel through DDI versus Diamond	Safer in DDI	Safer in DDI
More crashes in	Standard Diamond	Standard diamond
Center walk/path	Safer than outside facilities	Safer than outside facilities

In general, their responses on the prepared questions were similar except one expressed that traffic back-up was significantly less in the DDI compared to the other driver's response of only slightly less back-up. Their additional comments during the interview did highlight some different perspectives.

- Driver #1 mentioned traffic flow improving, emphasized the improvements to left turn movements and expressed the benefit of the crossover areas slowing traffic down that help reduce speed variations at the interchange.

- Driver #2 mentioned reduced traffic delay and back-ups, mentioned vacationers with larger vehicles (trailers and boats), and the reduction of left turn signals.
- Both drivers mentioned some confusion in traveling in the opposite direction especially for first-time users, professional drivers have little problems with the DDI, left turn improvements and a need to look at the crossover area design.

The opportunity to discuss with a local trucking firm that moves over-dimension loads also proved to be very beneficial. Over-dimension loads up to 18 foot wide and 200 foot long have been successfully moved through the DDI. The previous diamond interchange could not have handled this load or many of their other larger over-dimension loads because of tight turning conditions.

In moving the 200 foot long load, the guardrail from the bridge structure presented a concern when the load just missed it. The firm thought if the guardrail in future could be relocated a foot or so further from the roadway, it would reduce chance of it being hit. They also thought if the paved shoulder area could widen, then it would prevent damages to adjacent grass areas.

Pedestrian and Bicyclist Interviews

Interviews were conducted with a focus on the pedestrians and bicyclists using the DDI as a pedestrian and bike connector across I-44. Five questions were asked to two professionals who plan, design and operate pedestrian and bike facilities. The following presents the information received on the five questions:

Mobility/Access

1. What are your opinions on how pedestrians move through the DDI?
   - The center bridge location of the walk connector would be somewhat unexpected to pedestrians who normally move along the outside of the roadway. However, it was easily understood after using it.
   - The center location does provide for a wider median area that permits pedestrian storage and the ability to split the crossing of Route 13 into two separate crossings both under signal control. This would reduce walk and don't walk time settings when comparing a two-lane crossing to the previous five-lane crossing.
   - Pedestrian crossings are reduced by one crossing when going diagonally across the DDI (like from the southeast quadrant to the northwest quadrant of the interchange) when comparing a center walk connector to two outside walk connectors.
   - Provides a separate walk connector where the previous diamond interchange did not. A raised curb walkway is normally used for most interchanges in Missouri.
   - The DDI was able to provide an enhanced pedestrian facility within the existing bridge structure reducing project cost. This approach could be a good solution to increase pedestrian and bike facilities within existing interchanges.

2. What are your opinions on how bicyclists move through the DDI?
   - Experienced daily bike commuters would prefer a separate bike path (no mixing of pedestrians and bikes), a designated bike lane in the roadway or a shared bike lane in the roadway. Recreational bike users would use and find acceptable the DDI walk/path connector as long as the pedestrian traffic was low.

- The speed difference between pedestrians, bicyclists and vehicles, and the present and future volume of these users should be considered when planning and constructing new transportation improvements.

Safety

1. What are your opinions on the safety of pedestrians within the DDI?
   - Safety has been enhanced significantly with the separate facility.
   - Mixture of pedestrian and bike traffic within the same facility based on their speed differences could be a future safety concern, if both pedestrian and bike traffic increases. Present traffic demand does not present much of a problem.
   - Only the four right turn lane crossings have potential vehicle/pedestrian conflicts. If needed in future, all four crossings could be signalized to enhance pedestrian safety.
   - Signing and pavement markings are very good.
2. What are your opinions on the safety of bikes within the DDI?
   - Safety has been enhanced significantly with the separate facility.
   - Mixture of pedestrian and bike traffic within the same facility based on their speed differences could be a future safety concern, if both pedestrian and bike traffic increases. Future consideration should be given to separating pedestrian and bike traffic.
   - Signing and pavement markings are very good.

Understanding

1. What is your opinion on how well pedestrians and bicyclists understand the walk/path connector across I-44?
   - After using it the first time, it is easily understood.

Conclusions

Traffic Operation

This report compared various "*pre-construction*" and "*post-construction*" traffic operational characteristics of a typical diamond interchange to those of a diverging diamond interchange. Based on the results, it appears that the DDI provides roadway users with an overall design and operation that minimizes traffic delay and has capabilities to recover quicker to events and incidents. The following are the report's conclusions:

- Travel time along Route 13 (through movements) through the DDI is generally higher during low traffic flow periods when compared to the typical diamond interchange. This fact is due in part to the design of the crossover areas that requires traffic to reduce speed when compare to the straight traffic flow in normal diamond interchange;
- Left turning movements on Route 13 to I-44 on ramps have benefitted significantly from their free traffic flow movements. Traffic queues were only noticed a few times and were caused when through Route 13 movements (shared lane) block their traffic flow. These traffic queues existed only because of the shared lanes (through and left turn) used both Northbound and Southbound;
- Left turning movements from I-44 ramps to Route 13 have benefitted significantly from their free traffic flow movements. Significant reduction in delays and traffic queues has been observed during heavy traffic demand (PM peak and Fairground events);

- I-44 off ramps right turning movements have been signalized to address safety concerns with the unexpected traffic movement traveling on the opposite side of the roadway through interchange. Traffic queues of just a few vehicles were observed during peak traffic periods and they normally clear within a single signal cycle;
- Based on traffic modeling and field observations, the DDI solution will handle heavier traffic demands better today and will provide better service in the future as traffic demands increase. The only period that the standard diamond interchange out performs the DDI is during lower traffic demand periods. The traffic calming impact during these low traffic demand periods could and should lead to improve safety;

Safety

This report compared various "*pre-construction*" and "*post-construction*" safety characteristics of the previous diamond interchange to those of the current diverging diamond interchange. Based on the results, it appears that the DDI provides roadway users with an overall improved safety that has reduced crashes. The following are the report's conclusions:

- The transportation improvements that included the DDI construction and the relocation of the signal from Evergreen to the Commercial entrance further south have reduced crashes. While the disabling injury did increase to 2 crashes (same as 3 of the 5 pre-construction years), the total crash trend seen in the initial year after the construction of DDI shows a noticeable decrease in crashes;
- Crash rate that were weighted using, Average Annual Daily Traffic (AADT) counts, number of days and roadway lengths also showed a downward trend;
- The transportation improvements (DDI and adjacent improvements) have had a recognizable reduction in rear-end type crashes in the initial year after construction;
- Left turn and left turn right angle crash types have significantly been reduced or eliminated. The potential major factor is that left turn movements at the I-44 on ramps are now free left turn movements and left turns from the I-44 off ramps are a yielding movement. Previously under the diamond interchange configuration, these left turn movements were made under protected/permission left turn on Route 13 and protected only from the I-44 off ramps;
- The crashes that occurred within or near the DDI in the initial year of operation appear to be common crashes that normally occur at other signalized intersections;
- The conclusion that in the initial year of operation found a reduction related to rear-end and left turning type crashes. The free left turn movement and the elimination of the left turn signals under the DDI operations would explain the reason for these reductions;
- It also does not readily appear that the DDI operations have caused or created any additional types of crashes;
- These initial conclusions should be confirmed in the future when more crash data (3 to 5 years of post-construction) is available;

Public Perception

This report collected perceptions for three different user groups of the DDI. Traffic flow, safety, access and understanding were the four focus areas that questions and opinions were received.

The following are the report's conclusions:

- A very high percentage (80% plus) expressed that traffic flow had improved and traffic delay had decreased;
- A very high percentage (87%) expressed that crash were more likely to occur in a standard diamond when compared to DDI
- A very high percentage (around 80%) expressed that larger vehicles and pedestrian/bike had better or similar to standard diamond interchange.
- A very high percentage (91%) expressed good understanding on how the interchange operated based on design of islands, signing, signals and pavement markings.

Recommendations

1. The DDI has proven to be a good interchange design solution and should be considered as alternative design when interchanges are improved or a new interchange is needed.
2. Like other alternative design solutions, good transportation planning and assessment is needed to ensure that DDI solution does meet current and future conditions and transportation needs.
3. While cost was not discussed in detailed in this report, it was estimated that the DDI at I-44 and Route 13 saved $5.6 million. Because roadway conditions and transportation needs are different at almost every interchange, design and construction costs will vary. Cost data collection during the alternative solution selection process, would provide a greater in-sight and a high-level of predictability in addressing potential cost savings between the different interchange solutions.

Principal Investigator and Project Members

Tom Ryan – Principal Investigator –Safety and Public Perception development lead
Michael Trueblood – Traffic Engineer – Traffic Operation development lead
Dr. Venkata Chilukuri, PhD – QA/QC, and Data Analysis and Processing
Smith Siromaskul – Literature Research development lead

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Appendix A
Work Plan

DDI Performance Evaluation Work Plan and Schedule

Task	Description	Research Member	Days	Start	End	1-Mar	1-Apr	1-May	1-Jun	1-Jul	1-Aug	1-Sep	1-Oct	1-Nov	31-Dec	1-Jan	31-Jan	Percent Completion
	Diverging Diamond Interchange Evaluation	Ryan	316	3/1/2010	1/31/2011													
1	Literature Research	Ryan	20	3/1/2010	3/21/2010													
1.1	Summary Report	Siromaskul	14	3/1/2010	3/15/2010													
1.2	QA/QC	Chilukuri	6	3/15/2010	3/21/2010													
1.3	Delivery to MoDOT in 3rd Quarter Report			3/24/2010	3/24/2010													
																		5%
2	Performance Measurements (PM)	Ryan	20	3/1/2010	3/21/2010													
2.1	Draft PM Report	Trueblood - Chilukuri	14	3/1/2010	3/15/2010													
2.2	Draft PM Report - QC/QA	Siromaskul	6	3/15/2010	3/21/2010													
2.3	Develop Public Perception Survey	Ryan	15	3/1/2010	3/16/2010													
2.4	Delivery to MoDOT in 3rd Quarter Report			3/24/2010	3/24/2010													
																		10%
3	Data Collection	Ryan	254	3/1/2010	11/10/2010													
3.1	MoDOT Supplied Information	Ryan	30	3/1/2010	3/31/2010													
3.2	Field Collection	Springfield Staff	45	3/1/2010	4/15/2010													
3.3	Data Processing	Chilukuri	45	3/1/2010	4/15/2010													
3.4	Public Perception	Ryan	230	3/25/2010	11/10/2010													
3.5	QA/QC Data	Ryan	14	4/16/2010	4/30/2010													
																		40%
4	Data Analysis	Trueblood	214	4/1/2010	11/1/2010													
4.1	Traffic Operation Analysis	Trueblood - Chilukuri	60	4/1/2010	5/31/2010													
4.2	Safety Analysis (Baseline)	Ryan	60	4/1/2010	5/31/2010													
4.3	Safety Analysis (1-Year)	Ryan	14	11/1/2010	11/15/2010													
4.4	Public Perception (Interim)	Ryan	10	6/9/2010	6/19/2010													
4.5	Public Perception (Final)	Ryan	10	11/1/2010	11/11/2010													
4.6	Delivery to MoDOT 4th Quarter Report			6/23/2010	6/23/2010													
																		75%
5	Documentation - Reports	Kinzel	199	6/1/2010	12/17/2010													
5.1	Traffic Operation Report - Draft	Trueblood - Chilukuri	30	6/1/2010	7/1/2010													
5.2	Traffic Operation Report - Final	Trueblood	30	7/1/2010	7/31/2010													
5.3	Safety Report - Draft	Ryan	10	11/15/2010	11/25/2010													
5.4	Safety Report - Final	Ryan	22	11/25/2010	12/17/2010													
5.5	Public Perception Report - Draft	Ryan	10	11/15/2010	11/25/2010													
5.6	Public Perception Report - Fiani	Ryan	22	11/25/2010	12/17/2010													
5.7	Delivery to MoDOT 1st Quarter Report			9/23/2010	9/23/2010													
5.8	Delivery to MoDOT Final Invoice			1/1/2011	1/31/2011													100%

Evaluation Deliverables

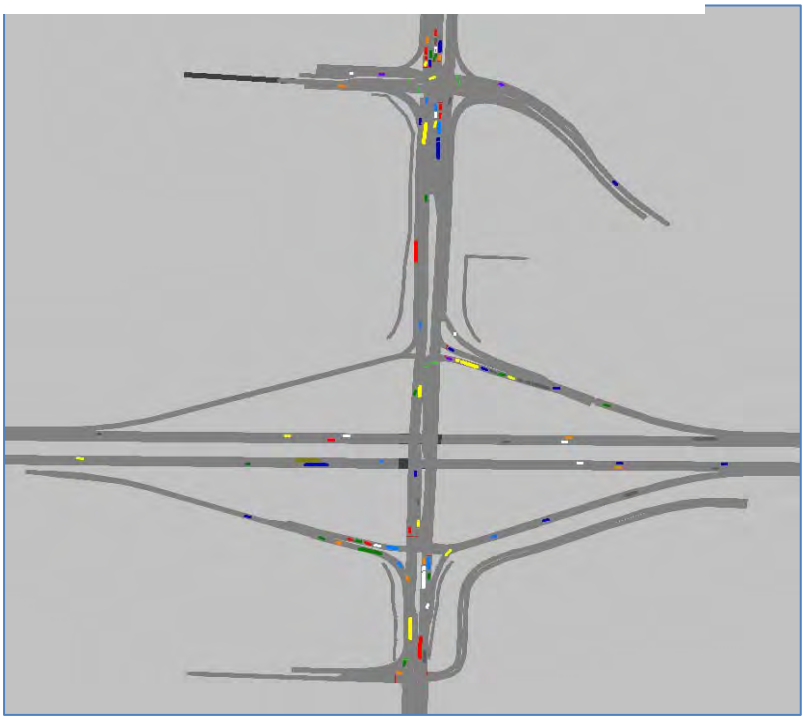
Appendix B

Traffic Operation

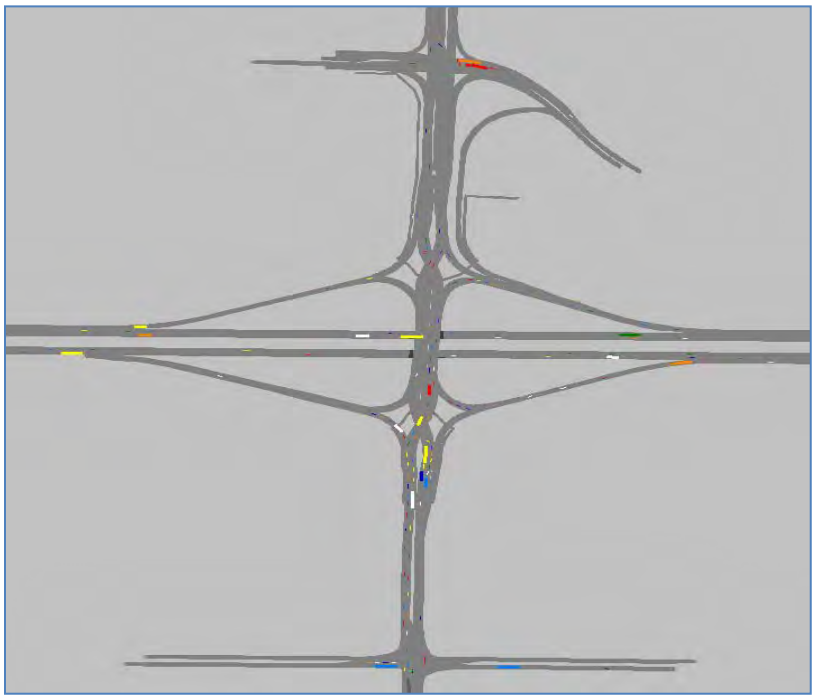
Aerial View – Previous Interchange

VISSIM Screen Shots

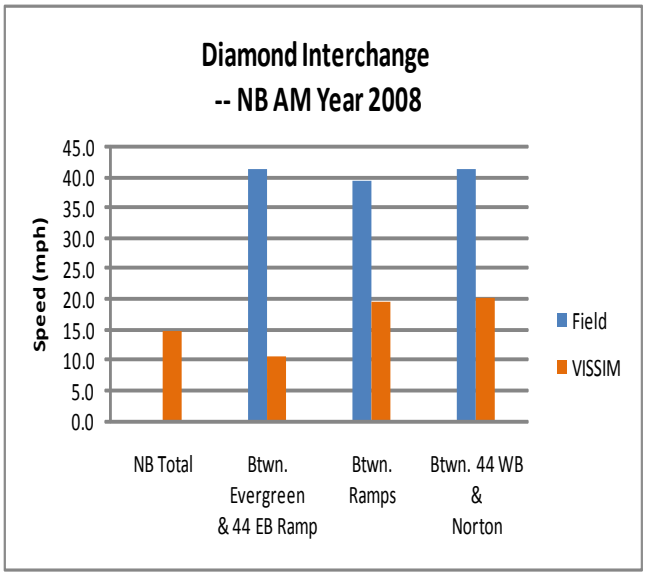
Typical Diamond Interchange VISSIM Model

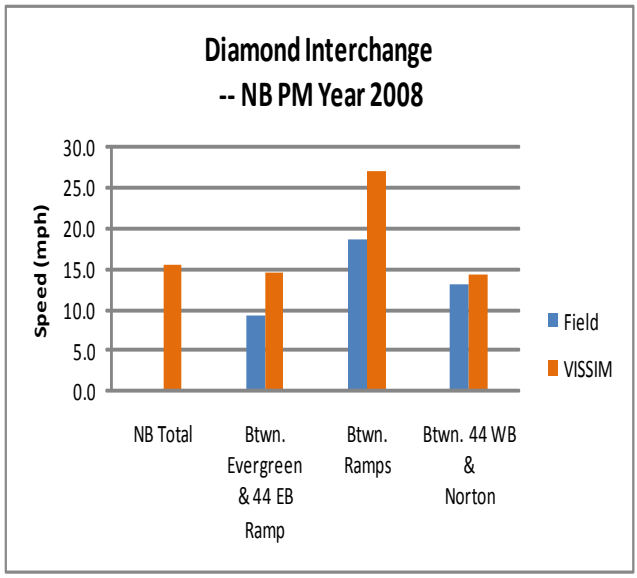


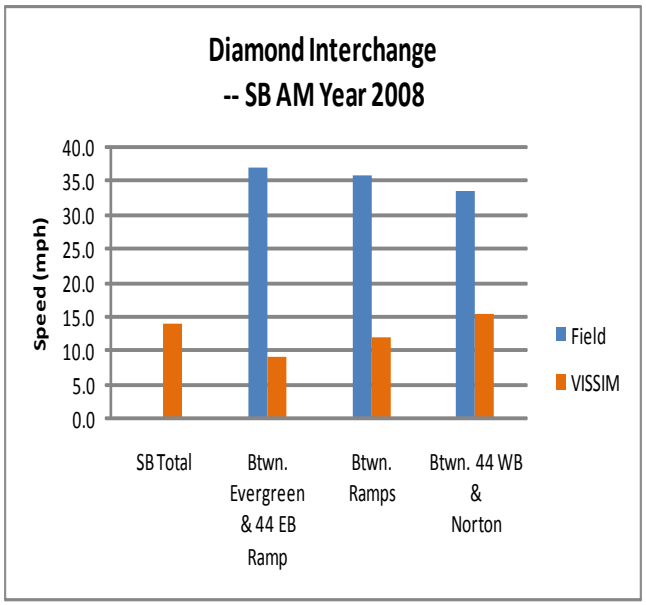
Diverging Diamond Interchange VISSIM Model

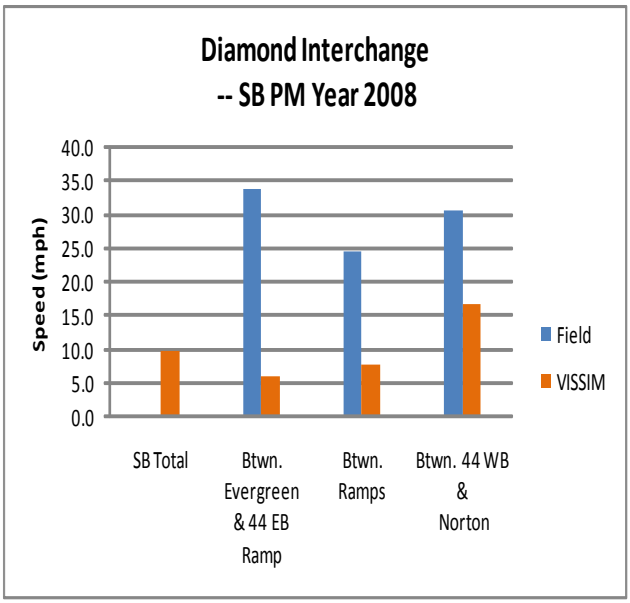


Diamond Interchange Travel Times

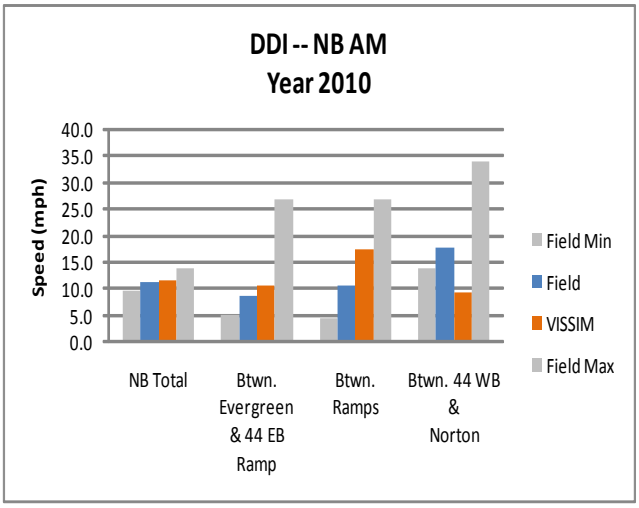


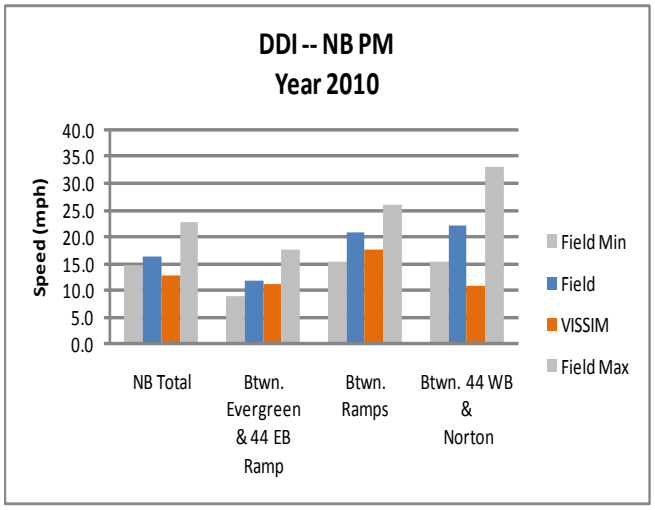


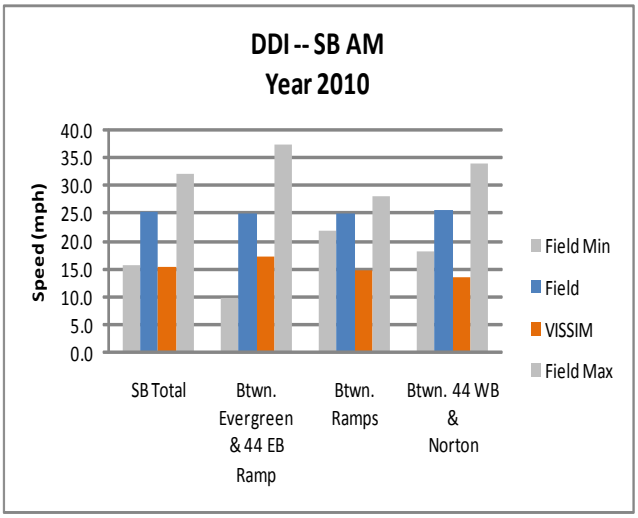


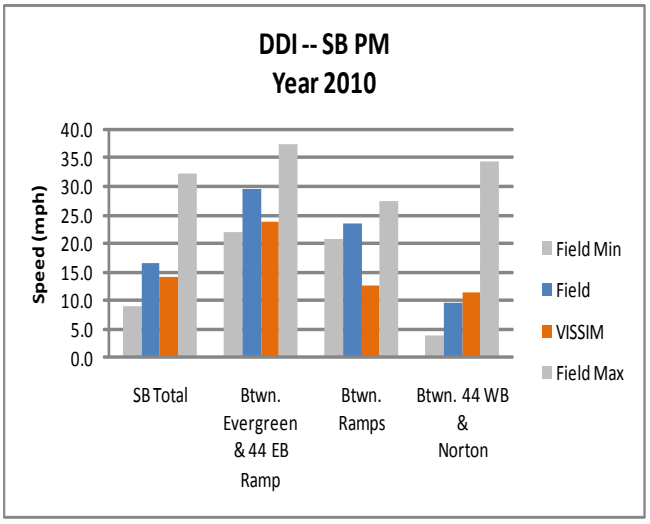


Diverging Diamond Interchange Travel Times









Appendix C

DDI Survey Questions – General Public Survey

Introduction – Interstate 44 and Missouri Route 13 Diverging Diamond Interchange (DDI)

We appreciate your time and interest in sharing your opinion. This survey is part of a study of the *First Diverging Diamond Interchange (DDI)* to be built in North America. We are an independent firm hired to collect and summarize information on the traffic operations and safety of this DDI. The study will assist in future transportation decisions made in Missouri and across our country regarding how applicable the DDI transportation solution is for other planned transportation improvements. Our only interest in this survey is to gain accurate information on what you think of the DDI, so please respond as accurately and completely as possible – your opinion is important.

We would encourage you to return and take the survey again, if while traveling through the interchange you notice something different that would change your opinion about the operation and safety of the interchange.

Have you taken this survey before?

- o **Yes**
- o **No**

How often do you travel through the new Diverging Diamond Interchange (DDI)?

- o **Daily**
- o **Weekly**
- o **Monthly**
- o **Never**

How often did you travel through the previous standard diamond interchange?

- o **Daily**
- o **Weekly**
- o **Monthly**
- o **Never**

Traffic Flow

My traveling experience through the new DDI compared to the previous standard diamond interchange is

- o **Better**
- o **About the same**
- o **Not as good**

Traffic delays/backups at the new DDI compared to the previous standard diamond interchange are

- o **Less**
- o **About the same**
- o **Greater**

Drivers traveling through the new DDI generally

- o **Are quick understand it**
- o **Show some confusion regarding traveling on the opposite side of the road**
- o **Are very confused**

Traffic control devices (signals, signs and pavement markings) at the new DDI are

- o **Very understandable and provide excellent guidance**
- o **Understandable and provide reasonable guidance**
- o **Confusing and provide poor guidance**

The larger traffic islands that guide drivers through the new DDI provide

- o **Excellent directional guidance**
- o **Reasonable directional guidance**
- o **Poor directional guidance**

Larger vehicles (trucks, campers and boats) traveling through the new DDI, compared to the previous standard diamond,

- o **Can do so more easily and smoothly**
- o **Experience similar conditions (considering lane changes and turns)**
- o **Experience more difficulties**
- o **Have not noticed any difference**

Pedestrian and Bicycle movements through the new DDI, compared to the previous standard diamond, are

- o **Easier to make**
- o **Neither easier nor more difficult to make**
- o **More difficult to make**
- o **Have not noticed any difference**

Safety

Traveling through the DDI interchange, compared to the previous standard diamond, I feel/felt

- o **More safe**
- o **About as safe**
- o **Less safe**

I believe crashes are/were more likely within

- o **The previous standard diamond interchange**
- o **The DDI**

I believe the center-of-bridge pedestrian and bicycle walk/path is

- o **Not as safe as a side-of-bridge walk/path**
- o **About as safe as a side-of-bridge walk/path**
- o **Safer than a side-of-bridge walk/path**

Traveling next to large truck, I feel/felt

- o **Safer in the DDI**
- o **About the same in both interchanges**
- o **Safer in the previous standard diamond interchange**

What do you like most about the DDI?

What do you dislike most about the DDI?

Do you have any ideas to improve the DDI's traffic operations or safety? If so, what are they?

My age group is

- **16 to 25 years old**
- **26 to 40 years old**
- **41 to 65 years old**
- **Over 65 years old**

My home zip code is _____

Trucker Driver #1 Interview

DDI Survey Questions – Trucking Industry Survey (Date of Interview - 10/14/2010)

Introduction – Interstate 44 and Missouri Route 13 Diverging Diamond Interchange (DDI)

We appreciate your time and interest in sharing your opinion. This information is being collected and summarized for inclusion into a report on the *First Diverging Diamond Interchange (DDI)* construction in North America. We are an independent firm who has been hired to collect and summarize information on the traffic operations and safety of this DDI. This study will assist in future transportation decisions made in Missouri and across our country regarding how applicable the DDI transportation solution is for other planned transportation improvements. Our only interest in this survey is to gain accurate information on what you think of the DDI, so please respond as accurately and completely as possible – your opinion is important.

We would encourage you to return and take the survey again, if while traveling through the interchange you notice something different that would change your opinion on the operation and safety of the interchange.

Have you taken this survey before?

- o **Yes**
- o No

How often do you travel through the new Diverging Diamond Interchange at I-44 and Route 13 (see photo to the right)?

- o Daily
- o **Weekly**
- o **Monthly**
- o **Never**

How often did you travel through the old Standard Diamond interchange at I-44 and Route 13 (see photo to the right)?

- o Daily
- o **Weekly**
- o **Monthly**
- o **Never**

Traffic Flow

My traveling experience through the DDI when compared with a standard diamond interchange was

- o Better
- o **About the same**
- o **Not as good**

Comment Free flowing LT is a major improvement

Traffic delays when comparing the new DDI and the previous standard diamond interchange are

- o Less
- o **About the same**
- o **Greater**

Traffic back-ups on Route 13 and I-44 Ramps when comparing the DDI and the previous interchange are

- o **Significantly less**
- o Slightly Less
- o **Unchanged**
- o **Slightly more**
- o **Significantly more**

Comment you can pick-out the first-time users because they are normally a little confused

Drivers traveling through the DDI generally

- o **Quickly understand it**
- o Show some confusion regarding traveling on the opposite of the road
- o **Are very confused**

Traffic control devices (signals, signs and pavement markings) are

- o Very understandable and provide excellent guidance

- **Understandable and provide reasonable guidance**
- **Confusing and provide poor guidance**

Pedestrian and Bicycle movements through the DDI are

- Easy to make
- **Similar to standard diamond interchange**
- **Difficult to make**

Comment careful attention must be paid to the tracking of the trailer – most professional drivers have no problems

Larger traffic islands constructed to help guide drivers through the DDI

- Provide excellent directional guidance
- **Provide reasonable directional guidance**
- **Provide poor directional guidance**

When navigating around the larger traffic islands and through the roadway curvature in the crossover areas, it is

- **Difficult to stay in the proper lane**
- Similar to driving through dual turning lanes
- **Easy to stay in the proper lane**

Larger vehicle units (like trucks, camper units and boat trailer units) travel through the DDI

- **Very easily and smoothly**
- Similar to other interchanges (when considering lane changes and turning movements)
- **With difficulty**

For larger vehicle units, left turns onto the ramps are

- Easy to make
- **Similar to standard diamond interchange**
- **Difficult to make**

Comment – a major improvement – free flowing left turn movements

Safety

Traveling through an interchange, I feel

- **Safer in a standard diamond interchange**
- Safer in the DDI
- **About the same in both type of interchanges**

Comment – the crossover area causes vehicles to slow down reducing speed differences in vehicles

I believe more crashes will occur within

- A standard diamond interchange
- **The DDI**

I believe the center of the bridge pedestrian and bicycle walk/path is

- **Less safe than an outside-of-the-bridge walk/path**
- **As safe as an outside-of-the-bridge walk/path**
- Safer than an outside-of-the-bridge walk/path

What do you like most about the DDI?

Left turn movements being either free or yielding

What do you dislike most about the DDI?

Crossover areas while they do slow down traffic, it would nice to make them larger to allow for a little higher speed.

What would you do or suggest to improve the DDI's operations or safety?

Probably, re-design the crossover area

I am

- o **Female**
- o Male

My age group is

- o **16 to 25 years old**
- o **26 to 40 years old**
- o 41 to 65 years old
- o **Over 65 years**

My home zip code is _65781_____

Trucker Driver #2 Interview

DDI Survey Questions – Trucking Industry Survey (Date of Phone Interview - 10/19/2010)

Introduction – Interstate 44 and Missouri Route 13 Diverging Diamond Interchange (DDI)

We appreciate your time and interest in sharing your opinion. This information is being collected and summarized for inclusion into a report on the *First Diverging Diamond Interchange (DDI)* construction in North America. We are an independent firm who has been hired to collect and summarize information on the traffic operations and safety of this DDI. This study will assist in future transportation decisions made in Missouri and across our country regarding how applicable the DDI transportation solution is for other planned transportation improvements. Our only interest in this survey is to gain accurate information on what you think of the DDI, so please respond as accurately and completely as possible – your opinion is important.

We would encourage you to return and take the survey again, if while traveling through the interchange you notice something different that would change your opinion on the operation and safety of the interchange.

Have you taken this survey before?

- o **Yes**
- o No

How often do you travel through the new Diverging Diamond Interchange at I-44 and Route 13 (see photo to the right)?

- o Daily
- o **Weekly**
- o **Monthly**
- o **Never**

How often did you travel through the old Standard Diamond interchange at I-44 and Route 13 (see photo to the right)?

- o Daily
- o **Weekly**
- o **Monthly**
- o **Never**

Traffic Flow

My traveling experience through the DDI when compared with a standard diamond interchange was

- o Better
- o **About the same**
- o **Not as good**

Comment Traffic congestion is less during peak times.

Traffic delays when comparing the new DDI and the previous standard diamond interchange are

- o Less
- o **About the same**
- o **Greater**

Traffic back-ups on Route 13 and I-44 Ramps when comparing the DDI and the previous interchange are

- o Significantly less
- o **Slightly Less**
- o **Unchanged**
- o **Slightly more**
- o **Significantly more**

Comment first-time drivers are fun to watch

Drivers traveling through the DDI generally

- o **Quickly understand it**
- o Show some confusion regarding traveling on the opposite of the road
- o **Are very confused**

Traffic control devices (signals, signs and pavement markings) are

- Very understandable and provide excellent guidance
- **Understandable and provide reasonable guidance**
- **Confusing and provide poor guidance**

Pedestrian and Bicycle movements through the DDI are

- Easy to make
- **Similar to standard diamond interchange**
- **Difficult to make**

Comment professional drivers have no problems – I noticed that some vacationers with trailers tracking in both lanes

Larger traffic islands constructed to help guide drivers through the DDI

- Provide excellent directional guidance
- **Provide reasonable directional guidance**
- **Provide poor directional guidance**

When navigating around the larger traffic islands and through the roadway curvature in the crossover areas, it is

- **Difficult to stay in the proper lane**
- Similar to driving through dual turning lanes
- **Easy to stay in the proper lane**

Larger vehicle units (like trucks, camper units and boat trailer units) travel through the DDI

- **Very easily and smoothly**
- Similar to other interchanges (when considering lane changes and turning movements)
- **With difficulty**

For larger vehicle units, left turns onto the ramps are

- Easy to make
- **Similar to standard diamond interchange**
- **Difficult to make**

Comment – removing the left turn signals was a great idea

Safety

Traveling through an interchange, I feel

- **Safer in a standard diamond interchange**
- Safer in the DDI
- **About the same in both type of interchanges**

I believe more crashes will occur within

- A standard diamond interchange
- **The DDI**

Comment – I think crashes will be less because there is less traffic congestion

I believe the center of the bridge pedestrian and bicycle walk/path is

- **Less safe than an outside-of-the-bridge walk/path**
- **As safe as an outside-of-the-bridge walk/path**
- Safer than an outside-of-the-bridge walk/path

What do you like most about the DDI?

Left turn movements – you don't have to wait for a signal

What do you dislike most about the DDI?

Crossovers are sharp curves and seem to be the problem area

What would you do or suggest to improve the DDI's operations or safety?

Probably, do something with the crossover area

I am

- o **Female**
- o Male

My age group is

- o **16 to 25 years old**
- o **26 to 40 years old**
- o 41 to 65 years old
- o **Over 65 years**

My home zip code is _65612_____

Pedestrian and Bike (Non-Motorized Transportation) Interview

Pedestrian and bike facilities were designed and constructed as part of the first DDI project in the US. This document was developed to assist in assessing pedestrian and bike movements through the DDI. It is very important to gain all transportation users perspectives, so that improvements and enhancements can be considered in future projects that will address mobility, safety and access issues. The picture to the right shows an aerial view of the DDI at I-44 and MO Route 13 in Springfield, Missouri. The following questions were asked to gain pedestrian and bike users' perspectives regarding mobility, safety and understanding.

The pedestrian and bike walk/path for the Northbound direction is designated by the white arrows shown in the picture above. The crossings of the 4 right turn lanes are not signalized (common at most major intersections with separate right turn lanes). The crossings of the 4 through lanes are signalized at both ends of the interchange. The construction of the walk/path facility (located down the center of the bridge) allowed the existing bridge to be rehabilitated only and not widened in this project. Also, it allows for free left turns to both the westbound and eastbound on ramps (shown by the green triangle in the picture above). The westbound and eastbound off ramp left turns are controlled by a yield sign control (shown by the red triangle in the picture above).

Mobility/Access

1. What are your opinions on how pedestrians move through the DDI?
2. What are your opinions on how bicyclists move through the DDI?

Safety

1. What are your opinions on the safety of pedestrians within the DDI?
2. What are your opinions on the safety of bicyclists within the DDI?

Understanding

1. What is your opinion on how well pedestrians and bicyclists understand the walk/path connector across I-44?

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