EVALUATION OF THE IMPACT OF REDUCED CONFLICT INTERSECTIONS ON TRUCK AND LARGE AGRICULTURAL VEHICLE CRASHES

1. INTRODUCTION

Rural multi-lane divided highways provide mobility and safety to the traveling public. This type of roadway is generally characterized by higher posted travel speeds and lower densities of intersections (which are typically at-grade and require only the side street motorists to stop). In some cases, this combination of multiple lanes of high speed traffic, the at-grade access, and driver performance can result in right angle collisions which are much more severe than found at smaller two-lane roadway at-grade intersections. Maze et al. (2010) reported that 57% of the intersection related crashes in Minnesota were right angle or turning crashes with similar results in Utah (69%) and Iowa (52%).

These at-grade intersections along multi-lane roadways present challenging conditions for drivers in terms of judging gaps between high-speed traffic from two different directions separated by a median. Comprehension and understanding on whether to stop within the median or cross the intersection in one movement has shown to be problematic for drivers along with a persistent stop compliance issue seen particularly in rural settings (Maze et al., 2010). Some states have begun to address crash or the potential for crash at such intersections through physically restricting vehicle crossing movements (across the median) thus simplifying driver decision making in terms of gap acceptance. These access limiting treatments are referred to be several names including Restricted Crossing U-Turn (RCUT), J-Turn, and as in this report and the Minnesota DOT the Reduced Conflict Intersection (RCI).

RCIs prohibits conflicting movements at an intersection through redirecting the side-street left/through movements and often times the major roadway left turn as well. The side-street movements are accomplished indirectly through requiring that the side-street motorists turn right onto the main roadway and then make a U-turn maneuver at a one-way median opening roughly 400 to 1,000 ft away from the intersection. While effective in controlling crossing maneuvers, and consequently preventing severe right-angle crashes, the RCI intersection requires additional maneuvers for side-street motorists.

Within Minnesota's rural corridors, introduction of the RCI design has been successful in preventing severe crashes, however, the unusual design has been met with some apprehension from operators of agricultural equipment and large trucks. This, in combination with a resistance to the unfamiliar, has created a desire for more information regarding RCI intersection configuration safety impacts for these types of vehicles.

This study reviews the crash performance of RCI intersections within Minnesota and three other states to consider if RCIs negatively impact the safety for large vehicle types (large trucks and ag-equipment).

1.1 Background

One promising strategy for mitigating right angle crashes is use of an RCI. This design restricts minor road vehicles from making left or through movements. Instead, these vehicles have to make a right turn and travel a short distance downstream on the major road and then execute a U-turn. Drivers intending to turn left then continue on the expressway and drivers who intended to cross the intersection, then make a right turn.

Turning traffic from the major roadway can be accommodated in two different ways. A J-turn is a variant of the RCI intersection where left turns from the major road are allowed while the minor road through and turning movements are restricted and will have to use a U-turn (Hughes et al., 2010). Figure 1 shows a typical J-turn. This type of intersection has been used in

Michigan as well as other states successfully for more than forty years (MDOT, 2010). A basic RCI intersection with no direct left turns is another variant of RCI in which drivers from the main road intending to turn left will have to make a U-turn maneuver at the median crossover and then turn right into the minor street. The left turn and through movements from the minor road are also routed through the U-turn crossovers (Hughes et al., 2010).

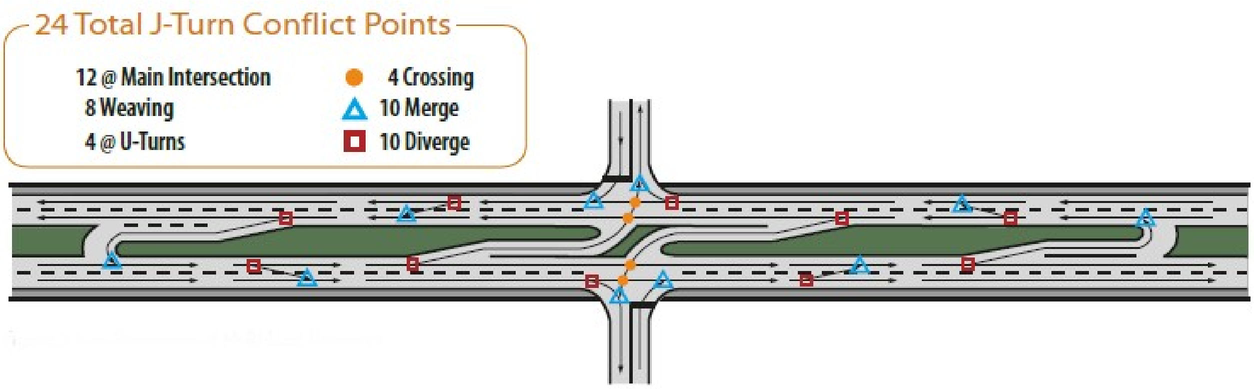

Figure 1: J-turn Intersection
Source: FHWA, 2009

The RCI design reduces conflict points. A typical two way stop controlled intersection has 42 total conflict points while a J-turn has only 24 conflict points as shown in Figure 1. The most severe crossing conflicts that can result in right angle crashes are eliminated (Maze et al., 2010). However, concerns have been raised in Minnesota that as large trucks make the U-turn maneuver they are occupying travel lanes for a longer period of time than would be required for a side street left-turn or through maneuver and consequently are more exposed to on-coming high speed vehicles.

1.2 Safety Impact of the Reduced Conflict Intersection

The following summarizes current literature regarding the safety impact of RCI intersections. It should be noted that different geometric designs are utilized so results across different studies are not necessarily comparable.

A study by Inman and Haas (2012) compared crashes for nine intersections in Maryland before and after installation of RCIs. Six of these intersections existed on U.S. 15, and three existed on U.S. 301. Crash data were obtained from the Maryland State Highway Administration which included crash locations, date, time and severity of crashes at the intersections. Nineteen years of crash data were obtained for six intersections located on U.S. 15. Twelve years of crash data were available to three intersections along U.S. 301.

Before and after comparisons of traffic crashes were made for each main intersection of the RCI, the sections between the RCI and the U-turn locations. An Empirical Bayes analysis was conducted for the nine intersections and found a 62% decrease in crashes after the RCI treatment was installed. Crashes decreased on the adjacent highway segments was decreased by about 14% and an overall decrease of 44% was reported.

They also found an overall reduction in crash severity after installation of the RCIs compared to conventional intersections. A total of 55% of all crashes at the nine intersections were injury or fatal crashes before the RCI treatment was employed but the percentage was reduced to 46% after the installation. Moreover, they concluded that there was a 70% drop in fatal crashes and a 42% reduction in injury crashes between the 3-year periods of installing the RCIs.

Edara et al. (2013) evaluated RCIs in Missouri. Five intersections where RCI's were installed were compared along with a control site which had two way stop control. The authors used an Empirical Bayes analysis to show a 34.8% reduction in crash frequency for all crashes and a 53.7% reduction for injury and fatal crashes. Minor injury crashes were reduced by 50% and annual disabling crashes by 86%. An overall 80% reduction in right angle crashes was noted for the five sites.

The authors suggested that the wait times will decrease even further when drivers become more familiar with RCIs. The additional travel time required at the RCI was found to be one minute in contrast to a conventional intersection. The report also contained a traveler survey which found that 41% of the people surveyed said that their trip was not adversely affected by RCIs compared to 33% people saying that it did affect their trip adversely (Edara et al., 2013). No specific details were provided regarding agriculture vehicles or large trucks.

1.3 Concerns with Use of Reduced Conflict Intersections

Although the few studies available have indicated that RCIs decrease crashes, several concerns have also been raised. First, drivers are often confused initially when presented with a new design. Edara et al. (2013) conducted a public opinion survey regarding the RCI intersections and noted that drivers found some difficulty in merging after the U-turn and there were issues using acceleration and deceleration lanes properly. There were respondents who felt that providing additional signage and striping would make RCIs better (Edara et al., 2013). However, Hughes et al (2010) reported that drivers adapted well with RCIs in North Carolina and in Maryland (Hughes et al., 2010). Pedestrians may also be confused by the need to follow a two staged process to cross the arterial.

RCIs also increase delay to some extent due to increased travel distance for minor road left and through movements (Hummer and Reid, 2000). Another concern that has been noted is changed access for businesses since the restricted movements may discourage drivers from accessing adjacent business.

In previous studies, concerns have been raised about the accommodation of large vehicles in an RCIs. When median widths are narrow difficulties may arise in providing appropriate turning radii at the U-turn. When appropriate width is available, bulb-outs or loons have been utilized at the U-turn location in order to provide more radius for large trucks as shown in Figure 2 (Hughes et al., 2010).

In a synthesis report of RCI design standards by the Mississippi Department of Transportation, a median width of greater than 64 feet was recommended to accommodate large trucks (MDOT, 2010). They also recommend that roadways with median widths of 64 feet or less should use measures such as supported and widened shoulders or median bulb-outs (MDOT, 2010).

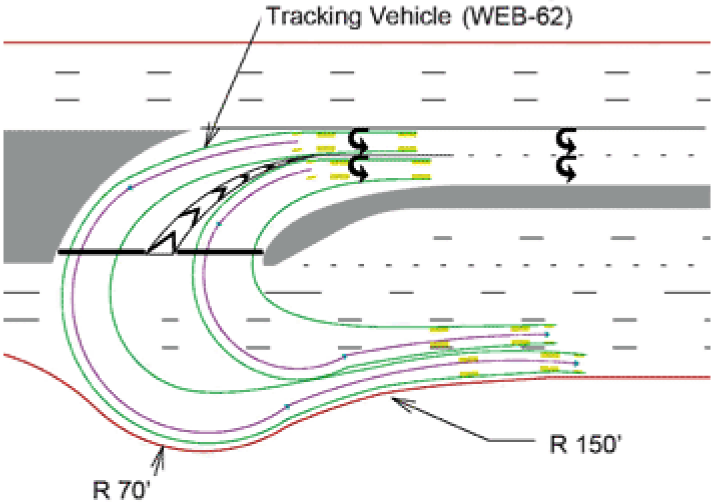

Figure 2- loon at a crossover
Source: FHWA, 2009a

A public opinion survey was conducted regarding an RCI at US 63 and Deer Park Rd in Missouri by Edara et al. (2013). The authors indicated that there were frequent concerns about insufficient U-turn radius at medians for large vehicles to smoothly use the intersections. Around 17% of the survey respondents said that their vehicle was too large for the U-turn turning radius that was provided. The percentage of tractor-trailer trucks at the RCI site of US 63 was about 5% of the AADT and, due to a narrow median width of 20 feet, the U-turn was unable to accommodate tractor-trailer trucks. However, there were interchanges on both sides of the RCI that accommodated larger vehicles such as tractor-trailer trucks. Thus in this case interchanges were considered to be the alternative for large trucks in order to avoid RCI (Edara et al., 2013).

1.4 Project Objectives

The goal of this research was to address concerns with increased exposure of large trucks with the RCI design. The study examined intersections in several states where RCIs have been implemented to determine whether there was an increase in crashes with large trucks.

2. RESTRICTED CROSSING INTERSECTION DATA

Crash and traffic data were requested for known RCI locations in six states: Maryland, Minnesota, Mississippi, Missouri, North Carolina and Wisconsin. The research team requested data from state department of transportation (DOT) contacts. Section 2.1 provides specific details regarding the type(s) and extent of data requested.

Five states provided before and after crash data for the intersections of interest in Microsoft Excel spreadsheets. The contents of these spreadsheets, with respect to the attributes provided and time periods, varied among all states. Additionally, a crash report form change in one state during the analysis period which yielded some internal attribute differences. Individual law enforcement crash reports, including narratives and diagrams, were provided as supplemental references by two states.

Lastly, one state simply provided access to 45 in-house prepared, spot safety project evaluations for directional crossovers. These directional crossovers were categorized as:

- Providing left in from mainline onto minor legs – both directions (32)
- Providing left out from minor legs onto mainline – both directions (1)
- Providing left out from minor leg onto mainline - one direction (2)
- Providing left in and left out from minor leg onto mainline – one direction (3)
- Providing left in from mainline onto minor leg – one direction (7)

The aforementioned evaluations were reviewed for the presence of a U-turn crossover or references to U-turn crashes. A total of 12 sites were identified. The findings of these evaluations will be discussed in Section 3.

2.1 Crash and Roadway Information Data Request

Each state was asked to provide the following information per intersection:

1. Provide a brief description specific to why RCI was installed over other options.
2. Provide crash/traffic/location information (see Figure 1 below) including:
    a) Existing crash data 5 years before and after where available.
    b) Given that the intersection physically changes (before versus after with RCI), we are assuming limits for the crash data as follows:
        i. Before RCI Installation: At the intersection and 300 feet along each leg
        ii. After RCI Installation: At the intersection plus 300 feet beyond the new "U" turns
    c) Location coordinates for each location

TIME	ELEMENT NAME
ACCIDENT DATE	ACC_DATE (A)
DAY OF WEEK	WEEKDAY (A)
MONTH OF ACCIDENT	MONTH (A)
ACCIDENT YEAR	ACCYR (A)
HOUR OF OCCURRENCE	HOUR (A)
DAY OF MONTH	DAYMTH (A)

ENVIRONMENT	
SURFACE ROAD CONDITION	RDSURF (A)
LIGHT CONDITION	LIGHT (A)
WEATHER CONDITION	WEATHER (A)

ACCIDENT-RELATED INFORMATION	
ACCIDENT/COLLISION TYPE	ACCTYPE (A)
ACCIDENT SEVERITY	SEVERITY (A)
NUMBER OF VEHICLES INVOLVED	NUMVEHS (A)
SEQUENCE OF EVENTS	EVENT (V)
DRIVER PHYSICAL CONDITION	PHYSCOND (V)
ACCID CONTRIB FACTORS	CONTRIB (V)

VEHICLE INFORMATION	
VEHICLE TYPE	VEHTYPE (V)

DRIVER INFORMATION	
DRIVER AGE	DRV_AGE (V)
DRIVER SOBRIETY	SOB_TEST (V)
DRIVER ALCOHOL PERCENT	DRV_BAC (V)

ROADWAY ELEMENTS (FROM ACCIDENT REPORT)	
ROUTE NUMBER	RTE_NBR (A)
MILEPOST	MILEPOST (A)
COUNTY	COUNTY (A)
TYPE OF ACCD LOCATION	LOC_TYPE (A)
ROUTE TYPE	RTE_TYPE (A)
ROAD ALIGNMENT	RD_CHAR1 (A)
URBAN/RURAL POPULATION CODES	POP_GRP (A)
FUNCTIONAL CLASSIFICATION	FUNC_CLS (A)
ROAD DEFICIENCY	RD_DEF (A)
TRAFFIC CONTROL DEVICES	TRF_CNTL (A)

LOCATION/LINKAGE ELEMENTS	
DISTRICT	DISTRICT (R)
COUNTY	COUNTY (R)
ROUTE NUMBER	RTE_NBR (R)
BEGINNING MILEPOST	BEGMP (R)
ENDING MILEPOST	ENDMP (R)
SECTION LENGTH	SEG_LNG (R)

TRAFFIC DATA	
AVERAGE DAILY TRAFFIC VOLUME	AADT (R)
SPEED LIMIT	SPD_LIMT (R)

LEGEND:	
R = Roadlog (Roadway Inventory)	A = Accident
T = Traffic Volume	V = Vehicle
I = Intersection/Interchange	O = Occupant
C = Curve	G = Grade

Figure 2. Requested data elements

2.2 Data Reduction

Crash information were provided for six states. Ultimately only data from four states could be utilized due to the following:

1. One state provided crash data but vehicle type was not available.

2. Another state provided naïve before and after spot safety evaluations and crash diagrams rather than crash data. The following is a summary of the state-provided naïve before and after spot safety evaluations for 12 locations, specifically addressing U-turn crossovers or U-turn movements.

    - Location 1: During the "after" time period (6 years), three U-turn crashes occurred at the treatment location itself. While a bulb out was provided at the treatment location, no acceleration lane was present to allow motorists to gain speed. Three crashes occurred at a pre-existing, intersection crossover, representing no change. Two crashes occurred at the newly constructed, U-turn crossover at a ramp (NCDOT, 2005a).

- Location 2: During the "after" time period (3 years), two total crashes occurred at two newly constructed, non-intersection U-turn crossovers with bulb-outs (NCDOT, 2005b).

- Location 3: During the "after" time period (3 years), the number of total crashes at the proximate crossover, also providing adjacent property access, did not change. The total number of crashes at the other proximate, intersection crossover decreased by approximately 11%. The non-intersection crossover experienced an increase in U-turn movement crashes from zero to two, while U-turn movement crashes decreased from two to one at the other intersection crossover (NCDOT, 2005c).

- Location 3: During the "after" time period (3 years and 8 months), one crash occurred at a dedicated U-turn crossover, which was consistent with the "before" period of equal duration. Two crashes occurred at the other proximate, intersection U-turn location. A fifty (50) percent decrease in crashes was observed at this location (NCDOT, no date).

- Location 4: One crash occurred at each of the proximate U-turn crossovers during the "after" period (6 years and 5 months). At one crossover, a lane departure crash possibly resulted from a vehicle trying to avoid a u-turning vehicle from the opposite direction of travel. A crash in advance of the other crossover was a same direction sideswipe, involving a vehicle changing lanes (NCDOT, 2010a).

- Location 5: During the "after" time period (3 years and 9 months), a forty-five (45) percent reduction in crashes occurred at the treatment location, which included two dedicated median crossovers (NCDOT, 2010b).

- Location 6: During the "after" time period (3 years and 11 months), no crashes occurred at one U-turn location, while four crashes occurred at the other U-turn location, representing a decrease of approximately 43%. Two of the crashes were U-turn related. Both U-turn locations were at existing intersections and were not dedicated crossovers (NCDOT, 2011a).

- Location 7: During the "after" time period (3 years and 8 months), no crashes occurred at the two U-turn crossover locations (NCDOT, 2011b).

- Location 8: During the "after" time period (4 years and 5 months), one left turn, different roadway (LTDR) crash occurred at the dedicated U-turn, bulb out location (NCDOT, 2013a).

- Location 9: During the "after" time period (4 years and 8 months), no U-turn related crashes were observed at the two proximate dedicated median crossovers (NCDOT, 2013b).

- Location 10: During the "after" time period (5 years and 2 months), no U-turn related crashes were observed at one U-turn location, while one U-turn related crash was observed at the other U-turn location (NCDOT, 2014a).

- Location 11: During the "after" time period (5 years and 2 months), seven crashes occurred at the U-turn location. However, this was not a dedicated U-turn crossover; access to an adjacent business was also provided. Only one crash involved a U-turn collision. All other crashes involved vehicles entering or exiting the adjacent business (NCDOT, 2014b).

Data for the four remaining states were utilized to compare total and truck crashes before and after installation of RCIs. Crash data were typically provided for a short distance around the intersection of interest before the RCI was installed (i.e. 150 feet). Since the RCI design extends the intersection area of influence to the upstream and downstream turning locations, most agencies provided data for the entire roadway section from the upstream to downstream points for the after period. This encompasses a greater section of roadway than was utilized for the before data. As a result, it was necessary to focus on types of crashes that are intersection related. Single vehicle crashes are not typically intersection crashes and were removed from both before and after data.

Same direction sideswipe crashes are also not likely to be intersection related. However a large truck occupying both travel lanes during a U-turn could conceivably have been coded as a same direction sideswipe by a law enforcement officer. The team debated the merits of including same direction sideswipes and decided that it would be better to include them since the crashes caused by turning vehicles were of the most interest.

Truck crashes included any crash in which one or more vehicles were a bus, recreational vehicle, farm vehicle, or large truck (defined as any single unit or larger truck).

Crash data were from four states, Maryland (MD), Minnesota (MN), Missouri (MO), and Wisconsin (WI) had the necessary data elements to conduct a simplistic before and after analysis.

Data were provided for 7 locations in Maryland. The RCI design in Maryland is such that the U-turn location is the nearest intersection. As a result, adjacent RCI intersections were combined when they shared a turning location. These sites are noted as Site 1 through 3 as Maryland did not want specific locations to be identified.

Data were available for 5 years before RCI installation in all cases. Data were available for 4 to 5 years for slightly less than half of the locations with one to two years of after data available for the rest.

3. ANALYSIS

3.1 Crash Comparison

Total crashes and truck crashes were compared before and after installation of the RCIs. Data were reduced as described in the previous chapter. The number of years of before crash data depended on what was provided by the corresponding agency. When more than five years of data were available, only the five years immediately before installation of the RCI were utilized since long term trends could not be accounted for. In some cases annual average daily traffic was provided, but not all. As a result, crashes per year was used as opposed to crashes per some unit of volume.

Table 1 summarizes the change in crash frequency observed. Crashes for the before and after period were divided by the number of years of data available to obtain crashes per year. Positive values indicate an increase in crashes. All large vehicles were included in the "truck" category since most large vehicles will experience similar turning issues as large trucks. This category includes single unit trucks, multi-unit trucks, buses and recreational vehicles.

Table 1. Comparison of crashes before and after installation of RCI

State	Site	Years of crash data		Total crashes per year		Truck crashes per year		Change in crashes	
		Before	After	Before	After	Before	After	All	Truck
MD	Site 1 (3 adjacent intersections)	5	5	5.4	7.6	0.4	1.4	2.2	1.0
MD	Site 2	5	5	3.2	0.2	0.0	0.0	-3.0	0.0
MD	Site 3 (2 adjacent intersections)	5	5	8.0	5.0	2.0	3.2	-3.0	1.2
MN	Cologne	5	2	4.4	3.0	1.0	0.5	-1.4	-0.5
MN	Cotton	5	2	2.8	2.0	0.2	1.0	-0.8	0.8
MN	Ham Lake	5	2	4.8	0.0	0.2	0.0	-4.8	-0.2
MN	Wilmar	5	4	3.0	0.0	0.2	0.0	-3.0	-0.2
MO	US 63 and Ponderosa	5	1	3.0	3.0	0.4	0.0	0.0	-0.4
MO	US 63 and Deer Park	5	1	11.2	0.0	1.4	0.0	-11.2	-1.4
MO	US 64 and Honey Creek	5	1	1.8	0.0	0.4	0.0	-1.8	-0.4
MO	US 54 and RE e	5	1	1.4	1.0	0.4	0.0	-0.4	-0.4
MO	MO 13 and Old Mo 13	5	4	3.0	2.5	0.4	0.5	-0.5	0.1
MO	RT M and Old Lemay Ferry Road	5	5	3.4	1.4	0.0	0.0	-2.0	0.0
MO	US 65 and Rochester	5	1	3.4	0.0	0.6	0.0	-3.4	-0.6
WI	US 53 and CTH B	5	2	3.4	1.0	1.8	0.5	-2.4	-1.3

The majority of sites (13 out of 15) experienced a decrease in total crashes per year with only one site experiencing an increase in crashes after installation of the RCI (Maryland Site 1 which includes 3 adjacent locations which had an increase of 2.2 crashes per year). US 63 and Ponderosa in Missouri had no change in total crashes. The other locations had decreases ranging from 0.4 to 11.2 crashes per year.

Similarly, the majority of sites experienced a decrease in truck crashes (9 of the 15) with 2 sites having no change and 4 sites having an increase. Increases of 1.0 and 1.2 crashes per year were noted at the Maryland Site 1 and 3 locations respectively. One site in Minnesota (Cotton) had an increase of 0.8 crashes. Three additional locations had minor increases or no change. US 53 and CTH B (WI) had an decrease of 1.3 and US 53 and Deer Park (MO) had a decrease of 1.4 truck crashes per year. US 65 and Rochester (MO) had a decrease of almost 1 crash per year. Six locations had minor decreases from 0.2 to 0.4 crashes per year.

It should be reiterated that crash data for the after period contains a larger segment of roadway than the before section (as described in Section 2.2). Agencies provided after data for the intersection of interest plus roadway sections extending to the upstream and downstream U-turn locations. Although the team attempted to account for this, the after data may have been biased.

3.2 Analysis of Truck Crash Patterns

One of the main goals of the research was to determine whether the frequency of truck crashes may have increased due to the added exposure of trucks in the oncoming lanes as they complete the U-turn. Truck crash patterns were evaluated for the periods before and after installation of the RCIs. The intent was to identify whether crashes were occurring which may have been a result of increased exposure of trucks in the on-coming travel lane. Several characteristics were explored including:

- crash type
- vehicle maneuver
- contributing circumstance

In a few cases, crash diagrams were available and were examined to determine whether the crash may have been due to a conflict between the turning truck and another vehicle. Any truck crashes in the after period, where a U-turn or left turn was indicated, were flagged since they were the most likely to have been this type of conflict. Unfortunately, the same crash variables were not available in all states. As a result, the variables utilized for each state are summarized in the corresponding sections.

3.2.1 Maryland

Truck crash patterns for Maryland were examined using collision type, first harmful event, primary cause, vehicle movement, direction, and contributing circumstance. Before installation of RCIs truck crashes were:

- Primarily right angle or left turn
- Commonly attributed to failure to pay attention, failure to yield right of way, or too fast for conditions
- Several same direction sideswipe crashes occurred
- One rear end crash occurred

After installation

- Rear end crashes were the predominant truck crash type
- Same direction sideswipes were also common
- No crashes were coded as having involved a U-turn

Overall, right angle truck crashes were reduced while rear end and same direction sideswipe crashes were the most common. Both rear end and sideswipe could be a result of a large trucks turning into adjacent lanes, however in most cases "straight" rather than some type of turn was the primary movement before the crash.

3.2.2 Minnesota

Truck crash patterns in Minnesota were evaluated using crash type, vehicle action, vehicle factor, sequence of events, most harmful events, and primary contributing factor.

Before installation of RCIs truck crashes were:

- Primarily same direction sideswipe or right angle

After installation

- Same direction sideswipes were the predominant truck crash type
- No crashes were coded as having involved a U-turn

Overall, no obvious change in truck crash type was apparent.

3.2.3 Missouri

Missouri truck crash patterns were examined using accident type and sequence of events from the crash data and crash diagrams since individual crash forms were also provided.

Before installation of RCIs truck crashes were:

- Left turn, right angle, rear-end, and passing crashes

After installation

- Passing crashes were the most common truck crash type
- No crashes were coded as having involved a U-turn

Overall, no obvious change in truck crash was apparent.

3.2.4 Wisconsin

Wisconsin truck crash patterns were evaluated using crash type, vehicle direction, vehicle movement, vehicle action and driver action.

Before installation of RCIs truck crashes were:

- Angle crashes, head-on or rear-end

After installation

- Only one truck crash was noted in the after period (rear-end)
- No crashes were coded as having involved a U-turn

Overall, no obvious change in truck crash was apparent.

4. SUMMARY

4.1 Conclusions

Based on the limited data available, this analysis did not show that the frequency of truck crash increased after the installation of an RCI. In addition, the installation of the RCI appears to have shifted crash patterns from the more severe right-angle crash to a less severe rear-end and side-swipe crash. Evaluation of truck crash patterns before and after installation of RCIs did not suggest increases in the type of crashes which would have appeared to result from increased truck exposure in the on-coming lanes as trucks completed a U-turn.

4.2 Study Limitations

Several limitations were present and as a result, findings from this research should be considered in light of those limitations.

The most significant is that only a limited after period (1 to 2 years) was available for a number of the sites. Additionally, only 15 locations in total were available. As a result, regression to the mean and short term crash trends could not be accounted for in the analysis.

Another major limitation is that crashes for a different area of intersection influence exist before and after installation of RCIs as described in Section 2.2. As a result, a larger area of influence was included for the after period and this could lead to an overestimate of the number of crashes in the after period.

5. REFERENCES

Edara et al. *Evaluation of J-turn Intersection Design Performance in Missouri.* Missouri Department of Transportation, Missouri. December 2013.

FHWA. (2009). *Low-Cost Safety Enhancements for Stop-Controlled and Signalized Intersections.* FHWA Publication No.: FHWA-SA-09-020. USDOT. *MAY 2009.*

FHWA. (2009a). *Restricted Crossing U-Turn Intersection.* FHWA Publication No.: FHWA-HRT-09-059. USDOT. *October 2009.*

Hughes, W., R. Jagannathan, D. Sengupta, and J. E. Hummer. 2010. *Alternative Intersections/Interchanges: Informational Report (AIIR),* Final Report, FHWA-HRT-09-060.

Hummer, J. E., Reid, J. D. *Unconventional Left-Turn Alternatives for Urban and Suburban Arterials.* TRB Circular E-C019: Urban Street Symposium. 2000.

Inman V.W., and R. P. Haas. 2012. *Field Evaluation of a Restricted Crossing U-turn Intersection*, Final Report, FHWA-HRT-11-067.

Maze, T., Hochstein, J., Souleyrette, R., Preston, H., Storm, R. *Median Intersection Design for Rural High-Speed Divided Highways*. NCHRP Report 650. TRB, Washington, D.C., 2010. *Synthesis of J-turn Design Standards and Criteria*. Mississippi Department of Transportation, Mississippi. December 2010.

MDOT, 2010

NCDOT. *Spot Safety Project Evaluation, Project Log # 200501203, Spot Safety Project # 14-97-017,* 9/14/2005a.

NCDOT. *Spot Safety Project Evaluation, Project Log # 200501214, Spot Safety Project # 14-97-018*, 9/16/2005b.

NCDOT. *Spot Safety Project Evaluation, Project Log # 200501215, Spot Safety Project # 05-99-243*, 9/16/2005c.

NCDOT. *Spot Safety Project Evaluation, Project Log # 200610096, Spot Safety Project # 05-00-015*, no date.

NCDOT. *Spot Safety Project Evaluation, Order # 41000006779, Spot Safety Project # 02-20-239*, 8/13/2010a.

NCDOT. *Spot Safety Project Evaluation, Order # 41000009271, Spot Safety Project # 06-04-213*, 11/4/2010b.

NCDOT. *Spot Safety Project Evaluation, Order # 410000011924, Spot Safety Project # 04-05-215*, 6/17/2011a.

NCDOT. *Spot Safety Project Evaluation, Order # 410000014517, Spot Safety Project # 03-04-219*, 10/12/2011b.

NCDOT. *Spot Safety Project Evaluation, Order # 410000025411, Spot Safety Project # 03-04-220*, 7/29/2013a.

NCDOT. *Spot Safety Project Evaluation, Order # 410000025426, Spot Safety Project # 08-05-204*, 7/16/2013b.

NCDOT. *Spot Safety Project Evaluation, Order # 410000027715, Spot Safety Project # 08-06-219*, 2/12/2014a.

NCDOT. *Spot Safety Project Evaluation, Order # 410000027763, Spot Safety Project # 03-06-213*, 3/11/2014b.