WISCONSIN DEPARTMENT OF TRANSPORTATION

IH-94 NORTH-SOUTH RECONSTRUCTION, MILWAUKEE COUNTY:

ROAD SAFETY AUDIT

OPUS

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IH-94 NORTH-SOUTH RECONSTRUCTION, WAUKESHA COUNTY:

ROAD SAFETY AUDIT

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APPENDIX A: INTERCHANGE SPACING ANALYSIS
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1.0 INTRODUCTION

1.1 Background

IH-94 in Milwaukee County is a major transportation corridor linking to Milwaukee, Racine, Kenosha, and the Chicago area. The corridor includes the Mitchell interchange in conjunction with IH-43 and IH-894, and the Airport Spur to the General Mitchell International Airport. The corridor also serves industrial parks, tourism, and growing commercial and residential areas in southern Milwaukee Counties. This creates high levels of demand at interchanges and increases the potential for conflicts between long-distance traffic (including trucks associated with the industrial areas along the freeway), local traffic, and non-motorized traffic near the interchanges. Average annual daily traffic levels reported in 2004 ranged from 83,400 to 161,400 vehicles in Milwaukee County and 29,200 vehicles at the Airport Spur. Volumes are forecasted to increase to a range from 115,000 to 196,000 vehicles in Milwaukee County and 55,000 vehicles at the Airport Spur by 2035. Trucks are expected to compose up to 18 percent of the traffic. The project corridor is shown in FIGURE 1.1.

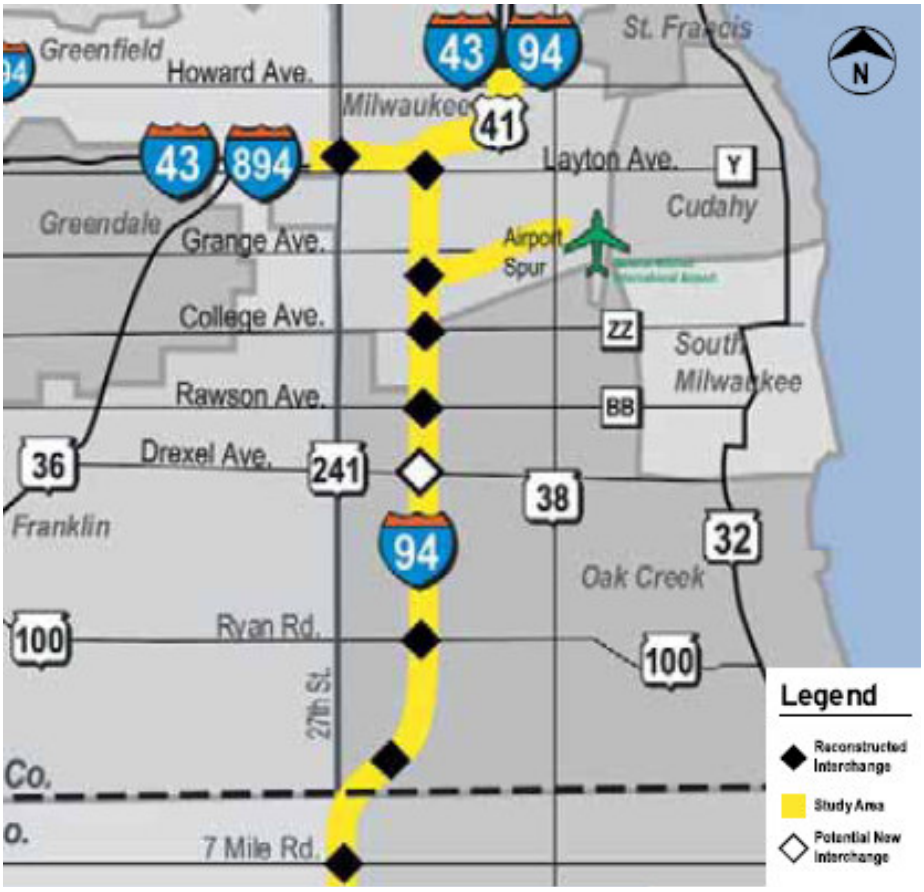


FIGURE 1.1 PROJECT LIMITS

The expansion and upgrades, described in Section 1.4 below, are currently in the 30% to 60% design phase. The expansion and upgrades are scheduled for construction beginning in 2009 to 2012 (Mitchell Interchange and Plainfield Curve) and in 2015 to 2016 (southern Milwaukee County). Programmed construction costs are about $1 billion.

Opus International Consultants was retained by the Wisconsin Department of Transportation (WisDOT) to perform a road safety audit (RSA) of the proposed improvements to IH-94 from Racine/Milwaukee County Line to Howard Avenue. This report discusses the findings of the RSA.

1.2 Road Safety Audits

A RSA is a formal safety performance examination of an existing or future road or intersection by an independent RSA team. RSAs help to promote road safety by identifying safety issues at the design and implementation stages, promoting awareness of safe design practices, integrating multimodal safety concerns, and considering human factors in the design.

1.3 Reminder

The RSA team has conducted this audit to the best of its professional abilities within the time available and by referring to available information. While every attempt has been made to identify significant safety issues, the design team and the project owner are reminded that responsibility for the design, construction, and performance of the project remains with the engineers of record.

1.4 Audit Scope

The Wisconsin Department of Transportation (WisDOT) is currently planning to expand IH-94 and upgrade interchanges between Racine/Milwaukee County Line and Howard Avenue. This project is currently at various design stages ranging from 30 percent to 60 percent complete. The following interchanges will be upgraded or implemented:

- Elm Road
- Ryan Road (STH 100)
- Drexel Avenue (Proposed interchange)
- Rawson Avenue
- College Avenue

- Airport Spur (STH 119)
- Layton Avenue
- Mitchell Interchange with IH-43 and IH-894
- 27th Street (STH 241)

The Plainfield curve will also be reconstructed to improve horizontal alignment. Included within the expansion is an eight lane cross-section and improvements to the intersection of 27th Street and Layton Avenue.

1.5 Audit Team and Process

The audit team and the project material on which the audit was based are described in *Section 3*.

Site visits were conducted in May 2008 to gain an understanding of the existing conditions and surroundings, as well as to identify existing safety concerns. Notes of the site visits are included in *Section 4.*

A RSA framework was applied in both the audit analysis and presentation of findings. The expected frequency and severity of crashes caused by each safety issue have been identified and rated according to the categories shown in TABLES 1.1 and 1.2. These two risk elements were then combined to obtain a risk assessment on the basis of the matrix shown in TABLE 1.3. Consequently, each safety issue is assessed on the basis of a ranking between F (highest risk and highest priority) and A (lowest risk and lowest priority).

For each safety issue identified, possible mitigation measures have been suggested. The suggestions have focused on measures that can be cost-effectively implemented at the current design stage, and consequently include few major geometric changes.

TABLE 1.1 FREQUENCY RATING

ESTIMATED		EXPECTED CRASH FREQUENCY (per audit item)	FREQUENCY RATING
EXPOSURE	PROBABILITY		
high	high	10 or more crashes per year	*Frequent*
medium	high		
high	medium	1 to 9 crashes per year	*Occasional*
medium	medium		
low	high		
high	low	less than 1 crash per year, but more than 1 crash every 5 years	*Infrequent*
low	medium		
medium	low	less than 1 crash every 5 years	*Rare*
low	low		

TABLE 1.2 SEVERITY RATING

TYPICAL CRASHES EXPECTED (per audit item)	EXPECTED CRASH SEVERITY	SEVERITY RATING
crashes involving high speeds or heavy vehicles, pedestrians, or bicycles	probable fatality or incapacitating injury	*High*
crashes involving medium to high speed; head-on, crossing, or off-road crashes	moderate to severe injury	*Moderate*
crashes involving medium to low speeds; left-turn and right-turn crashes	minor to moderate injury	*Low*
crashes involving low to medium speeds; rear-end or sideswipe crashes	property damage only or minor injury	*Negligible*

TABLE 1.3 CRASH RISK ASSESSMENT

FREQUENCY RATING	SEVERITY RATING			
	Negligible	*Low*	*Moderate*	*High*
Frequent	**C**	**D**	**E**	**F**
Occasional	**B**	**C**	**D**	**E**
Infrequent	**A**	**B**	**C**	**D**
Rare	**A**	**A**	**B**	**C**

Crash Risk Ratings:

A: minimal risk level
B: low risk level
C: moderate risk level
D: significant risk level
E: high risk level
F: extreme risk level

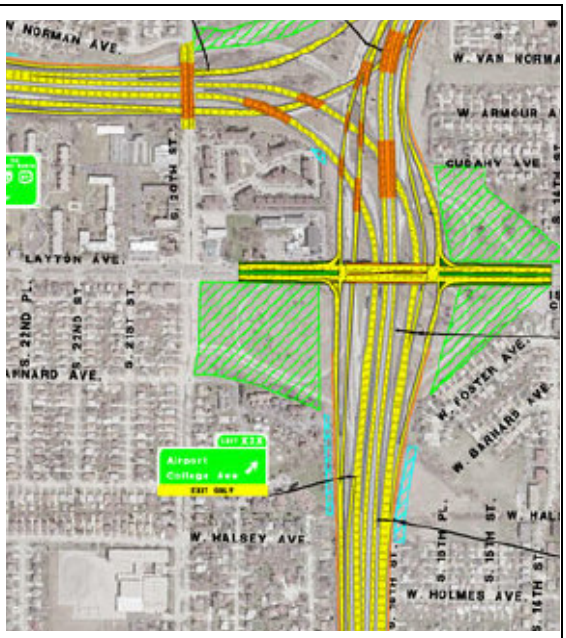
2.0 AUDIT FINDINGS

2.1 Safety Benefits of the New Design

Improvements to IH-94 are motivated by the goal of reducing congestion and traffic crashes for all users including long-distance/industrial traffic and local/regional traffic in Milwaukee County. In addition, the freeway and many features of its design already incorporate many enhancements that are expected to substantially improve traffic safety in the area:

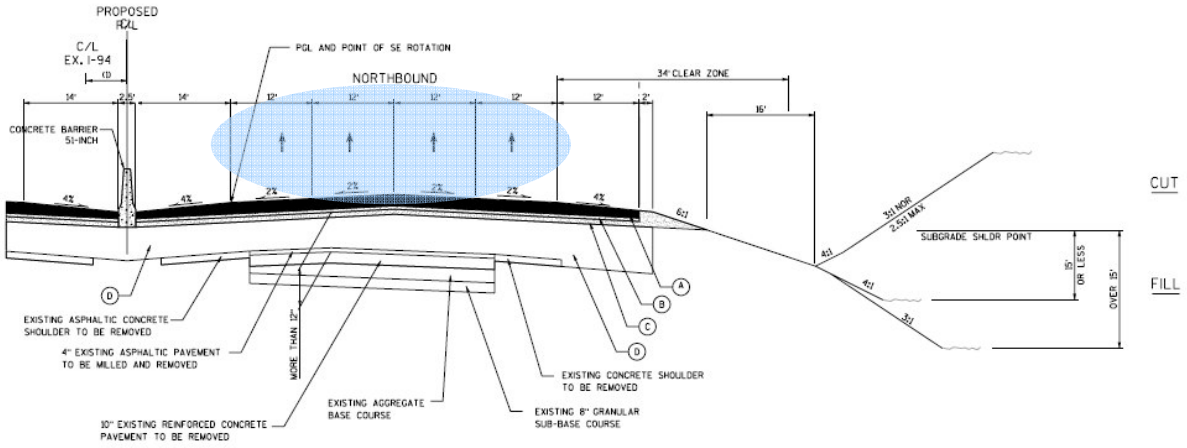
Right-side ramps: Existing left-side entry and exit ramps will be replaced with right-side ramps. Right-side entry and exit ramps will better meet driver expectations, and reduce the collision risk associated with late lane changes and with mixing higher-speed through traffic in the left-lanes with slower speed entering and exiting vehicles.

The 2005 ITE *Freeway and Interchange Geometric Design Handbook*[1] states that in the early 1960s significant operational problems with many of the left exit and entrance interchanges existed. It suggested that all right exits and entrances should be incorporated into a system interchange to provide safer operations and remain consistent with driver expectations.

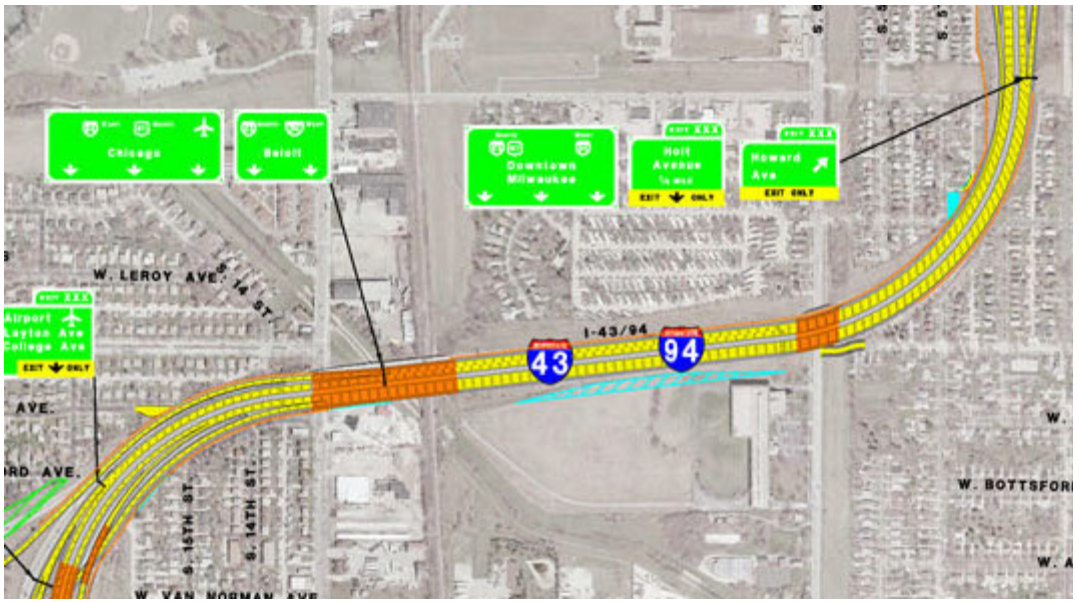


[1] Institute of Transportation Engineers, *Freeway and Interchange Geometric Design Handbook* (2005).

Reduced congestion: The cross-section is proposed to expand from a six-lane to an eight-lane cross-section, to accommodate increased traffic growth. Increasing capacity on IH-94 will reduce speed variation and travel time which may lead to a reduction in crashes along the mainline.

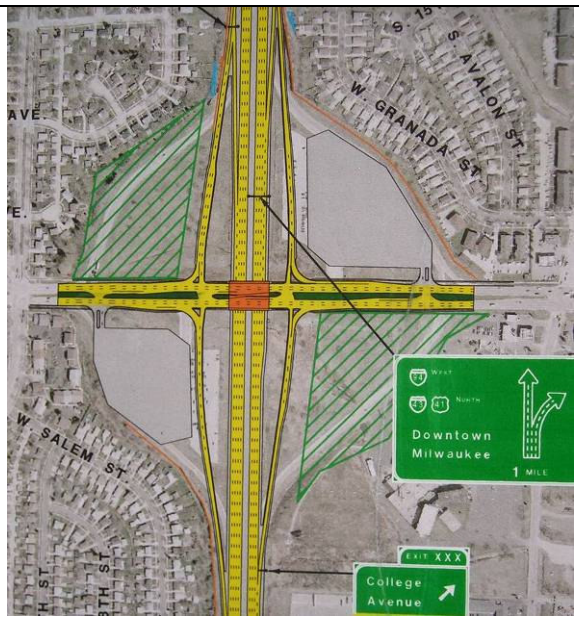


Improved Plainfield Curve geometry: The proposed realignment of Plainfield Curve provides drivers with improved super elevation and geometry to safely transition through the horizontal alignment.

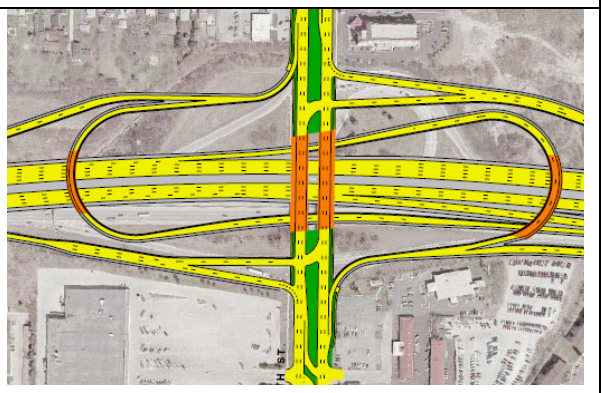


Improved interchange ramp geometry: The tight diamond interchange design eliminates horizontal curves which currently exist on exit and entrance ramps. This improvement should help reduce run-off-road crashes and truck crashes on the ramps.

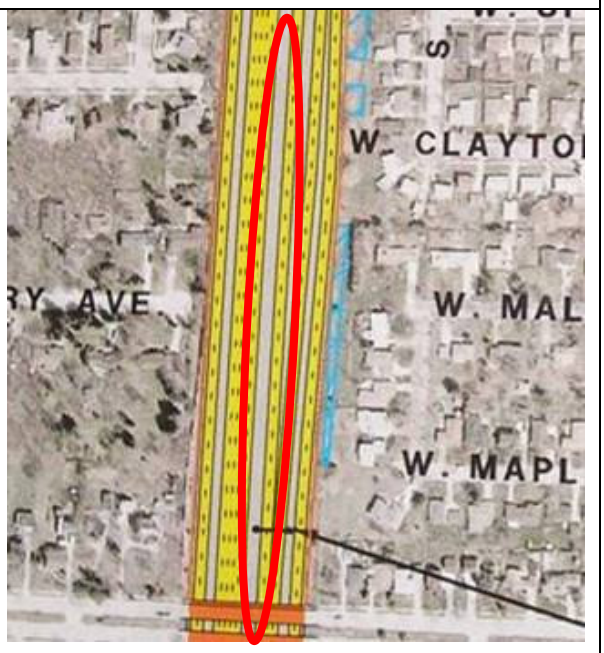
The tight diamond interchange design also allows greater distance between the ramp terminals and the adjacent cross streets, eliminating queues into the intersections.



Removing left-turn movement at 27th Street: Existing crash patterns show predominantly high left-turn collisions at the 27th street interchange. The proposed design eliminates the risk of left-turn collisions, by removing the left-turn movement at the 27th Street interchange.



Improved weaving section: Two northbound through lanes will be provided separate from exiting traffic, decreasing volume within the 2000 ft weave section on the collector-distributer road north of the Airport Spur. The 2005 ITE *Freeway and Interchange Geometric Design Handbook*[2] states that a greater number of lanes result in a higher capacity within the weaving segment which affects both weaving and non-weaving vehicles. Therefore, weaving will be eliminated for the northbound through traffic, on the mainline, decreasing the likelihood of conflicts occurring.



2.2 Existing Safety Features

Existing safety features of IH-94 are incorporated in the proposed design to maintain their effective traffic safety performance within the project limits:

Concrete median barrier: The continuous concrete median barrier on the corridor significantly reduces the number of median crossover crashes and their severity throughout the corridor. Specifically, the median barrier will help to prevent head-on crashes associated with vehicles crossing the median.	
Wide shoulders: The entire corridor provides a wide shoulder. This existing element contributes to safety by a moderate reduction in crash frequency and a high reduction in crash severity due to the recovery room/refuge.	
Lighting: Lighting is provided north of Rawson Avenue, improving corridor conspicuity and visibility during night time hours.	

Active warning signs at curves: Existing active warning sign at the Airport Spur, "TOO FAST FOR CURVE", provides advance information regarding sharp curve which reduces speeds and the likelihood of collisions occurring along the loop ramp.	
Rumble strips: Shoulder rumble strips exist along IH-94 to alert drivers who have left the travel lane and entered the shoulder. Therefore, shoulder rumble strips reduce the likelihood of fixed object and run-off-road collisions.	

2.3 Summary of Audit Findings

Five main safety issues were identified, all of which have a low to significant risk rating. The five main issues and suggested alternatives are described in detail in Section 5 *(Issues and Suggestions),* and are summarized in TABLE 2.1.

TABLE 2.1 SUMMARY OF RSA SAFETY ISSUES AND SUGGESTIONS

SAFETY ISSUE (Number and Description)		Risk Rating	Suggestions
1. Plainfield Curve Merging, Weaving and Lane Drops			
1a	Southbound, between Howard Avenue and Mitchell Interchange	**C**	▪ Consider four lanes instead of five between Howard Avenue and Mitchell Interchange
1b	Traffic from eastbound IH-894 to Milwaukee	**D**	▪ Extend project limits to north of Howard Avenue
1c	Northbound IH-94 Volume and Level of Service at Howard Avenue		

SAFETY ISSUE (Number and Description)		Risk Rating	Suggestions
2. IH-43/894 Merging, Weaving and Lane Drops			
2a	IH-894 Westbound	**D**	▪ Consider consolidating the two 27th Street westbound on-ramps ▪ Rationalize westbound IH-894 laning at 35th Street
2b	Eastbound IH-894 to northbound IH-94	**C**	▪ Consider consolidating the two 27th Street eastbound on-ramps
3. IH-94 Merging, Weaving and Lane Drops			
3a	IH-94 southbound lane drop north of Airport Spur	**C**	▪ Carry two lanes from southbound IH-894
3b	Weaving on four-lane section on northbound IH-94	**D**	▪ Drop one lane at Layton Avenue instead of IH-94 Downtown Milwaukee
3c	Northbound ramps, north of College	**C**	▪ Provide a two-lane optional exit to Airport Spur
4. Queuing and Operations at Interchange Ramps and Ramp Terminals			
4a	Tight diamond traffic operations	**D**	▪ Review Synchro files ▪ Improve ramp spacing
4b	27th Street westbound “U” on-ramp	**B**	▪ Consolidate on-ramps ▪ High friction pavement
4c	Southbound 27th Street to IH-43/894 on-ramp		▪ Relocate the split point further west
4d	Three-lane to one-lane merge		▪ Meter at all time ▪ Successive merge
4e	Tighter radius on Airport Spur Loop Ramp		▪ Review the feasibility of radius
5. Impacts on the Arterials: Layton Avenue and 27th Street			
5a	27th Street and Layton Avenue Intersection	**D**	▪ Conduct operations and safety study
5b	Left-turn movements on 27th Street between Layton and IH-894		▪ Restrict left-turn movements ▪ Consolidate driveways
5c	Layton Avenue and 26th Street intersection		▪ Extend project limits

Five safety issues have been identified in this design-stage road safety audit. Suggestions for improvements have been identified and are described in this report. The owner and design team are invited to consider the suggested changes. To complete the audit process, the owner and design team may prepare a short written response to the issues and options outlined in this report.

3.0 ROAD SAFETY AUDIT TEAM AND MATERIALS

Project: IH-94 North-South Reconstruction, Milwaukee County, Wisconsin

Audit Team Members:

Jeffrey S. Bagdade, P.E.	Opus International Consultants
Sany R. Zein, P.Eng.	Opus International Consultants
Joyce Abinader, EIT	Opus International Consultants
Rebecca Yao, P.E.	WisDOT BHO
Chris Quesnell, P.E.	WisDOT Southeast Region Traffic
Beth Blum, P.E.	WisDOT Southeast Region Planning
Marie Treazise, EIT	WisDOT BHO
Dave DeSmet	Milwaukee County Sheriff

Project Owner: Wisconsin Department of Transportation

Design Team: Milwaukee Transportation Partners

Review Stage: 30% to 60% Design Stage

Start Up Meeting: May 5, 2008

Preliminary Findings Meeting: May 9, 2008

Attended by: Wisconsin Department of Transportation
Milwaukee County Sheriff
Milwaukee Transportation Partners
Opus International Consultants

Project Documents Available for the Audit:

- 1030-20-00: N-S Freeway Reconstruction 30% Plans (updated January 2008).
- Public Hearing Designs including design year freeway operations
- Existing Volumes and 2035 Projected Volumes
- SEWRPC Interchange Volume and Turning Movements
- I-94 North-South Corridor Transportation Management Plan:
  - Preliminary List of PIDM Projects
  - Preliminary List of TO Projects
- Summary of Value Engineering Study Recommendations
- Preliminary Closure and Alternate Route Guides
- 2009 and 2010 Work Zone Impact Management Recommended Strategies

All documents were provided prior to or at the start-up meeting of May 5, 2008.

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4.0 SITE VISIT NOTES

Project Name: IH-94 North-South Reconstruction: Milwaukee County

Site Visit Dates: Monday, May 5, 2008 3:00 to 5:30 PM, clear and dry
Wednesday, May 7, 2008 1:30 to 4:00 PM, cloudy

Land Uses

IH-94 is located in the urban Milwaukee area. Adjacent land uses are residential, industrial, and commercial areas in the cities of Milwaukee, Oak Creek, Franklin and Greenfield, Wisconsin.

Road User Characteristics

Moderate traffic was observed at the time of the site visit including a proportion of trucks due to the surrounding industrial areas. Trucks compose about 13 to 18 percent of traffic during non-peak hours. Pedestrians were observed near the intersection of Layton Avenue and 27th Street. Pedestrians and bicycles were observed near 20th Street due to schools in the surrounding area. In addition, the design team advises that motorcycles are present during warmer weather.

Road and Roadside Physical Characteristics

A six lane divided highway, IH-94, accommodates entering and exiting traffic using various interchange designs consisting of diamond interchanges and partial cloverleaf interchanges. The on and off ramps consist of horizontal curves and loop ramps. The posted speed limit changes from 65 mph to 55 mph near Rawson Avenue and 50 mph between the Airport Spur and Layton Avenue. Approach alignments south of the Mitchell interchange are generally straight and level, and alignment north of the Mitchell interchange consists of two horizontal curves comprising the Plainfield Curve.

Adjacent Network and Connectivity:

IH-94 connects to the Mitchell interchange in junction with IH-43 and IH-894, providing connections to several city arterials, as well as the cities of Green Bay (to the north),

Chicago (to the south), Madison (to the west), Beloit (to the southwest) and Fond du Lac (to the northwest). The General Mitchell International Airport provides access to IH-94 through the Airport Spur Interchange. The Airport Spur also connects to STH 38 (Howell Avenue) at the General Mitchell International Airport. IH-43/894 connects to STH 241 (27th Street), west of IH-94, providing north-south connection between the cities of Oak Creek and Greenfield.

Other Observations

Weaving activity was observed due to the left-side entry and exit ramps. Vehicles were observed maintaining operational speeds between 60 and 65 mph north of Rawson Avenue and between 70 and 75 mph south of Rawson Avenue.

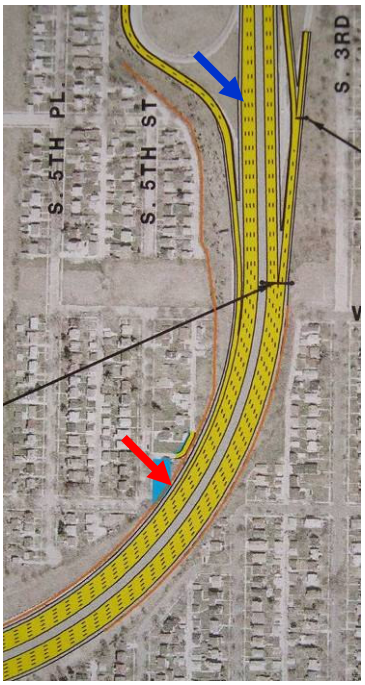
Horizontal alignment issues were addressed along the corridor by implementing chevrons, transverse markings, and active warning sign “TOO FAST FOR CURVE”.

5.0 ROAD SAFETY AUDIT ISSUES AND SUGGESTIONS

5.1 Safety Issue 1: Plainfield Curve Merging, Weaving and Lane Drops

Safety Issue 1(a) Description:

Southbound, between Howard Avenue and Mitchell Interchange



The Howard Avenue southbound ramp joins IH-94 on a curve *(red arrow)*. Vehicles traveling on IH-94 may not expect vehicles joining the freeway on a curve. Also, vehicles entering the freeway may have difficulty merging into adjacent lanes to travel in the desired lane necessary to continue on IH-94.

Vehicles entering southbound on Howard Avenue are required to change three lanes to continue on IH-94. Three lane changes in a short distance increases driver frustration and weaving which may lead to sideswipe and rear-end collisions.

A fourth lane is added south of the Howard Avenue Bridge *(blue arrow).* This additional lane increases the need for lane changes along the Plainfield Curve.

Expected Crash Types: weaving, rear-end collisions

Expected Frequency: occasional

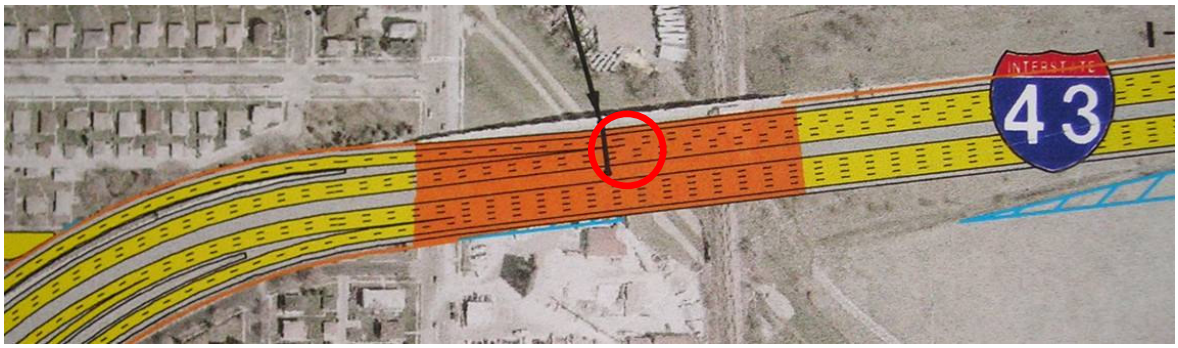
Expected Severity: low

Risk Rating: C (moderate risk level)

Opportunities for Improvement

Consider four lanes instead of five between Howard Avenue and Mitchell Interchange

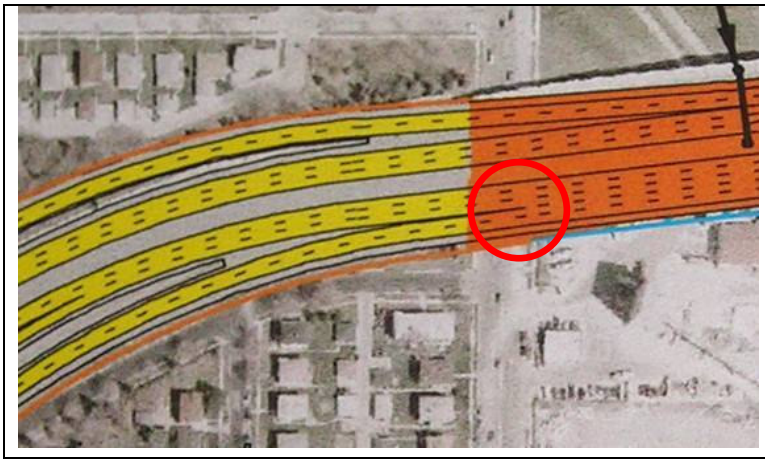
Removing the added lane south of Howard Avenue will decrease the number of lane changes needed to remain on IH-94. An optional two-lane exit at westbound IH-894 may also be implemented to provide three lanes on IH-94 and two lanes on the ramp. Implementing four lanes instead of five lanes between Howard Avenue and Mitchell Interchange will reduce the number of lane changes needed, to continue on IH-94, from three to two.

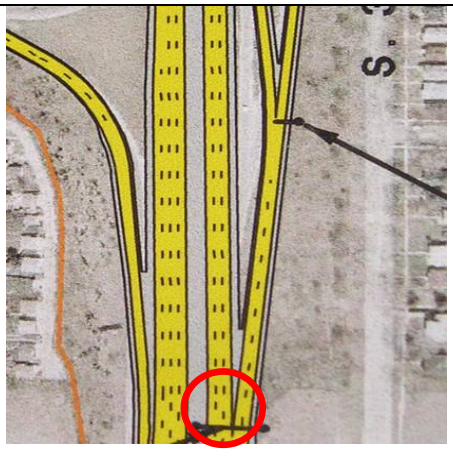


Safety Issue 1(b) Description:

Traffic from eastbound IH-894 to Milwaukee

The two-lane traffic from eastbound IH-894 to northbound IH-94 exits off onto Howard Avenue. Therefore, two lane changes are required along the Plainfield Curve to continue northbound on IH-94. Heavy volumes are required to weave over two-lanes increasing sideswipe and rear-end collisions along this segment.





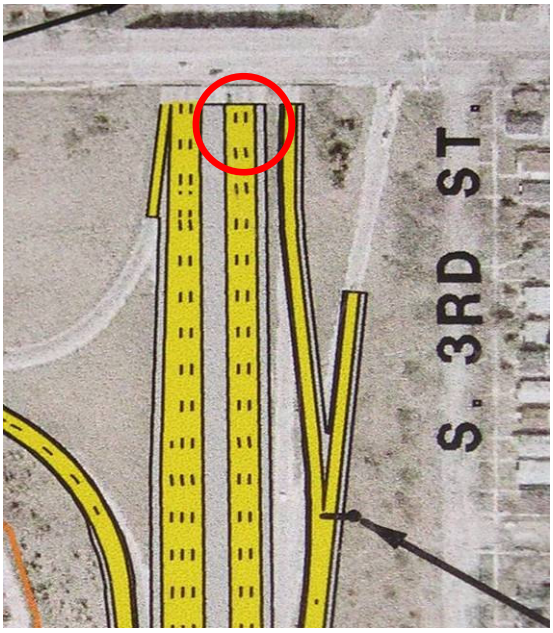
Opportunities for Improvement

See the proposed solutions for Safety Issue 1(c).

Safety Issue 1(c) Description:

Northbound IH-94 Volume and Level of Service at Howard Avenue

The projected volume of 6,120 veh/hr exceeds the three lane capacity at Howard Avenue. The projected volumes north from IH-94 may also include an additional 500 veh/hr during the AM peak hour. The LOS (level of service) is projected to be an "E" indicating the increase in vehicle delay.



The bottleneck at Howard Avenue increases congestion and vehicles may begin to back into the Plainfield Curve. Vehicles traveling through the Plainfield Curve may not expect back-up beyond the curve and therefore have insufficient time to react to slower speeds, resulting in rear-end collisions.

Expected Crash Types: weaving, rear-end collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

Opportunities for Improvement:

Extend project limits to north of Howard Avenue

A four-lane section may be implemented further north of Howard Avenue to accommodate the projected volumes. A four-lane section will decrease delay and unexpected speed variation beyond the Plainfield Curve. A reduction in congestion improves safety by eliminating bottlenecks and back-ups onto the Plainfield Curve.

A four-lane section will also decrease the number of lane changes necessary to remain on IH-94 from eastbound IH-894 reducing the heavy volume of weaving.

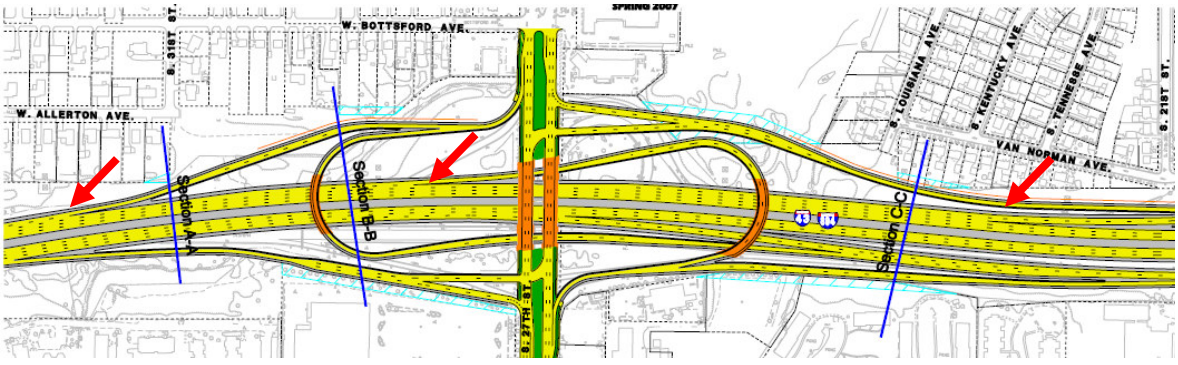
5.2 Safety Issue 2: IH-43/894 Merging, Weaving and Lane Drops

Safety Issue 2(a) Description:

IH-894 Westbound

Three successive add-lanes exist on westbound IH-894. Two lanes are added from IH-94 with a volume of 3,000 veh/hr and two lanes are added from 27th Street at two separate locations with a volume greater than 1,000 veh/hr. The add-lanes merge further downstream prior to the next add-lane resulting in a heavy shift in traffic at three separate locations in close proximity to each other.

When a lane ends, the required lane change typically results in braking and reduction in speed. The presence of multiple lane drops closely in succession can create speed variation which may lead to rear-end and sideswipe collisions.



At 35th Street the design shows four westbound lanes east of the bridge and three westbound lanes west of the bridge. During site visits it was recorded that the width between the bridge abutments is too narrow to allow for a fourth lane underneath the bridge.	

Expected Crash Types: weaving, rear-end collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

Opportunities for Improvement

Consider consolidating the two 27th Street westbound on-ramps

Consolidating the two 27th Street westbound on-ramps would eliminate an add-lane and a merge that through vehicles would have to otherwise navigate through. This would decrease the number of merging conflict points within close proximity of each other.

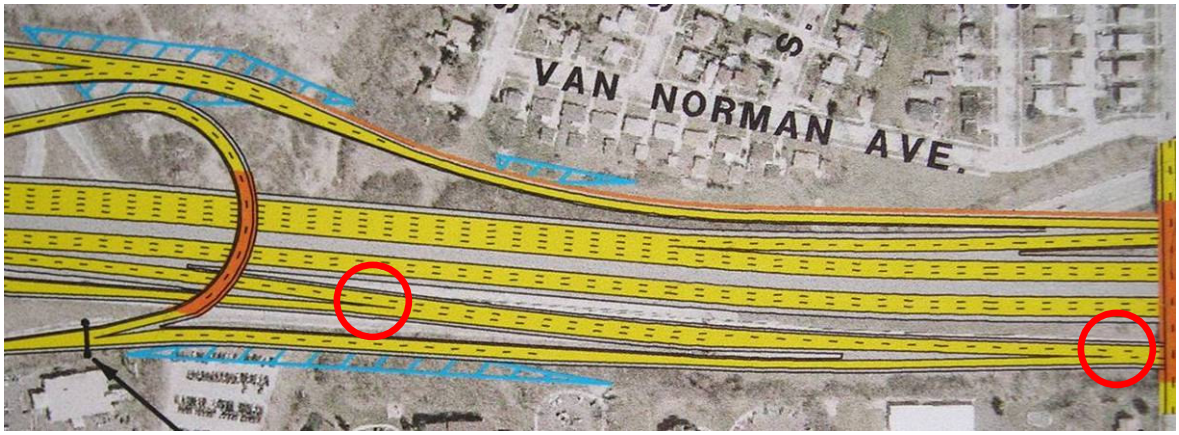
Rationalize westbound IH-894 laning at 35th Street

The project limits may need to be extended further west to accommodate westbound IH-894 laning. What was shown on the laning drawings at the time of the Road Safety Audit is unworkable.

Safety Issue 2(b) Description:

Eastbound IH-894 to northbound IH-94

Two successive add-lanes from 27th Street exist on eastbound IH-894 to northbound IH-94. The add-lanes merge further downstream prior to the next add-lane resulting in a shift in traffic at separate locations in close proximity to each other.



Expected Crash Types: weaving, rear-end collisions

Expected Frequency: occasional

Expected Severity: low

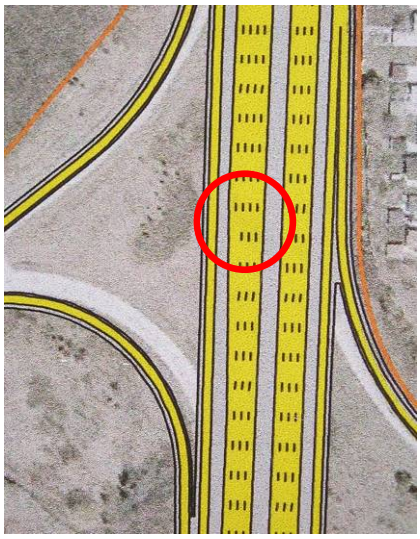
Risk Rating: C (moderate risk level)

Opportunities for Improvement

Consider consolidating the two 27th Street eastbound on-ramps

Consolidating the two 27th Street eastbound on-ramps would eliminate an add-lane and a merge that through vehicles would have to otherwise navigate through. This would decrease the number of merging conflict points within close proximity of each other.

5.3 Safety Issue 3: IH-94 Merging, Weaving and Lane Drops



Safety Issue 3(a) Description:

IH-94 southbound lane drop north of Airport Spur

IH-94 drops from five lanes to four lanes north of Airport Spur in the southbound direction. When a lane ends, the required lane change typically results in braking and reduction in speed. A variation of speeds combined with merging may increase crash risk.

Expected Crash Types: weaving, rear-end collisions

Expected Frequency: occasional

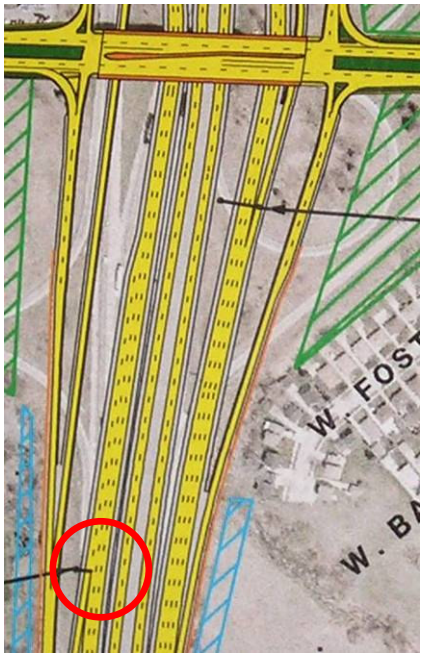
Expected Severity: low

Risk Rating: C (moderate risk level)

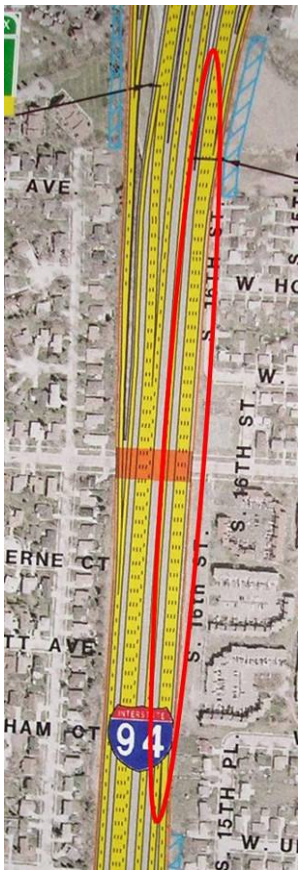
Opportunities for Improvement

Carry two lanes from southbound IH-894

Consider carrying two lanes from southbound IH-894 instead of three lanes. A lane may be dropped at the College Avenue/Airport Spur Exit south of Layton Avenue *(circled right)*. Therefore, two southbound IH-894 lanes will converge with two southbound IH-94 lanes. This will eliminate the need for a merge downstream, north of Airport Spur.



Safety Issue 3(b) Description:



Weaving on four-lane section on northbound IH-94

A four-lane weave section is designed on northbound IH-94 along a distance of about 2,000 feet between Grange Avenue and Layton Avenue. Depending on what lane a vehicle is traveling in, a two-lane or three-lane change is needed for vehicles exiting off of IH-94 to exit onto Layton Avenue.

Expected Crash Types: weaving, rear-end collisions

Expected Frequency: frequent

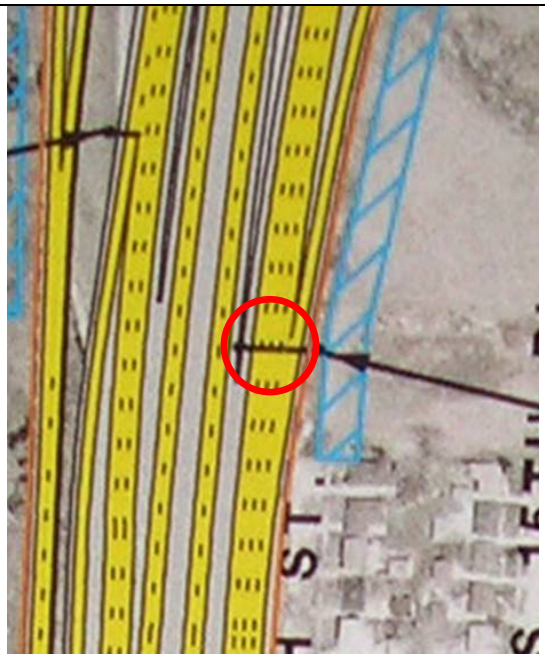
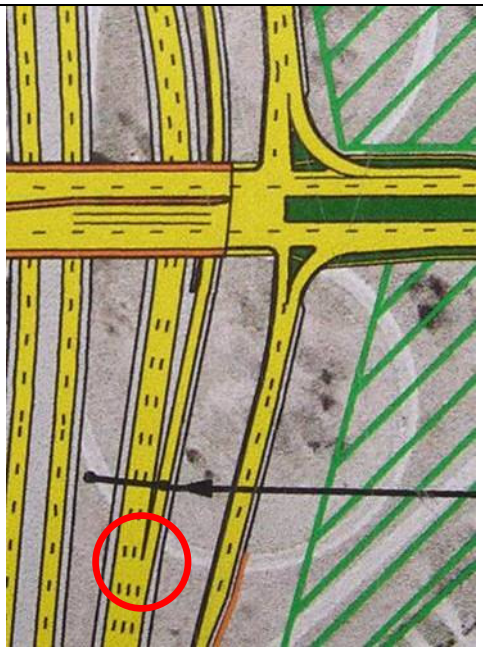
Expected Severity: low

Risk Rating: D (significant risk level)

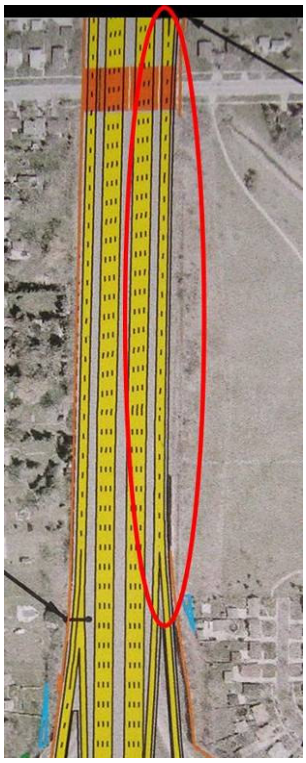
Opportunities for Improvement

Drop one lane at Layton Avenue instead of IH-94 Downtown Milwaukee

Consider a two-lane optional exit to Layton Avenue and a one-lane optional exit to IH-94 Downtown Milwaukee. A lane drop at Layton Avenue instead of IH-94 Downtown Milwaukee would reduce weaving by eliminating a necessary lane change.

	
Proposed design at Layton Avenue Exit	***Proposed Design at IH-94 Downtown Milwaukee Exit***

Safety Issue 3(c) Description:



Northbound ramps, north of College

A collector-distributer road provides a two-lane weave section between College Avenue and Airport Spur. Vehicles entering northbound IH-94 from College Avenue will join the collector-distributor road in the right lane. Vehicles exiting northbound IH-94 to Airport Spur will join the collector-distributer road in the left lane. These vehicles are required to weave between each other to travel in the necessary lane, whether it's to exit onto Airport Spur from IH-94 or merge onto IH-94 from College Avenue.

Expected Crash Types: weaving, rear-end collisions

Expected Frequency: occasional

Expected Severity: low

Risk Rating: C (moderate risk level)

Opportunities for Improvement

Provide a two-lane optional exit to Airport Spur

Consider providing a two-lane optional exit to Airport Spur. A two-lane optional exit would only require one-lane change, involving vehicles entering northbound IH-94 from College Avenue. This would result in eliminating the necessary lane change for vehicles exiting northbound IH-94 to Airport Spur. Decreasing the number of necessary lane changes, reduces weaving and the number of conflict points that may result in sideswipe or rear-end collisions.

5.4 Safety Issue 4: Queuing and Operations at Interchange Ramps and Ramp Terminals

Safety Issue 4(a) Description:

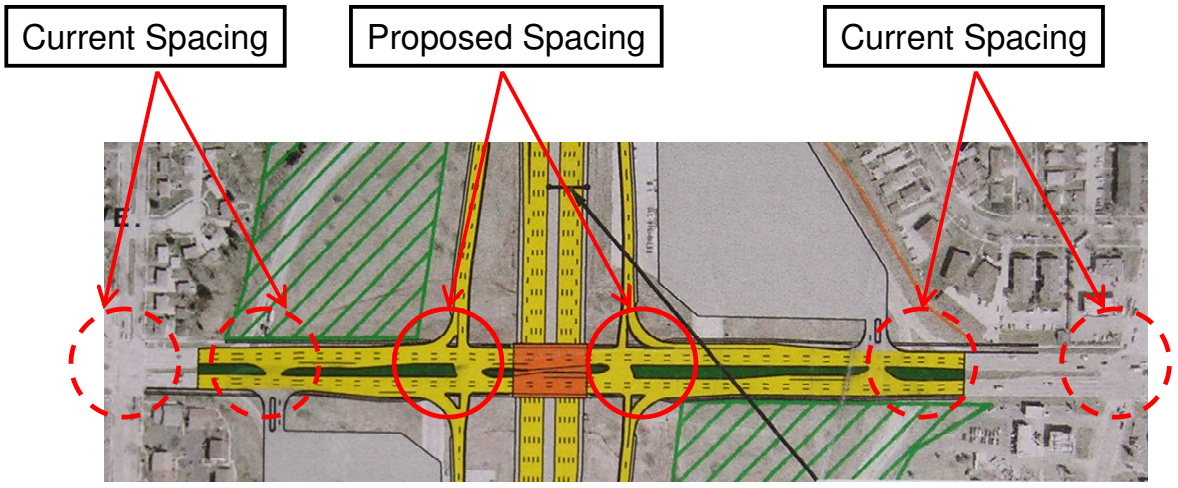
Tight diamond traffic operations

The tight diamond interchange design allows greater distance between the ramp terminal and the adjacent cross street, eliminating queues into the intersection. By providing greater spacing between the ramp terminal and the adjacent cross street, the proposed spacing between the signals at the ramp terminals are closely spaced *(shown below)*.

The proposed design provides limited space between tight diamond signals which may result in queues and congestion at the ramp terminals instead of the adjacent intersection. Queues may also back-up into the freeway resulting in sudden braking on a high-speed arterial, increasing the likelihood of rear-end collisions.

Synchro files were reviewed and some inconsistencies noted:

- Left-turn and right-turn volumes may have been transposed
- Level of Service “F” existed on some of the approaches
- Storage area geometrics did not match the proposed plans



Expected Crash Types: rear-end, weaving, left-turn, crossing collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

Opportunities for Improvement

Review Synchro files

Review Synchro files and results to ensure that tight diamond signal operations will be efficient and that queues from the turning lanes will not back into through lanes. Include all the affected nearby cross-street intersections in the Synchro analysis.

Improve ramp spacing

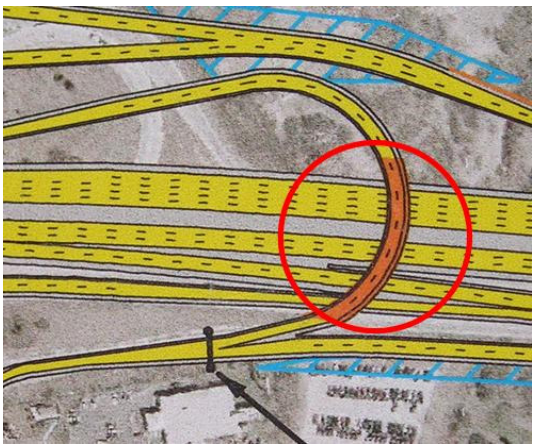
Consider improved spacing between ramp terminals by providing relatively equal spacing between the signals at the ramp terminals and between the ramp terminal and adjacent intersection. Improved spacing would improve safety and operations by reducing congestion and queues.

Also, provide adequate sight distances relative to vertical grades on bridges between intersections.

Safety Issue 4(b) Description:

27th Street westbound "U" on-ramp

A ramp meter will be provided on the westbound "U" on-ramp resulting in a queue on a bridge structure. The combination of a sharp horizontal curve, vertical curve, and super elevation may make it difficult for motorists to stop, particularly during adverse weather conditions.



Expected Crash Types: rear-end collisions

Expected Frequency: occasional

Expected Severity: negligible

Risk Rating: B (low risk level)

Opportunities for Improvement

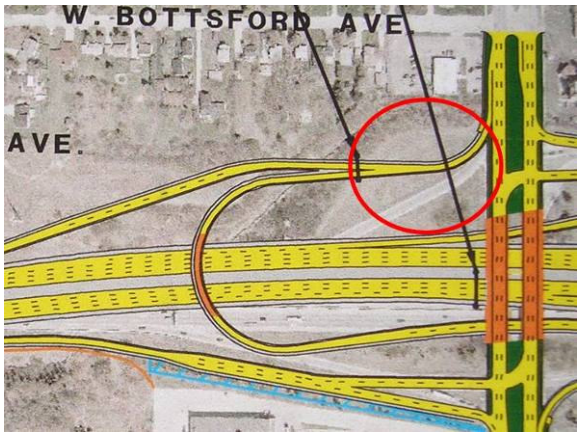
Consolidate on-ramps

Consider consolidating the two 27th Street on-ramps to westbound IH-43/894 and the two 27th Street on-ramps to eastbound IH-43/894. The combined merge further downstream from the "U" curve would avoid back-ups onto the curve, reducing the risk of rear-end collisions due to sudden stops in traffic. See also Safety Issue 2a.

High friction pavement

Consider high friction pavement on the "U" on-ramp. Higher friction pavement may decrease the chances of drivers losing control of the vehicle, especially on icy and wet pavement.

Safety Issue 4(c) Description:



Southbound 27th Street to IH-43/894 on-ramp

Vehicles on southbound 27th Street entering the on-ramp to merge onto IH-43/894 are faced with a decision point located about 100 feet after the sharp horizontal curve. The short distance may not provide drivers with sufficient time to read the guide signs, which may result in incorrect lane selection.

Expected Crash Types: rear-end collisions

Expected Frequency: occasional

Expected Severity: negligible

Risk Rating: B (low risk level)

Opportunities for Improvement

Relocate the split point further west

Increasing the decision time for drivers would provide more opportunity to determine the desired route. This would also reduce the potential for sudden braking and erratic maneuvers.

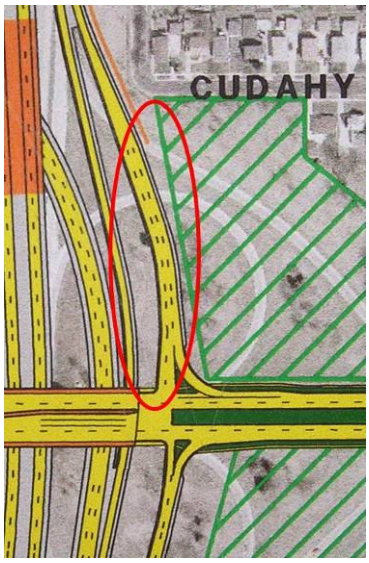
Safety Issue 4(d) Description:

Three-lane to one-lane merge

At multiple on-ramps along the corridor, three lanes merge into one lane. This may cause right-of-way confusion when ramp metering is off.

The three-lane to one-lane merge exist at the following on-ramps:

- Ryan Road northbound on-ramp
- Rawson Avenue northbound on-ramp
- Layton Avenue northbound on-ramp



Expected Crash Types: weaving, rear-end collisions

Expected Frequency: occasional

Expected Severity: negligible

Risk Rating: B (low risk level)

Opportunities for Improvement

Ramp meter at all times

Consider operating the ramp metering signals during all times at the three-lanes to one-lane merge locations (not just during peak periods). This will eliminate right-of-way confusion and decrease merging conflict points.

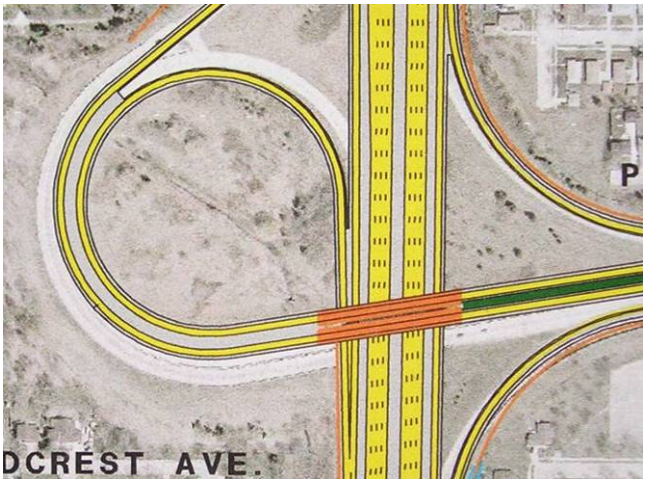
Successive merge

If metering is not implemented at all times, consider successive merging from three-lanes, to two-lanes, to one-lane.

Safety Issue 4(e) Description:

Tighter radius on Airport Spur Loop Ramp

The loop radius is being designed at a tighter radius. Currently there is a risk with the existing radius, apparent with the active speed warning sign. The replacement of the loop ramp with one having a tighter radius may increase the risk of crashes resulting from failure to follow the tight horizontal alignment and truck rollover crashes.



Expected Crash Types: off-road, rear-end collisions

Expected Frequency: occasional

Expected Severity: negligible

Risk Rating: B (low risk level)

Opportunities for Improvement

Review the feasibility of radius

Review the feasibility of maintaining the current radius or possibly improving it. Increasing the radius would improve driver comfort and operations.

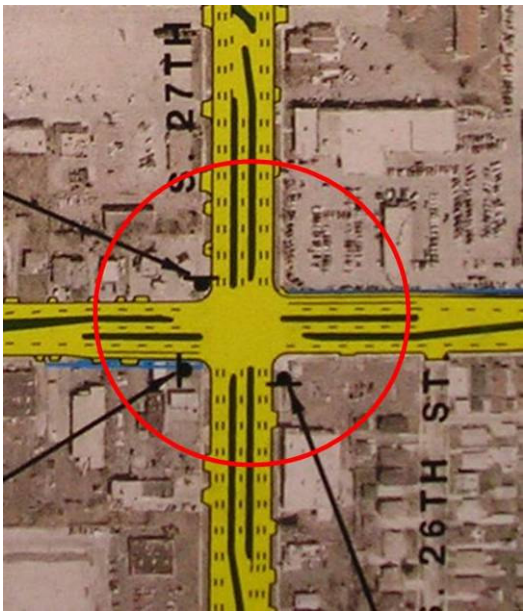
5.5 Safety Issue 5: Impacts on the Arterials: Layton Avenue and 27th Street

Safety Issue 5(a) Description:

27th Street and Layton Avenue Intersection

Layton Avenue and 27th Street will be expected to carry additional traffic volume, particularly for southbound left-turn and westbound right-turn movements. Capacity for these movements is not being expanded due to land use constraints.

Therefore, significant congestion is projected for the year of 2035, with many movements performing at a level of service "F".



Expected Crash Types: weaving, left-turn, crossing collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

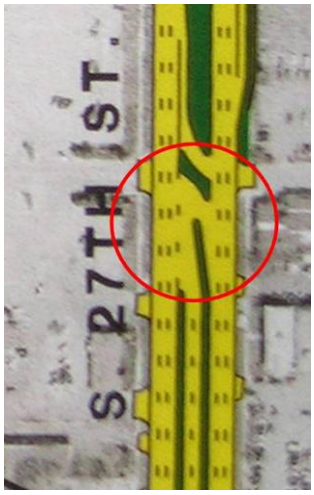
Opportunities for Improvement

Conduct operations and safety study

Conduct an operations and safety study along Layton Avenue between 35th Street and 13th Street, and along 27th Street between Carpenter Avenue and Bolivar Avenue. An operations and safety study would determine future congestion and delay along the Layton Avenue and 27th Street corridor. Improving operations by signal coordination and signal timing upgrades along the corridors would improve intersection operations and safety at Layton Avenue and 27th Street.

Safety Issue 5(b) Description:

Left-turn movements on 27th Street between Layton and IH-894



The storage in the northbound left-turn lane to the K-Mart shopping center gas been reduced. Volumes on 27th Street are projected to increase, resulting in the potential for left-turn queues backing into the through lanes due to inadequate left-turn storage lanes. Vehicles stopped in the through lanes will cause vehicles following them to brake suddenly and make erratic maneuvers, resulting in rear-end collisions. Delay may also increase drivers' decision in choosing inadequate gaps to turn left, resulting in an increase in left-turn collisions.

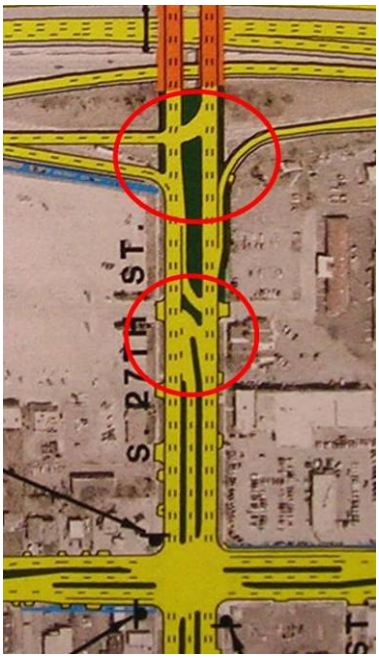
Expected Crash Types: left-turn, rear-end collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

Opportunities for Improvement



Restrict left-turn movements

Restrict left-turn movements into driveways where left-turn storage lanes are not adequate. Consider accommodating left-turn movements by exploring the potential of providing a roundabout at the south ramp terminal intersection on 27th Street and IH-43/894.

Consolidate driveways

Implement access management an access management strategy along the corridor by consolidating driveways where feasible. Consolidation of access locations within the study area will result in a reduction in congestion. Access management improvements would also improve safety by limiting turning movements to fewer locations. Access management improvements will increase safety by reducing the number of conflict points between 27th Street and the intersecting driveways.

Safety Issue 5(c) Description:

Layton Avenue and 26th Street intersection

Entry into the westbound dual left-turn lanes appears unconventional and difficult *(circled right).* Wrong way maneuvers may occur at the taper of the left-turn lanes. Vehicles turning left from 26th Street may conflict with traffic entering the left-turn lanes or with through traffic. These drivers may also unintentionally enter the left-turn lanes.

Drivers accessing 26th Street from Layton Avenue may also wait in the taper of the left-turn lane until an adequate gap exists. Queues may back into the through lanes which will cause vehicles following them to brake suddenly and make erratic maneuvers, resulting in rear-end collisions. Vehicles waiting in the taper will also interfere with vehicles entering the westbound dual left-turn.

Expected Crash Types: rear-end, weaving, left-turn collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

Opportunities for Improvement

Extend project limits

Extend project limits to the east of 26th Street to better rationalize lane alignment into the dual left-turn lane.

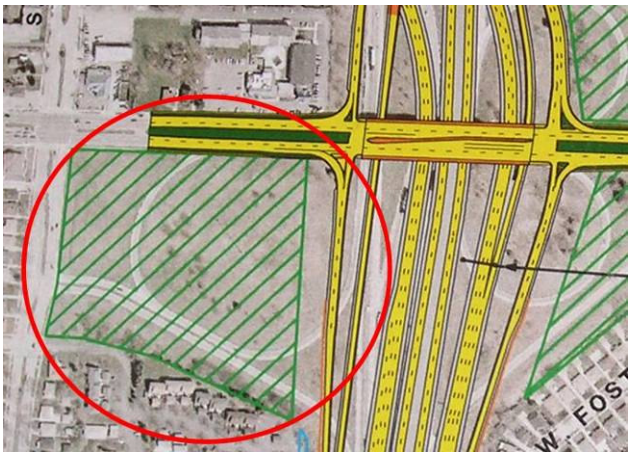
Consider closing left-turn access into 26th Street allowing right-in/right-out movements. Right-in/right-out control at 26th Street may be implemented to reduce conflict points by eliminating left-turn movements. Restricting left-turn movements significantly reduces the number of conflict points. This improvement option would need to include an analysis of traffic re-routing due to any left-turn movement restrictions.

Consider relocating the driveway access to the Dodge dealership, on the northeast corner, further east.

6.0 SAFETY NOTES

6.1 Note 1: Safety Impacts of Future Development at Layton Interchange

Future development at the Layton Avenue interchange could increase congestion and turning movements along Layton Avenue corridor, which currently experiences congestion.



Suggestions

- Define acceptable access locations and movements prior to sale of land.
- Include a safety assessment as part of development review.

6.2 Note 2: Accommodating Cyclists and Pedestrians at Tight Diamonds

Cyclists and pedestrians may be present at tight diamond interchanges, due to surrounding developments and future growth. Accommodating cyclists and pedestrians with adequate facilities is important to minimize the risk of crashes involving vulnerable road users.

Suggestions

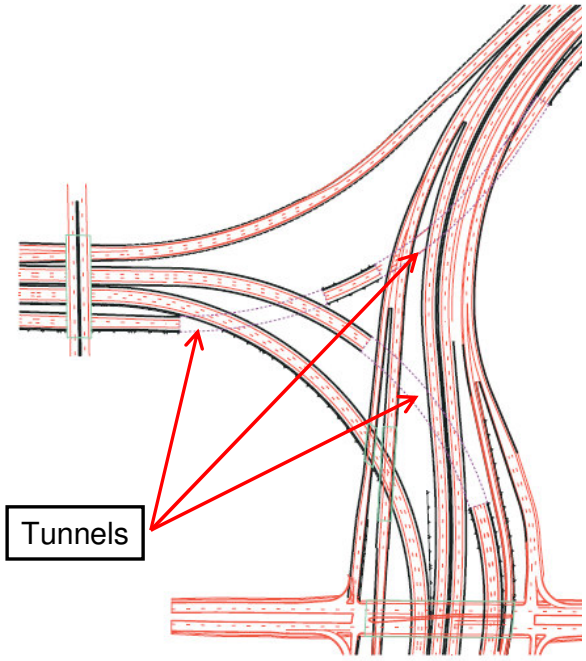
Review path continuity and facilities at Ryan Road, Drexel Avenue, Rawson Avenue, College Avenue, and Layton Avenue. The proposed design should include a complete and continuous network of sidewalks near all tight diamond interchanges. These improvements are expected to improve comfort and safety for non-motorized road users.

6.3 Note 3: Tunnel Safety

Tunnels are planned through the Mitchell Interchange area. Tunnels along horizontal curves have unique safety and operational characteristics. The following safety comments are provided for the consideration of the designers as the design of the tunnels progresses.

Suggestions

- Provide lateral and vertical space for directional, informational, regulatory and advisory signs, as well as work zone signs. Consider the need for overhead signs and the lateral placement of roadside signs when designing the tunnel dimensions.
- Implement continuous shoulder width through the tunnels to provide recovery room and refuge for vehicles who may exit the lanes along the horizontal curve.
- Consider lighting and contrast during daylight and night-time hours. The short gap between the two planned tunnel sections amplifies lighting concerns.



- Raised pavement markers may be implemented due to lack of snow in the tunnel. Raised pavement markers would improve lane conspicuousness and better guide drivers through the tunnel along a horizontal curve.
- Implement an incident management plan. The use of cameras would provide road agencies with traffic conditions necessary to improve tunnel operations and safety. Variable Message Signs prior to the tunnels are useful to inform drivers of unexpected events and lane closures in the tunnels.
- Discourage lane changes by implementing a solid white line through the tunnel.

6.4 Note 4: Draft Detour Plan – Preliminary Safety Comments

The following are preliminary safety-related notes on the draft detour plans. The draft detour plans were still at the early conceptual stage during the time of the audit.

- 2009: Howell Avenue and Grange Avenue intersection may experience extreme congestion and delay due to the detour traffic from Rawson Avenue to the Airport Spur. In particular, northbound left-turn lane capacity may be unable to accommodate left-turn volumes.
- 2010: An alternate route is not marked northbound to the Airport Spur.
- Avoid prohibiting, then permitting, then prohibiting movements at 27th Street. Consider upgrading Layton Avenue prior to 27th Street.

7.0 ROAD SAFETY AUDIT RELATED TO VALUE ENGINEERING STUDY

A Value Engineering (VE) study was conducted by Robinson, Strafford & Rude, Inc. from April 28 to May 2, 2008. A summary of the VE recommendations were provided to the RSA team. The RSA team reviewed each of these recommendations to determine whether it was in agreement, disagreement or whether the recommendation was not relevant to the RSA. The results of the VE review are summarized in TABLE 7.1. The safety benefits of the VE recommendations are discussed further in Section 7.1. A safety risk analysis and suggestions are provided where safety issues arose, in section 7.2.

TABLE 7.1 VALUE ENGINEERING REVIEW

Idea No.	Description	Agree	Disagree	Not Relevant
	Cross-section (C)			
C-5	Reduce median width to 28 ½ foot			√
C-18	Reduce center median to 22 ½ feet		√	
C-26	Use reinforced earth slopes instead of retaining wall type			√
C-27	Let contractor determine retaining wall type			√
C-39	Replace storm drains with ditches			√
C-42	Construct periodic emergency accesses between CD lanes and core lanes			√
C-43	Use 32" median barrier on Airport Spur			√
	Interchanges (I)			
I-3	Build 20th Street structure ahead of Mitchell interchange			√
I-6	Don't do anything to Airport Spur			√
I-7	Use 10 lane cross section instead of core collector system		√	
I-8	Extend touchdown west of 35th Street	√		
I-9	Provided 3 lanes in each direction for I-94 through Mitchell interchange		√	
I-16	Modify EB and WB ramp geometry at the bridge over the Canadian Pacific RR to move the ramp geometry off the bridge		√	
I-23	Increase radius from 894 to 94 to 60 mph design speed and basketweave SB connection			√
I-24	Extend touchdown north of Howard	√		
I-37	Provide 2-lane exit ramps on diamond interchanges for storage	√		
I-38	Move northbound major divergence to south of airport spur			√
I-45	Construct south Milwaukee County section as 1 prime contract			√
I-46	Use a major fork for 894 approaching Mitchell interchange			√
I-61	Put separate pedestrian crossing at/near 20th Street	√		

Idea No.	Description	Agree	Disagree	Not Relevant
I-66	Redesign N half of 27th Street interchange to avoid moving ATC towers	Reviewed & Rejected		
	Miscellaneous (M)			
M-6	Provide reflective lane markers (recessed studs) (plowable raised pavement markers)	√		
M-11	Reduce construction time to a minimum			√
M-12	Modify signals and lane marking in advance for planned alternative routes			√
M-28	Include incident management facilities for tunnels	√		
	Pavement Substructure (P)			
P-2	Eliminate 2" surface course and provide longitudinal tining	√		
P-10	Rubblize existing instead of removing			√
P-11	Rubblize and widen south of College			√
P-13	Use breaker run stabilization only where required			√
P-20	Match pavement section to traffic level			√
P-25	Use different design method other than Wis-pave			√
	Structures (S)			
S-1	Eliminate super-elevation transition from bridges		√	
S-2	Avoid slab bridges for main line			√
S-9	Don't replace Airport Spur bridges			√
S-15	Use jointless bridges			√
S-22	Revise high performance concrete specification			√
S-38	Reduce substructures with longer spans			√
S-40	Realign Layton slightly to south to allow construction of a new bridge prior to demolishing existing bridge	Reviewed & Rejected		
S-44	Re-deck and widen Airport Spur bridges			√

7.1 SAFETY BENEFITS RELATED TO VE STUDY

VE Recommendation I-8: Extend touchdown west of 35th Street

Refer to issue 2a: Extending the project limits would allow rationalizing the lane transitions, which are currently unworkable.

VE Recommendation I-24: Extend touchdown north of Howard

Refer to issue 1b: Extending the project limits north of Howard would allow opportunities to accommodate the projected volumes, by providing a four-lane cross-section. This would improve safety by reducing congestion and decreasing the number of lane changes.

VE Recommendation I-24: Provide two-lane exit ramps on diamond interchanges for storage

Refer to issue 4: A two-lane exit ramp may be provided at specific site locations to improve storage and accommodate queuing off of I-94.

VE Recommendation I-61: Put separate pedestrian crossing at/near 20th Street

A school is located north of IH-894 near 20th Street generating pedestrians in the area. To accommodate the pedestrians, a crossing is recommended to reduce the possibility of pedestrian related collisions.

VE Recommendation M-6: Provide reflective lane markers (recessed studs) (plowable raised pavement markers)

Refer to Note 3: Raised pavement markers would improve lane conspicuity and driver guidance, particularly during night-time or adverse weather conditions. This may result in a reduction of lane departure collisions.

VE Recommendation M-28: Include incident management facilities for tunnels

The use of cameras would provide road agencies with traffic conditions necessary to improve tunnel operations and safety. Variable Message Signs prior to the tunnels are useful to inform drivers of unexpected events and lane closures within the tunnels.

VE Recommendation P-2: Eliminate 2" surface course and provide longitudinal tining

Higher friction pavement may decrease the chances of drivers losing control of the vehicle, especially on icy and wet pavement.

7.2 ISSUES AND SUGGESTIONS RELATED TO VE STUDY

VE Recommendation C-18: Reduce center median to 22 ½ feet

Narrowing the paved shoulder would reduce the space provided for drivers to recover if they result in lane departures. The paved shoulder provides for recovery room and clearance for drivers that drift off the road. Narrowing the paved shoulder may result in an increase of fixed object and run-off the road collisions. Below is the risk assessment for this proposed modification to the design.

Expected Crash Types: fixed object and run-off the road collisions

Expected Frequency: frequent

Expected Severity: moderate

Risk Rating: E (high risk level)

VE Recommendation I-7: Use 10-lane cross-section

A ten-lane cross-section would increase weaving between heavy volumes of traffic north of the Airport Spur. The collector-distributer road reduces weaving and volume on the mainline. Providing a ten-lane cross-section may result in an increase in sideswipe and rear-end collisions. Below is the risk assessment for this proposed modification to the design.

Expected Crash Types: weaving, rear-end collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

VE Recommendation I-16: Modify EB and WB ramp geometry at the bridge over the Canadian Pacific RR

Modifying eastbound and westbound ramp geometry at the Mitchell Interchange over the Canadian Pacific Railroad may move merging and diverging traffic along a curve. Vehicles traveling through a curve may not anticipate vehicles joining the freeway. Vehicles joining or exiting the freeway may have difficulty merging into adjacent lanes to travel in the desired lane. Providing merging and diverging traffic along a curve may result in an increase in rear-end and sideswipe collisions. Below is the risk assessment for this proposed modification to the design.

Expected Crash Types: rear-end and sideswipe collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

VE Recommendation S-1: Eliminate super-elevation transition from bridges

Maximum super-elevation is functional on interchange ramps to prevent skidding and overturning of vehicles that have high centers of gravity[3]. Eliminating super-elevation on interchange ramps would increase skidding and truck roll-over crashes. Below is the risk assessment for this proposed modification to the design.

Expected Crash Types: fixed object and roll-over collisions

Expected Frequency: frequent

Expected Severity: low

Risk Rating: D (significant risk level)

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APPENDIX A

INTERCHANGE SPACING ANALYSIS

A1. SAFETY ASSESSMENT OF INTERCHANGE SPACING

A new tight diamond interchange has been proposed at Drexel Avenue to provide additional access between Ryan Road and Rawson Avenue for future development in the cities of Oak Creek and Franklin. To determine whether there is adequate spacing for a new interchange between Ryan Road and Rawson Avenue, a safety assessment of interchange spacing has been performed.

A safety performance function discussed in the *Safety Assessment of Interchange Spacing on Urban Freeways*[4] has been utilized to determine if any safety risks exist in implementing a new interchange. Results have been summarized in TABLE A-1.

The assessment is based on data from seven urban freeway sections, consisting of 95 interchanges, in California, and ten urban freeway sections, consisting of 100 interchanges, in Washington. A regression model was designed to determine total crash frequency and fatality/injury crash frequency as a function of highway characteristics, listed below:

- Annual Average Daily Traffic (AADT)
- Number of lanes
- Spacing, measured from crossroad to crossroad
- Ramp AADT
- Median Width

A2. RESULTS

TABLE A-1 INTERCHANGE SPACING RESULTS

	Road Segment	AADT	Lanes	Spacing	Ramp AADT	Med Width	Total Crashes	Injury & Fatality Crashes
Existing Interchange Spacing	Rawson to Ryan	139,000	8	3 miles	53,000	30.5 feet	112	33
Proposed Interchange Spacing	Rawson to Drexel	139,000	10	1 mile	21,000	30.5 feet	36	10
	Drexel to Ryan	130,000	8	2 miles	32,000	30.5 feet	71	20

Results have shown an overall reduction in crashes between Ryan Road and Rawson Avenue with the addition of a new interchange. A total of 107 crashes were calculated to occur between Rawson Avenue and Ryan Road with the implementation of an

interchange at Drexel Avenue. This results in 5 less crashes than the existing interchange spacing. The injury and fatality crashes also decrease.

A3. QUALIFIER

The interchange spacing utilized in this model is measured from crossroad to crossroad. The disadvantage is that the distance between the merging and diverging points of ramps is not considered which may have a major impact on safety. Other highway characteristics that may have an impact on the safety of interchange spacing and were not taken into consideration are:

- ramp lengths;
- horizontal and vertical alignment of ramps;
- horizontal and vertical alignment of freeway.

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APPENDIX B

INTERCHANGE CRASH PREDICTION ANALYSIS

B1. INTERCHANGE SAFETY ANALYSIS TOOL

All the interchanges along the study corridor are being redesigned. Tight diamond interchanges are being implemented to allow greater distance between the ramp terminal and the adjacent cross street, eliminating queues into the intersection. The redesign of the Mitchell Interchange utilizes right entrances and exits, eliminating the existing left entrances and exits. To determine whether the proposed interchange designs are safer than the existing interchange designs, a safety assessment of the interchange geometric design, traffic control features and performance has been performed. The *Interchange Safety Analysis Tool* (ISAT)[5], has been utilized to determine if any safety risks exist in implementing the new interchange design.

The assessment is based on interchange/ramp safety performance functions (SPFs) developed using data from existing safety knowledge and predictive relationships from previous and ongoing safety research of freeway locations. Highway characteristics included in the analysis are:

- Interchange inputs including area type, analysis years, crash data available
- Direction, length, number of lanes, ADT, ADT year, and growth rate of Mainline Freeway Segments
- Direction, type, configuration, length, ADT, ADT year, and growth rate of Interchange ramps and Acceleration lanes
- Traffic control, number of legs, ADT, ADT year, growth rate, and terminal type of Crossroad Ramp Terminals/Intersections
- Direction, length, number of lanes, presence of median, ADT, ADT year, and growth rate of Crossroad Roadway Segments

Results of the analysis include predicted crashes for the following:

- entire interchange area
- interchange element type (mainline freeway segments, ramps, ramp terminals/intersections, and crossroad segments)
- by year and by type

The comparison of existing ramp crashes and predicted ramp crashes have been summarized in TABLE B-1.

B2. RESULTS

TABLE B-1 INTERCHANGE DESIGN SAFETY RESULTS

Interchange	Existing Condition	Proposed Condition	Existing Crash Rate	Proposed Crash Rate	Expected Accident Frequency	Percent Change	Level of Confidence
Elm Road	2.4	1.7	0.645	0.291	3.76	55%	89%
Ryan Road	19.2	14.215	1.235	0.95	18.48	23%	80%
Drexel Ave.	-	1.545	-	0.249	-	-	-
Rawson Ave.	10.4	8.98	0.807	0.615	11.78	24%	<80% LOC
College Ave.	18	12.32	1.566	0.804	24	49%	99%
Airport Spur	5.8	12.265	0.544	0.611	10.92	-12%	<80% LOC
Mitchell	-	40.075	-	0.61	-	-	-
27th Street	4.6	5.27	0.438	0.39	5.91	11%	<80% LOC

Results have shown an overall reduction in ramp crashes at Elm Road, Ryan Road, and College Avenue with a level of confidence greater than 80 percent. Airport Spur showed an increase in crashes with a level of confidence less than 80 percent. This increase is likely due to the reduction in radius of the proposed loop ramp.

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- Road Safety Engineering
- Transportation Planning
- Traffic Operations
- Transit and Sustainability
- Community and School Safety
- Asset Management