WISCONSIN DEPARTMENT OF TRANSPORTATION

INTERSECTION SAFETY AUDIT: STH 16/67 AND CTH Z

OCONOMOWOC, WI

OPUS

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OCONOMOWOC, WI

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July 2008

H-U0011.07

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1.0 INTRODUCTION

1.1 Background

The Wisconsin Department of Transportation (WisDOT) has requested a Road Safety Audit be performed for the intersection of STH 16/67 and CTH Z in Oconomowoc, WI. A new school and YMCA are planned for the northwest corner of this intersection. Several new subdivisions are currently being constructed on the northeast and southeast corners of the intersection. These new developments are expected to generate substantial non-motorized traffic crossing STH 16/67 at the intersection. WisDOT has retained Opus International Consultants to conduct a safety audit to identify possible safety enhancements to this intersection to address these concerns. .

1.2 Study Location

The intersection of STH 16/67 and CTH Z is a four-legged intersection located on the western edge of the Milwaukee metropolitan area in Waukesha County. The intersection is located on the northeast side of Oconomowoc on the Oconomowoc Bypass. North of the intersection, the Oconomowoc Bypass is fully access controlled with no at-grade intersections. The land use near the study intersection is a mix between residential, academic and rural and is rapidly changing. The study intersection is shown in FIGURE 1.1.

FIGURE 1.1 STUDY INTERSECTION

1.3 Study Objectives

The objectives of this study are to:

- review traffic operations and safety at the intersection;
- identify physical and operational problems that may affect traffic safety;
- develop and evaluate potential countermeasures to reduce the frequency and severity of collisions.

1.4 Methodology

The safety review has been conducted based on the following reviews or analyses:

Kick-off Meeting: A meeting was held on March 26, 2006 with all of the project stakeholders to discuss the project. At this information sharing meeting, the perceived issues were discussed, which included specific constraints that will affect possible mitigation measures.

Site Visit: Site visits were conducted on March 26 and 27, 2008 in order to become familiar with the intersection geometry, adjacent land use, and to observe traffic operations.

Traffic counts: WisDOT provided two sets of 12-hour turning movement counts for the study intersection. Turning movement counts were collected Monday December 4, 2006 (AM peak) and Wednesday December 6, 2006 (PM peak).

Speed Study: WisDOT conducted a speed study on February 23, 2006 to calculate the 50^{th} and 85^{th} percentile speeds on STH 16/67 near CTH Z.

Review of Intersection Geometry: Intersection geometry was reviewed, including recent and planned intersection upgrades.

Review of Crash Data and Analysis of Crash Trends: MV4000 crash reports were provided by WisDOT for the years 2005 to 2007.

Signal Warrant Study: A traffic signal warrant study using the process outlined in the *2003 Manual of Uniform Traffic Control Devices: Wisconsin Supplement* was conducted. This study was used to identify the need for a traffic signal.

Identification of Countermeasures: On the basis of the above tasks, intersection safety issues and collision causes were identified. Mitigation measures were identified to address the safety issues and collision causes, along with collision reductions that are anticipated to result from their implementation.

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2.0 INTERSECTION CHARACTERISTICS

2.1 Roadway Characteristics

TABLE 2.1 INTERSECTION CHARACTERISTICS

CHARACTERISTIC	STH 16/67	CTH Z	PHOTO
Functional Classification	Principal arterial	Minor arterial	--
Jurisdiction	WisDOT	East Leg: Waukesha County West Leg: City of Oconomowoc	
Laning	▪ Two Through Lanes ▪ One slotted left-turn lane ▪ One right-turn lane	▪ One through/left Lane ▪ One right-turn lane	
Posted Speed Limit	45 mph North of the Intersection: 55 mph	East Leg: 35 MPH West Leg: 25 MPH	--
Influences	▪ Oconomowoc Bypass ▪ Proposed Clark Farm Intermediate School ▪ Proposed YMCA ▪ Several new subdivisions		 *Clark Farm School*

CHARACTERISTIC	STH 16/67	CTH Z	PHOTO
Accesses	Fully access controlled	Accesses for the subdivisions and the proposed school and YMCA are provided.	 *Northbound Approach*
Paving	Concrete	Asphalt	
Guide Signing	Multiple trailblazing signing assemblies are located around the intersection.		
Horizontal Alignment	Straight		

CHARACTERISTIC	STH 16/67	CTH Z	PHOTO
Vertical Alignment	Slight gradient on the northbound approach	Level	 *Looking Southbound*
Non-Motorized Facilities	None	East Leg: sidewalks on both sides end before STH 16/67 West Leg: sidewalk on the south side of CTH Z ends before STH 16/67	 *Sidewalk on the west leg*

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3.0 TRAFFIC OPERATIONS

The intersection currently operates under two-way stop control with the stop movement on CTH Z. Traffic on CTH Z crossing STH 16/67 is required to Yield in the median.

3.1 Traffic Volumes

Traffic count data is summarized in TABLE 3.1.

TABLE 3.1 TRAFFIC VOLUMES

APPROACH	Existing			Projected (2008+Trip Generation)	
	VOLUME (veh/hr)	PEAK HOUR	AADT	VOLUME (veh/hr)	PEAK HOUR
Northbound	646	5:00 PM to 6:00 PM	4,870	672	5:00 PM to 6:00 PM
Southbound	467	7:00 AM to 8:00 AM	4,160	486	7:00 AM to 8:00 AM
Eastbound	33	7:00 AM to 8:00 AM	750	98	7:00 AM to 8:00 AM
Westbound	180	5:00 PM to 6:00 PM	1,950	187	5:00 PM to 6:00 PM

The results of the turning movement count of the existing and proposed conditions are shown in FIGURE 2.1. No pedestrian volumes were recorded at any time during any of these hours. However, the proposed school, YMCA and subdivisions are expected to generate significant pedestrian volumes. The highest traffic volumes are the through movements on STH 16/67. The following movements are expected to increase in volume once the school opens:

Morning Drop-off

- Northbound left turns
- Southbound right turns
- Westbound through

Afternoon Dismissal

- Eastbound left-turns
- Eastbound throughs
- Eastbound right-turns

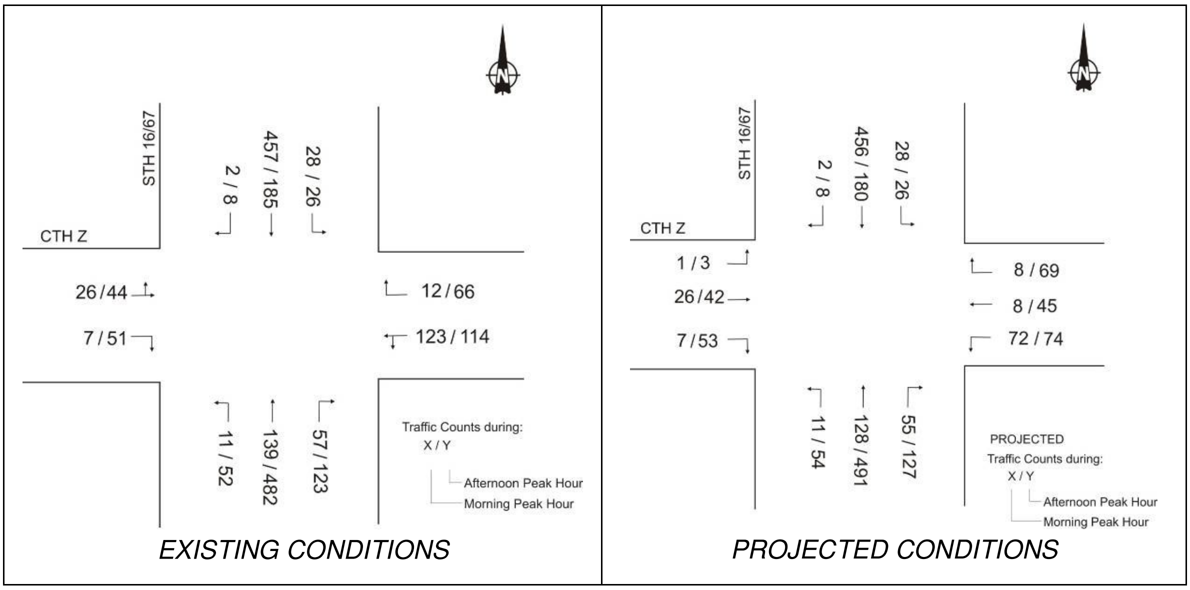

FIGURE 3.1 TRAFFIC COUNTS

3.2 Traffic Operational Analysis

A traffic operational analysis was performed to analyze the existing conditions using Synchro. The existing and proposed levels of service (LOS) are illustrated in FIGURE 3.2 for both morning and afternoon peak periods. Synchro output reports are provided in APPENDIX B. As can be seen in FIGURE 3.2, traffic on STH 16/67 currently operates at a LOS A for both the morning and afternoon peak hours. The westbound through/left turn movements currently operate at a LOS D during the afternoon peak hour.

If no change to the intersection traffic control are implemented after the school and YMCA open, the LOS for eastbound through/left is expected to decrease from C to F in the morning and C to E in the afternoon. The westbound through/left movement is expected to decrease from a LOS C to F in the morning. The westbound through/left movement is expected to decrease from LOS D to F in the afternoon. No significant additional delay is expected on STH 16/67.

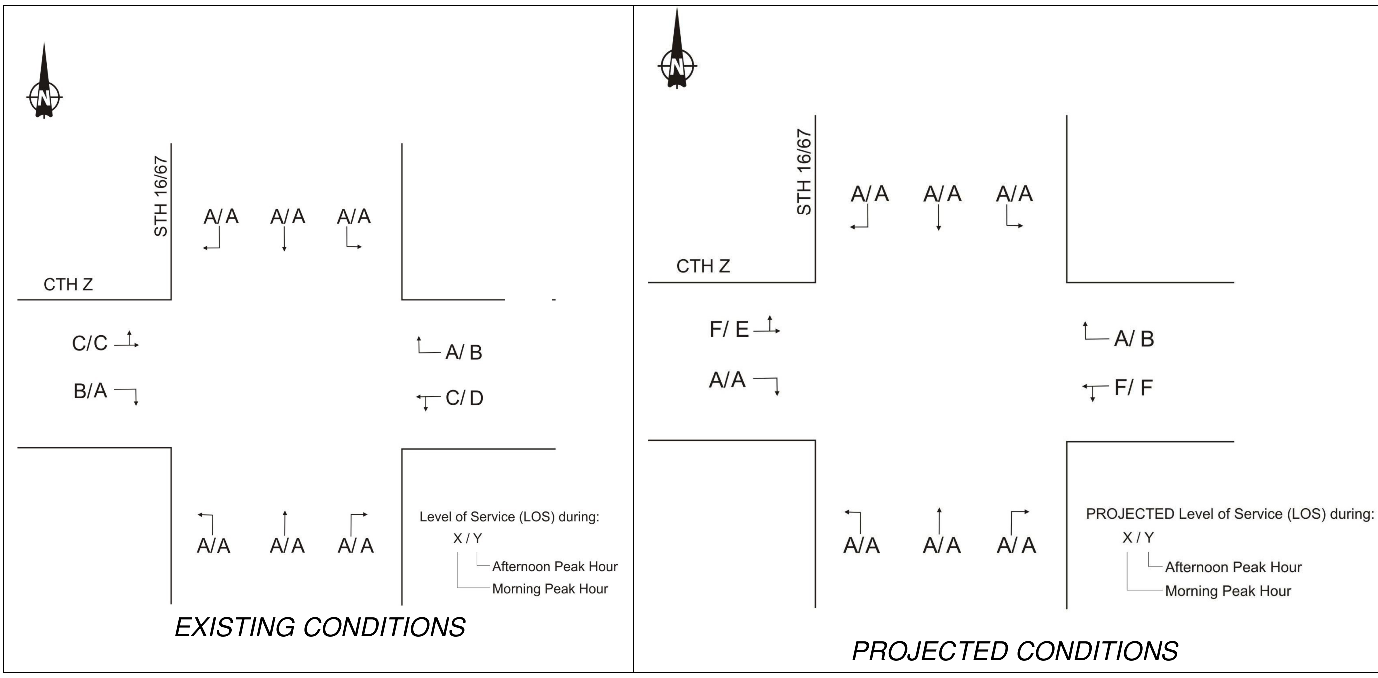

FIGURE 3.2 TRAFFIC OPERATIONS ANALYSIS

3.3 Speed Study

WisDOT provided vehicle speeds on STH 16/67 which were conducted as part of a speed study. The speed limits, 50th and 85th percentile speeds are listed below in TABLE 3.1.

Posted Speed Limit (MPH)	OBSERVED SPEEDS (MPH)			
	50th Percentile Speeds		*85th Percentile Speeds*	
	Northbound	***Southbound***	***Northbound***	***Southbound***
45	47.1	47.7	51	51

TABLE 3.2 VEHICLE SPEEDS

The speed limit drops from 55 mph to 45 mph for southbound traffic just north of the intersection. The 85th percentile speeds for both northbound and southbound STH 16/67 are 6 mph higher than the posted speeds at the intersection. The 51 mph 85th percentile speed indicates that vehicles are successfully lowering their speeds as they transition from the fully access controlled section of the Oconomowoc Bypass into a section with at-grade intersections. The 6 mph difference on the northbound approach is likely due to the downward gradient.

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4.0 COLLISION ANALYSIS

Police collision reports (MV4000) for 2005 through 2007 were reviewed as part of this study. Over these three-years, five collisions were recorded at or near the intersection. As summarized in TABLE 4.1, one fatality and one injury occurred at the intersection. The remainder of the collisions involved property damage only.

TABLE 4.1 COLLISION DETAILS

Date	Time	Injury Resulting		Summary
		Unit 1	Unit 2	
November 2, 2005	9:05 AM	PDO	C-Level	On a dry, clear, day Unit 1 disregarded a stop sign on CTH Z causing Unit 2 to swerve to avoid a crash, resulting in Unit 2 hitting a traffic sign.
December 19, 2005	5:11 PM	PDO	PDO	Unit 1, headed west on CTH Z, failed to yield the right of way to Unit 2, headed north on STH 16/67. Unit 1 was subsequently struck by Unit 2.
December 24, 2005	4:28 AM	PDO	PDO	Unit 1, headed east on CTH Z, failed to yield the right of way to Unit 2, headed north on STH 16/67. Unit 1 was subsequently struck by Unit 2.
February 10, 2006	7:20 PM	Fatality	PDO	Unit 1, traveling west on CTH Z failed to stop for a stop sign and was struck by Unit 2, traveling North on STH 16/67.
June 17, 2007	10:20 AM	C-level	C-level	Unit 1, headed east on CTH Z, failed to yield the right of way to Unit 2, headed north on STH 16/67. Unit 1 was subsequently struck by Unit 2.

A collision diagram illustrating the spatial distribution of the collisions is shown in FIGURE 4.1.

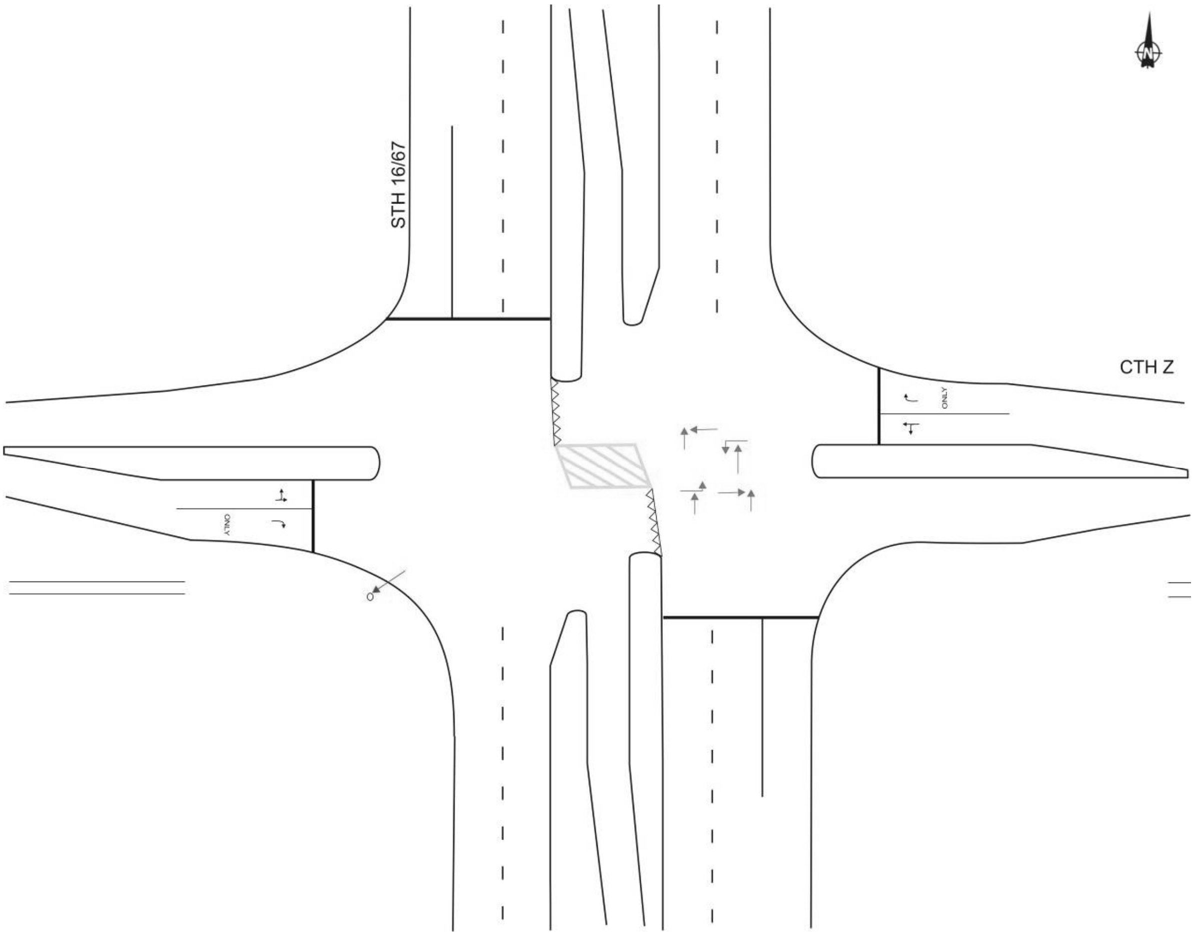


FIGURE 4.1 COLLISION DIAGRAM

5.0 Existing Safety Measures

Positively Offset Left-Turn Lanes on STH 16/67

Slotted positively offset left-turn lanes have been provided for drivers on STH 16/67 at CTH Z. The positively offset left-turn lanes provide enhanced sight distance of oncoming traffic by locating the left-turn lane to the left of the opposing left-turn lane. This eliminates any blocking of the oncoming through traffic by the opposing left-turn lanes.

Left-turn lane on northbound STH 16/67

Advance Street Name Signs

Advanced street signing is currently provided for on all of the intersection's approaches. These signs provide additional guidance for unfamiliar and older drivers. The advanced street signing helps drivers locate lanes they need to be in prior to the intersection, reducing lane changes close to the intersection. The oversized signing on STH 16/67 approaches provides enhanced guidance to approaching drivers on these high speed approaches.

Intersection Warning Signs

STH 16 is a fully access controlled roadway between IH-94 and the Jefferson County line other than this short section. The intersection warning signs on STH 16/67 help to inform drivers they are approaching an at-grade intersection which is inconsistent with the rest of the corridor. Research by the Missouri DOT has found the use of intersection warning signs to reduce crashes by 40%.

Rumble Strips

Shoulder rumble strips are widely used on freeways and expressways throughout Wisconsin. The use of shoulder rumble strips on STH 16/67 reduces the risk of run-off-road single vehicle run-off-road crashes.

Lighting

Lighting has been provided at the intersection of STH 16/67 and CTH Z. Lighting improves intersection conspicuousness, so that approaching drivers are more aware of the intersection and the potential for conflicting movements. Lighting also improves the visibility of other road users, including pedestrians and bicyclists, at night.

6.0 SAFETY ISSUES

On the basis of the reviews summarized in Sections 2 through 4, issues affecting traffic safety have been identified. These issues are summarized in FIGURE 5.1 and discussed below. Mitigation measures are discussed in Section 6.

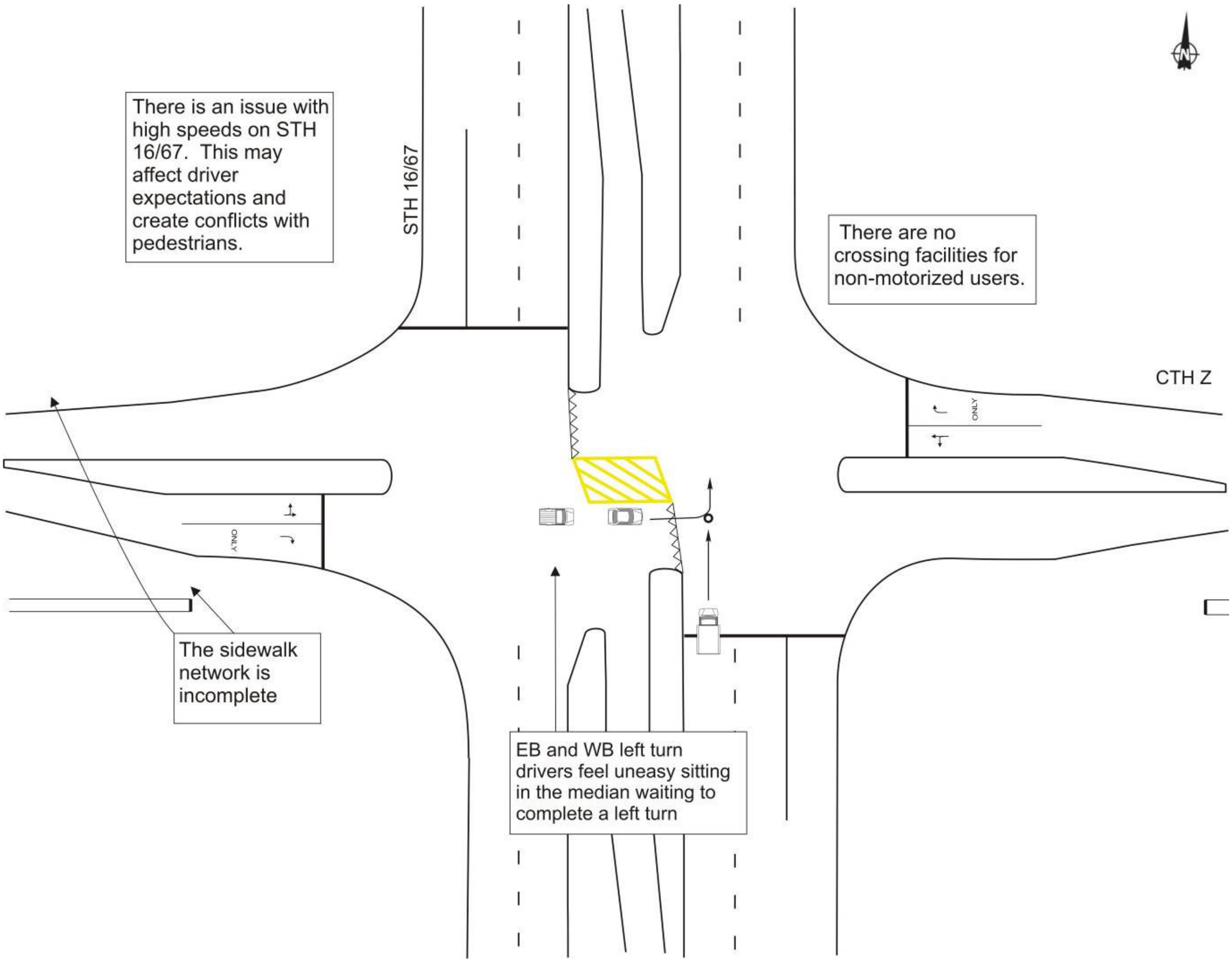


FIGURE 6.1 SAFETY ISSUES

6.1 Issue 1: Non-Motorized Road Users

In September 2008, a new middle school is scheduled to open on the northeast quadrant of the intersection. A YMCA is also scheduled to open in early 2009. The nearby residential subdivisions are expected to generate substantial numbers of younger non-motorized road users. As this is a middle school many of these non-motorized road users are expected to be walking or bicycling across STH 16/67 will be between the ages

11 and 14 years old. There are currently no pedestrian or bicycle facilities at this intersection as it was part along a high-speed bypass. The existing sidewalks adjacent to CTH Z terminate prior to the intersection.

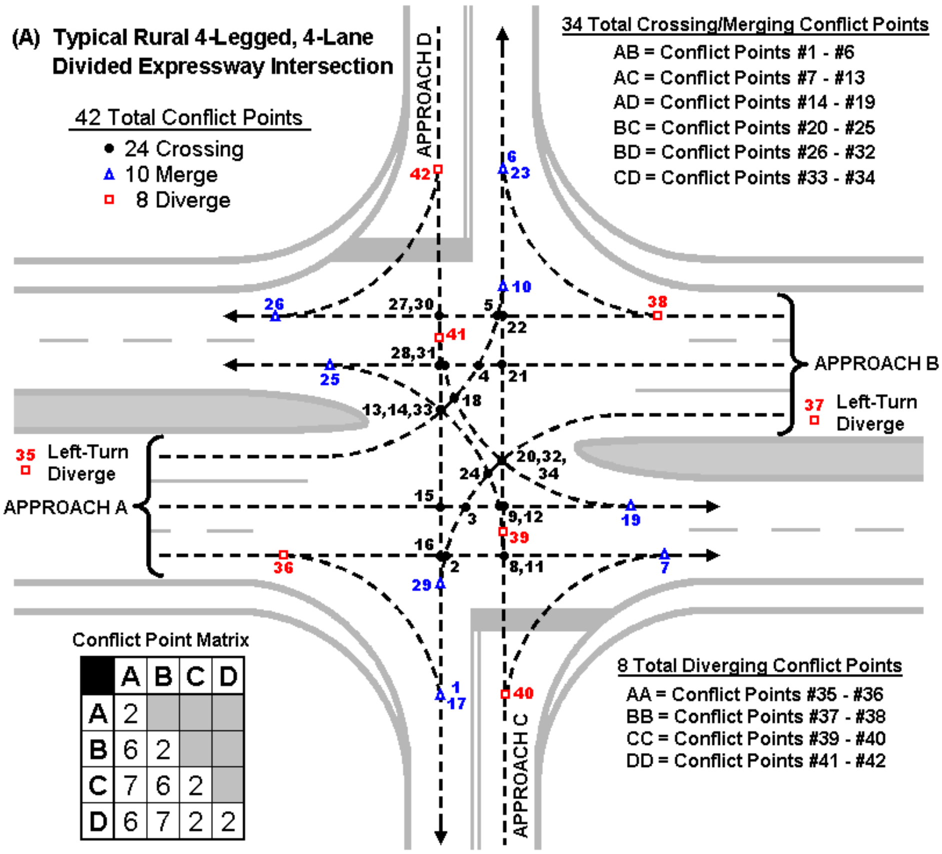
Younger pedestrians are typically more inexperienced and have a high propensity to take risks. These inexperienced pedestrians may choose inadequate gaps as they are not as good at judging approach speeds. In addition, as is shown in the photo on the right, younger road users also will make risky maneuvers as a means to “show off.”

6.2 Issue 2: CTH Z Approaches

There are multiple conflict points associated with making a direct left-turns onto STH 16/67 from CTH Z. This intersection involves an unprotected left-turn across multiple lanes of opposing or crossing traffic. The risk and potential severity of left-turn crashes is aggravated by:

- high speeds on STH 16/67;
- a high proportion of truck traffic (with slower acceleration and braking capabilities) which is the primary truck route around Oconomowoc;
- the presence of young and inexperienced non-motorized road users;
- winter road conditions (contributing to poor acceleration and braking capabilities).

FIGURE 6.1 illustrates a conflict diagram for the typical four-leg the intersection. A total of 42 conflict points exist for this type of intersection configuration. Drivers who misjudge the gaps required to turn left or cross increase the risk of a higher severity rear-end or angle crash with through vehicles traveling at high speeds.



	A	B	C	D
A	2			
B	6	2		
C	7	6	2	
D	6	7	2	2

FIGURE 6.2 INTERSECTION CONFLICT POINTS[1]

6.3 Issue 3: Speeds on Bypass

The speeds on the bypass appear to be higher than the posted speed limit. Currently the speed limit on the Oconomowoc Bypass is set at 45 mph, but based on the design and the appearance of the roadway the driver expectation of the speed limit seems to be higher. STH 16/67 has the look and feel of a freeway. As a result, drivers were observed travelling through the intersection at high speeds. The 85th percentile speed of 51 mph is likely due to the active presence of law enforcement, from multiple jurisdictions, work this intersection daily.

[1] Maze, T., NCHRP 15-30 Median Intersection Design for Rural High-Speed Divided Highways, Draft Report and Powerpoint Presentation, Transportation Research Board (2008).

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7.0 Mitigation Measures

To address the issues that have been discussed in Section 6, mitigation measures have been identified. The proposed measures are summarized in FIGURE 7.1, and discussed below.

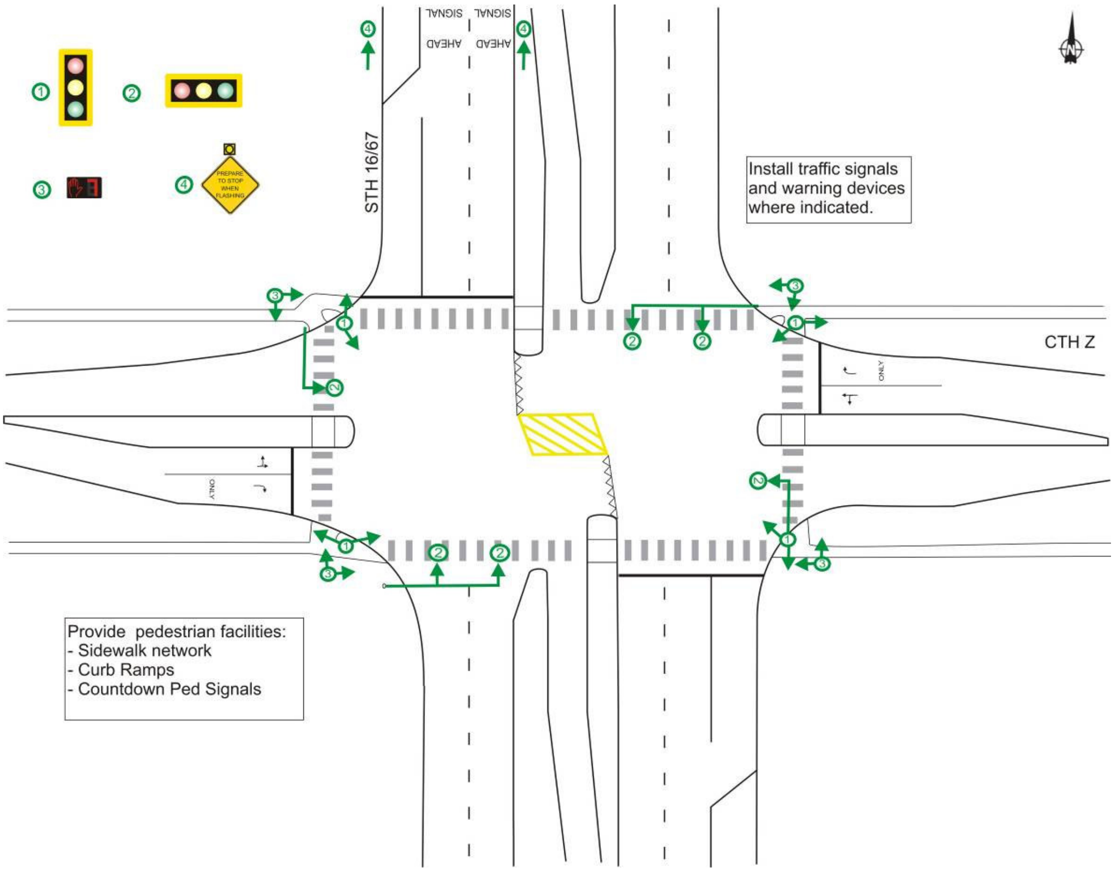

FIGURE 7.1 PROPOSED MITIGATION MEASURES

7.1 Near Term Mitigation Measures

Installation of a Traffic Signal

Based on the results of the analyses, it is suggested that WisDOT consider installing a fully operational traffic signal for this intersection. It is expected that pedestrian volumes of school children will exceed 20 pedestrians per hour. This traffic signal will help to provide gaps for pedestrians to cross STH 16/67.

Pedestrian Countdown Signals

Pedestrians (particularly younger pedestrians) may unintentionally enter the crosswalk with an insufficient amount of clearance time remaining. A pedestrian countdown display *(right)* may be added to a pedestrian signal head to accurately inform pedestrians of the time remaining in the pedestrian clearance interval, so that they can complete their crossing before conflicting traffic starts up.

Two concerns about countdown signals include pedestrian confusion over the meaning of the countdown display, and the potential for motor vehicle drivers to inappropriately use the countdown display. Recent evaluations of countdown signals[2] indicate that pedestrians have an adequate understanding of the display, and that the displays do not have a negative impact on driver behavior. Guidance on timing the pedestrian countdown display is provided in Section 4E.07 of the MUTCD. FHWA is currently proposing that countdown pedestrian signals be installed at all locations with pedestrian signals.

Advance Warning Flasher

In conjunction with a new signal, an advance warning flasher should be considered for the southbound approach of STH 16/67. The advance warning flasher should utilize the message "PREPARE TO STOP WHEN FLASHING." These devices have been found to be extremely effective at locations where drivers are transitioning from a high speed access controlled expressway into an area with at-grade signalized intersections. This advance dilemma zone warning device has been found to reduce traffic fatalities and injuries by 39 percent[3] at rural high speed intersections. While some drivers may increase their speeds right when the device starts flashing, the majority of drivers have been found to be more aware of the signal. These devices can be installed either overhead or post mounted. Examples of the two types of mountings are shown below on the following page.

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[2] including Botha et al, *Pedestrian Countdown Signals: An Experimental Evaluation* (San Jose State University and City of San Jose Department of Transportation, 2002); Eccles et al, *Evaluation of Pedestrian Countdown Signals in Montgomery County MD* (Compendium of Transportation Research Board Annual Meeting, 2004)

[3] Bahar et al, *Desktop Reference for Crash Reduction Factors,* Federal Highway Administration, 2007.

Overhead Mounting

Post Mounting

FIGURE 7.2 ADVANCE WARNING FLASHER MOUNTING OPTIONS

Signal Ahead Pavement Markings

To supplement the advance warning flasher it is suggested that "SIGNAL AHEAD" pavement markings be considered. Warning messages on the pavement have been found to be effective in drawing attention to hazardous situation and are meant to supplement other traffic control devices.

Adult Crossing Guard

Adult crossing guards help to provide gaps for and assist school children cross the street. It is suggested that adult crossing guards be considered for this intersection. If adult crossing guard supervision is utilized, it is suggested that two adult crossing guards be posted at this intersection due to the width and that it is a two-stage crossing.

High Visibility Crosswalks

High visibility crosswalks should be considered for this location. High visibility crosswalks which utilize the ladder or zebra style striping are more visible to approaching drivers.

Sidewalks

Filling in the gaps on the sidewalk network should also be considered to accommodate pedestrians at this intersection. Sidewalks should also be considered along the north side of CTH Z adjacent to the proposed school. Sidewalks will help to define the path which pedestrians are encouraged to take when accessing the school.

7.2 Longer Term Options

The following longer term options for improving the safety of this intersection may be considered as part of the larger corridor study which is proposed for STH 16/67.

J-Turn

It is suggested that the J-turn intersection configuration near intersections where vehicles would make a direct left-turn on to STH 16/67. The J-Turn intersection configuration was has been implemented by the State DOTs including Florida, Iowa, Maryland, Michigan, Missouri and North Carolina at at-grade intersections on high speed expressways and bypasses. FHWA has also been promoting the concept using the term “Superstreet Intersection.” Under a J-Turn configuration, direct left-turn movements would be allowed from STH 16/67 while cross traffic would have to make a right-turn followed by a U-turn. This is a similar treatment to what was recently applied on the USH 151 Bypass in Fond du Lac, but also includes median u-turn crossovers.

The J-turn configuration reduces the total number of intersection conflicts from 42 to 24. Of the conflict points which are eliminated, cross street left-turn and crossing conflicts which are those typically result in high severity angle crashes. These have been replaced with additional merge and diverge conflict points associated with the right-turn and u-turn movements which typically result in less severe crashes.

The J-turn configuration is considered an interim measure between allowing direct left-turns and an interchange. An Example of the layout of an intersection with Median U-turns/J-turns is shown in FIGURE 7.3. FIGURE 7.4 illustrates an effective guide sign which the Michigan Department of Transportation utilizes at these types of intersections.

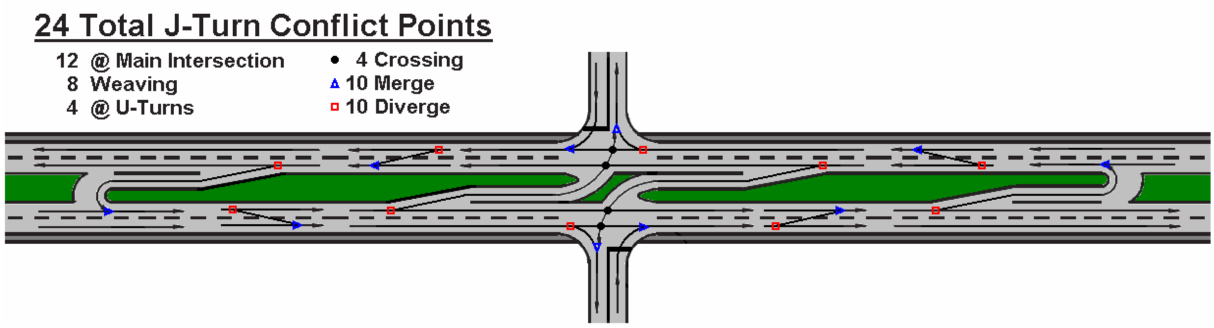


FIGURE 7.3 J-TURN INTERSECTION CONFIGURATION WITH CONFLICT POINTS

FIGURE 7.4 J-TURN GUIDE SIGNING[4]

Roundabout

Roundabouts have been found to reduce delays and are effective in transitioning drivers from one type of facility to another. The use of the roundabouts this location would provide a physical transition from the high speed access controlled expressway to this segment with at-grade intersections. Providing a roundabout at this location is expected to improve safety by reducing the number of conflict points and result in a high reduction of severity of all crashes.

[4] Jagannathan , R., *Synthesis of Median U-Turn Intersection Treatment, Safety and Operational Benefits*, Federal Highway Administration, Washington, DC, FHWA-HRT-07-033 (2007).

Interchange

The use of grade separation reduces the potential for high-speed conflicts associated with at-grade intersections. An interchange will provide design consistency for STH 16 both to the west of this intersection and to the east of the STH 16/67 and Lisbon Road intersection. An interchange will also physically separate the pedestrians from the high speed traffic on STH 16/67.

Grade Separated Pedestrian Crossing

A grade separated pedestrian crossing would be an effective means of physically separating the pedestrian traffic from the high speed traffic on STH 16/67. In addition to the high cost of these bridges, many pedestrians have been found to not use them if there is an alternate path which does not involve walking up the long ramps. The most effective grade separated pedestrian crossings utilize an extensive system of fencing to channelize pedestrians to the bridge.

Pedestrian underpasses have been found to be not as effective as overpasses. Pedestrians have been found to be concerned for their personal safety when using underpasses.

APPENDIX A:

TRAFFIC SIGNAL WARRANT STUDY

TRAFFIC SIGNAL WARRANT ANALYSIS WORKSHEET

Sheet 1

Intersection:	STH 16/67 & CTH Z		Date:	July 24, 2008		
County:	Waukesha					
Town	N/A					
Village	N/A					
City	Oconomowoc					
Major Street	STH 16/67	Critical Approach Speed	45 mph		Lanes	4
Minor Street	CTH Z	Approach Speed	35 mph		Lanes	2

Volume Level

1. Critical speed of major road traffic > 40 mph : ☒ Yes ☐ No
2. In built-up area of isolated community of < 10,000 pop.: ☐ Yes ☒ No

If Question 1 or 2 above is answered "Yes" then use "70%" volume level: ☒ 70% ☐ 100%

WARRANT 1 – Eight-Hour Vehicular Volume

Warrant is satisfied if Condition A or B is "100 % satisfied." Warrant also satisfied if Condition C (80% of A and B) is satisfied.

	8 Highest Hours							
Hour	4	5	7	6	3	8	2	1
Major Road Both App. vph	886	876	757	694	596	568	510	429
Minor Road High App. vph	122	114	140	123	80	99	87	79

Record hours where condition is met and the corresponding volumes in boxes provided. Condition is 100% satisfied if the minimum volumes are met for eight hours.

Condition A – Minimum Vehicular Volume

(volumes in veh/h)	Minimum Requirements (80% Shown in Brackets)			
Approach Lanes:	1		2 or more	
Volume Level:	100%	Hours	100%	Hours
Major Road-Both Approaches	**350**		**420**	8
	(280)		**(335)**	8
Minor Road-Highest Approach	**105**	4	**140**	
	(85)	6	**(110)**	

100% Satisfied: NO
80 % Satisfied: NO

Condition B – Interruption of Continuous Traffic

(volumes in veh/h)	Minimum Requirements (80% Shown in Brackets)			
Approach Lanes:	1		2 or more	
Volume Level:	100%	Hours	100%	Hours
Major Road-Both Approaches	**525**		**630**	4
	(420)		**(505)**	7
Minor Road-Highest Approach	**50**	8	**70**	
	(40)	8	**(55)**	

100% Satisfied: NO
80 % Satisfied: NO

Condition C – Combination of Condition A and B: Condition A and B Both 80% Satisfied?: NO

Warrant Satisfied?: NO

% Right Turns Included: 100

TRAFFIC SIGNAL WARRANT ANALYSIS WORKSHEET

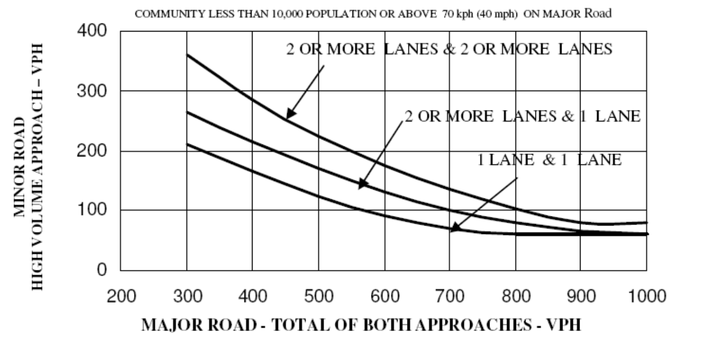
Sheet 2

Warrant 2 – Four-Hour Vehicular Volume

Plot four volume combinations on the applicable figure below. If four points lie above the appropriate line, then the warrant is satisfied.

Figure A. Criteria for "70%" volume level.

Hour	4	5	7	6
Major Vol.	886	876	757	694
Minor Vol.	122	114	140	123



* NOTE: 80 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR ROAD APPROACH WITH TWO OR MORE LANES AND 60 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR ROAD APPROACH WITH ONE LANE

Satisfied?: YES

Warrant 3 – Peak Hour

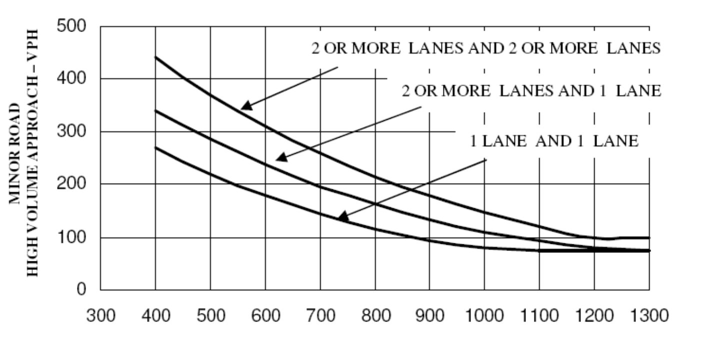
Unusual condition justifying use of warrant: None.

Record hour where criteria are fulfilled and the corresponding delay or volume in boxes provided. Plot the peak hour volume combination on the applicable figure below. If all three criteria are fulfilled or the plotted point lies above the appropriate line, then the warrant is satisfied.

Criteria	Approach Lanes		No. of Approaches		Hour	Fulfilled?	
	1	2	3	4		Yes	No
1. Delay on Minor Approach (veh-h)	4	5			5.0	☐	☒
2. Volume on Minor Approach (veh/h)	100	150			66	☐	☒
3. Total Entering Volume (veh/h)			650	800		☐	☐

Figure A. Criteria for "70%" volume level.

Hour	4
Major Vol.	886
Minor Vol.	122



MAJOR ROAD - TOTAL OF BOTH APPROACHES - VPH

* NOTE: 100 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR ROAD APPROACH WITH TWO OR MORE LANES AND 75 VPH APPLIES AS THE LOWER THRESHOLD VOLUME FOR A MINOR ROAD WITH 1 LANE.

Satisfied?: NO

TRAFFIC SIGNAL WARRANT ANALYSIS WORKSHEET

Sheet 3

Warrant 4 – Pedestrian Volume

Record hours where criteria are fulfilled and the corresponding volume or gap frequency in the boxes provided.
The warrant is satisfied if all three of the criteria are fulfilled.

Criteria	Hour				Fulfilled?	
					Yes	No
1. Pedestrian volume crossing the major road is **100 ped/h** or more for each of any four hours or is **190 ped/h** or more during any one hour.	Volume				☐	☒
2. There are less than **60** gaps per hour in the major road traffic stream of adequate length for pedestrians to cross during the same hours as the pedestrian volume criterion is satisfied.	GAPS				☒	☐
3. The nearest traffic signal along the major road is located more than 300 ft away. Or, the nearest traffic signal is within 300 ft but the proposed traffic signal will not restrict the progressive movement of traffic.					☒	☐

Satisfied?: NO

Warrant 5 – School Crossing

Record hours where criteria are fulfilled and the corresponding volume or gap frequency in the boxes provided.
The warrant is satisfied if all three of the criteria are fulfilled.

Criteria	Fulfilled?	
	Yes	No
1. There are a minimum of **20** students during the highest crossing hour.	☒	☐
2. There are fewer adequate gaps in the major road traffic stream during the period when the children are using the crossing than the number of minutes in the same period.	☒	☐
3. The nearest traffic signal along the major road is located more than 300 ft away. Or, the nearest traffic signal is within 300 ft but the proposed traffic signal will not restrict the progressive movement of traffic.	☒	☐

Satisfied?: YES

Warrant 6 – Coordinated Signal System

Indicate if the criteria are fulfilled in the boxes provided. The warrant is satisfied if either criterion is fulfilled. This warrant should not be applied when the resulting signal spacing would be less than 300 m (1000 ft).

Criteria	Fulfilled?	
	Yes	No
1. On a one-way road or a road that has traffic predominantly in one direction, the adjacent signals are so far apart that they do not provide the necessary degree of vehicle platooning.	☐	☒
2. On a two-way road, adjacent signals do not provide the necessary degree of platooning and the proposed, adjacent signals will collectively provide a progressive operation.	☐	☒

Satisfied?: NO

TRAFFIC SIGNAL WARRANT ANALYSIS WORKSHEET

Sheet 4

Warrant 7 – Crash Experience

	8 Highest Hours							
Hour	4	5	7	6	3	8	2	1
Major Road - Both App. vph	886	876	757	694	596	568	510	429
Minor Road High App. vph	122	114	140	123	80	99	87	79

Table 1: 80% Volume Comparison Criteria

(Volumes in veh/h)		Minimum Requirements			
Approach Lanes:		**1**		**2 or more**	
Volume Level:		80%	Hours	80%	Hours
Major Road Both App. vph	1A	**280**		**335**	8
	1B	**420**		**505**	7
Minor Road High App. vph	1A	**85**	6	**110**	
	1B	**40**	7	**55**	

Record hours where criteria are fulfilled, the corresponding volume, and other information in the boxes provided.
The warrant is satisfied if all three of the criteria are fulfilled.

Criteria (Must use 80% - Urban - Condition Warrant Volume Levels)		**Hour**				**Met?** Yes	**Met?** No	**Fulfilled?** Yes	**Fulfilled?** No
1. One of the warrants to the right is met.	Warrant 4.1 is 80% of volume requirements: **56 ped/h** for 4 hrs or **106 ped/h** for 1 hr					☐	☒		
	Warrant 1, Condition A (80% satisfied from Table 1 above)					☐	☒		
	Warrant 1, Condition B (80% satisfied from Table 1 above)					☐	☒	☐	☒
2. Adequate trial of other remedial measures has failed to reduce crash frequency.	Measures tried: Installing lighting, medians, upgraded signs.							☒	☐
3. Five or more reported crashes, of types susceptible to correction by signal, have occurred within a 12-mo. Period.	Number of crashes per 12 months: 1.67							☐	☒

Warrant Satisfied?: NO

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TRAFFIC SIGNAL WARRANT ANALYSIS WORKSHEET

Sheet 5

Warrant 8 – Roadway Network

Record hours where criteria are fulfilled, the corresponding volume, and other information in the boxes provided. The warrant is satisfied if at least one of the criteria is fulfilled and if all intersecting routes have one or more of the characteristics listed.

Criteria			Met? Yes	Met? No	Fulfilled? Yes	Fulfilled? No
1. Both of the criteria to the right are met.	a. Total entering volume of at least **1,000 veh/h** during typical weekday peak hour.	Entering volume: 1065	☒	☐	☒	☐
	b. Five-year projected volumes that satisfy one or more of Warrants 1, 2, or 3.	Warrant(s) satisfied: 1108	☒	☐		

2. Total entering volume at least **1,000 veh/h** for each of any 5 hrs of a non-normal business day (Sat. or Sun.)							Fulfilled? Yes	Fulfilled? No
						-Hr.		
						-Vol.	☐	☒

Characteristics of Major Routes	Fulfilled? Yes	Fulfilled? No
1. Part of the road or highway system that serves as the principal roadway network for through traffic flow.	☒	☐
2. Rural or suburban highway outside of, entering, or traversing a city.	☒	☐
3. Appears as a major route on an official plan.	☒	☐

Warrant Satisfied?: YES

Left Turn Conflict Analysis

Criteria
(Condition satisfied when the product of the mainline left turns in one direction and the opposing traffic exceed the thresholds given. NOTE: This is not a signal warrant.)

	A		B	Product of peak left turning vehicles (A) and opposing plus right turn vehicles (B).			
No. of Left Turn Lanes	Peak Volume Left Turns	No. of Opposing Lanes	Peak Opposing Volume in Same Hour	**A x B**	**Threshold**	**Exceeded? Yes**	**Exceeded? No**
1		1		0	**80,000**	☐	☐
1	89	2	36	3,204	**100,000**	☐	☒

Condition Satisfied?: NO

CONCLUSIONS: See table A.1 and Section 7.1.

TABLE A.1 SIGNAL WARRANT STUDY RESULTS

Warrant	Result
Warrant 1: Eight-Hour Vehicular Volume	Not Satisfied
Warrant 2: Four-Hour Vehicular Volume	Satisfied
Warrant 3: Peak Hour	Not Satisfied
Warrant 4: Pedestrian Volume	Not Satisfied
Warrant 5: School Crossing	Satisfied
Warrant 6: Coordinated Signal System	Not Satisfied
Warrant 7: Crash Experience	Not Satisfied
Warrant 8: Roadway Network	Satisfied

APPENDIX B

SYNCHRO REPORTS

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FIGURE B.1 EXISTING CAPACITY ANALYSIS (AM)

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Volume (veh/h)	3	40	51	113	8	10	11	123	53	27	438	2
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Hourly flow rate (vph)	3	43	55	123	9	11	12	134	58	29	476	2
Pedestrians												
Lane Width (m)												
Walking Speed (m/s)												
Percent Blockage												
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (m)												
pX, platoon unblocked												
vC, conflicting volume	641	750	238	532	695	67	478			191		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	641	750	238	532	695	67	478			191		
tC, single (s)	7.5	6.5	6.9	7.5	6.5	6.9	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	99	87	93	65	98	99	99			98		
cM capacity (veh/h)	340	328	763	350	353	983	1080			1380		

Direction, Lane #	EB 1	EB 2	WB 1	WB 2	NB 1	NB 2	NB 3	NB 4	SB 1	SB 2	SB 3	SB 4
Volume Total	47	55	132	11	12	67	67	58	29	238	238	2
Volume Left	3	0	123	0	12	0	0	0	29	0	0	0
Volume Right	0	55	0	11	0	0	0	58	0	0	0	2
cSH	329	763	350	983	1080	1700	1700	1700	1380	1700	1700	1700
Volume to Capacity	0.14	0.07	0.38	0.01	0.01	0.04	0.04	0.03	0.02	0.14	0.14	0.00
Queue Length 95th (m)	3.9	1.9	13.6	0.3	0.3	0.0	0.0	0.0	0.5	0.0	0.0	0.0
Control Delay (s)	17.8	10.1	21.3	8.7	8.4	0.0	0.0	0.0	7.7	0.0	0.0	0.0
Lane LOS	C	B	C	A	A				A			
Approach Delay (s)	13.6		20.4		0.5				0.4			
Approach LOS	B		C									

Intersection Summary			
Average Delay	4.8		
Intersection Capacity Utilization	38.8%	ICU Level of Service	A
Analysis Period (min)	15		

FIGURE B.2 EXISTING CAPACITY ANALYSIS (PM)

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Volume (veh/h)	1	25	7	71	43	66	52	472	122	25	173	8
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Hourly flow rate (vph)	1	27	8	77	47	72	57	513	133	27	188	9
Pedestrians												
Lane Width (m)												
Walking Speed (m/s)												
Percent Blockage												
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (m)												
pX, platoon unblocked												
vC, conflicting volume	707	1001	94	796	877	257	197			646		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	707	1001	94	796	877	257	197			646		
tC, single (s)	7.5	6.5	6.9	7.5	6.5	6.9	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	100	88	99	67	82	90	96			97		
cM capacity (veh/h)	239	225	944	237	266	743	1373			936		

Direction, Lane #	EB 1	EB 2	WB 1	WB 2	NB 1	NB 2	NB 3	NB 4	SB 1	SB 2	SB 3	SB 4
Volume Total	28	8	124	72	57	257	257	133	27	94	94	9
Volume Left	1	0	77	0	57	0	0	0	27	0	0	0
Volume Right	0	8	0	72	0	0	0	133	0	0	0	9
cSH	225	944	247	743	1373	1700	1700	1700	936	1700	1700	1700
Volume to Capacity	0.13	0.01	0.50	0.10	0.04	0.15	0.15	0.08	0.03	0.06	0.06	0.01
Queue Length 95th (m)	3.4	0.2	20.7	2.6	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
Control Delay (s)	23.3	8.8	33.3	10.4	7.7	0.0	0.0	0.0	9.0	0.0	0.0	0.0
Lane LOS	C	A	D	B	A				A			
Approach Delay (s)	20.2		24.9		0.6				1.1			
Approach LOS	C		C									

Intersection Summary			
Average Delay	5.4		
Intersection Capacity Utilization	39.2%	ICU Level of Service	A
Analysis Period (min)	15		

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FIGURE B.3 PROPOSED CAPACITY ANALYSIS (AM)

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Volume (veh/h)	3	42	53	72	8	8	11	128	55	456	28	2
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Hourly flow rate (vph)	3	46	58	78	9	9	12	139	60	496	30	2
Pedestrians												
Lane Width (m)												
Walking Speed (m/s)												
Percent Blockage												
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (m)												
pX, platoon unblocked												
vC, conflicting volume	1128	1245	15	1250	1187	70	33			199		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	1128	1245	15	1250	1187	70	33			199		
tC, single (s)	7.5	6.5	6.9	7.5	6.5	6.9	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	97	58	95	0	93	99	99			64		
cM capacity (veh/h)	107	109	1060	61	119	979	1578			1371		

Direction, Lane #	EB 1	EB 2	WB 1	WB 2	NB 1	NB 2	NB 3	NB 4	SB 1	SB 2	SB 3	SB 4
Volume Total	49	58	87	9	12	70	70	60	496	15	15	2
Volume Left	3	0	78	0	12	0	0	0	496	0	0	0
Volume Right	0	58	0	9	0	0	0	60	0	0	0	2
cSH	109	1060	64	979	1578	1700	1700	1700	1371	1700	1700	1700
Volume to Capacity	0.45	0.05	1.37	0.01	0.01	0.04	0.04	0.04	0.36	0.01	0.01	0.00
Queue Length 95th (m)	15.5	1.4	58.8	0.2	0.2	0.0	0.0	0.0	13.4	0.0	0.0	0.0
Control Delay (s)	62.2	8.6	347.9	8.7	7.3	0.0	0.0	0.0	9.1	0.0	0.0	0.0
Lane LOS	F	A	F	A	A				A			
Approach Delay (s)	33.2		317.1		0.4				8.5			
Approach LOS	D		F									

Intersection Summary			
Average Delay	40.9		
Intersection Capacity Utilization	49.9%	ICU Level of Service	A
Analysis Period (min)	15		

FIGURE B.4 PROPOSED CAPACITY ANALYSIS (PM)

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Volume (veh/h)	1	26	7	74	45	69	54	491	127	126	180	8
Peak Hour Factor	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Hourly flow rate (vph)	1	28	8	80	49	75	59	534	138	137	196	9
Pedestrians												
Lane Width (m)												
Walking Speed (m/s)												
Percent Blockage												
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (m)												
pX, platoon unblocked												
vC, conflicting volume	953	1259	98	1045	1129	267	204			672		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	953	1259	98	1045	1129	267	204			672		
tC, single (s)	7.5	6.5	6.9	7.5	6.5	6.9	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	99	80	99	39	70	90	96			85		
cM capacity (veh/h)	128	138	939	132	165	731	1364			915		

Direction, Lane #	EB 1	EB 2	WB 1	WB 2	NB 1	NB 2	NB 3	NB 4	SB 1	SB 2	SB 3	SB 4
Volume Total	29	8	129	75	59	267	267	138	137	98	98	9
Volume Left	1	0	80	0	59	0	0	0	137	0	0	0
Volume Right	0	8	0	75	0	0	0	138	0	0	0	9
cSH	137	939	143	731	1364	1700	1700	1700	915	1700	1700	1700
Volume to Capacity	0.21	0.01	0.91	0.10	0.04	0.16	0.16	0.08	0.15	0.06	0.06	0.01
Queue Length 95th (m)	6.2	0.2	49.5	2.7	1.1	0.0	0.0	0.0	4.2	0.0	0.0	0.0
Control Delay (s)	38.2	8.9	113.0	10.5	7.8	0.0	0.0	0.0	9.6	0.0	0.0	0.0
Lane LOS	E	A	F	B	A				A			
Approach Delay (s)	32.1		75.4		0.6				3.9			
Approach LOS	D		F									

Intersection Summary				
Average Delay	14.0			
Intersection Capacity Utilization	43.7%	ICU Level of Service		A
Analysis Period (min)	15			

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