DEPARTMENT OF TRANSPORTATION

Criteria and Guidelines for Three-Lane Road Design and Operation

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A 4-3 conversion involves changing a four-lane undivided road into one with two general travel lanes separated by a two-way left turn lane. A commonly-used guideline states that a 4-3 conversion can be considering as long as the road's average annual daily traffic (AADT) volume does not exceed 15,000 vehicles/day but opinions vary, from lowering the AADT threshold to 10,000 vehicles/day to anecdotal evidence for successful 4-3 conversions with AADTs as high as 20,000. The main objective of this project was to identify conditions where 4-3 conversions might be feasible at AADTs greater than 15,000. After reviewing the literature, we conducted simulation studies on three different roads to identify combinations of major and minor road flow where three-lane configurations provided acceptable levels of service. Eight intersections, with 16 approaches, were then selected to represent our findings. These results were presented as summary tables that practitioners could use to make initial assessments regarding 4-3 conversion feasibility.

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CRITERIA AND GUIDELINES FOR THREE-LANE ROAD DESIGN AND OPERATION

FINAL REPORT

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EXECUTIVE SUMMARY

A 4-3 conversion, also known as a road-diet, involves converting a four-lane undivided road to one with a three-lane cross-section, where the two travel lanes are separated by a two-way, left-turn lane. A 4-3 conversion is recognized as a proven safety countermeasure in the *Highway Safety Manual* and can make space available for uses in addition to automobile traffic, for example, by providing bikeways or transit lanes. The underlying assumption, though, is that sufficient unused capacity exists on the four-lane road so that the loss of travel lanes does not lead to an unacceptable decline in level of service (LOS). A commonly-used guideline is that 4-3 conversions can be considered when a main road's average daily traffic volume (ADT) is below approximately 15,000 vehicles per day. There is no consensus on this, however, and recommendations have ranged from lowering the cutoff to 10,000 vehicles per day to suggesting that 4-3 conversions can still work for ADTs greater than 20,000 vehicles per day.

This project involved two main phases. The first phase was an extensive review of literature regarding operational effects of two-way, left-turn lanes and 4-3 conversions. Project staff identified, in consultation with the project's Technical Advisory Panel (TAP), a list of 36 relevant design features. By drawing on previous literature reviews and electronic databases, project staff also identified 48 documents relevant to this problem and rated each document as to whether or not it offered guidance regarding each of the 36 design features. Summaries of these findings were provided to the project's TAP, and the TAP members were asked to rate each design feature regarding priority for further investigation. Four features were identified as important by all TAP members and one, main road traffic volume, was selected for futher investigation.

In the second phase, the goal was to quantify how LOS on three-lane converted roads varied with main and crossroad traffic demand, for a set of typical roads and intersections. In particular, we sought to identify those combinations of traffic conditions where a three-lane converted road should provide acceptable LOS versus those conditions where LOS on a three-lane converted road would be unacceptable. Three sections on existing Minnesota roads were selected, and a factorial simulation experiment was conducted for each. Using Transmodeler SE, four levels of main road demand, three levels of crossroad demand at signalized intersections, and three levels of crossroad demand at unsignalized intersections, for a total 36 different demand combinations, were simulated for each of the road sections, and the results summarized. A subset of eight intersections with 16 separate approaches was then selected as exemplifying the results of the simulation study. For each approach, summary tables of how LOS varied with main and crossroad demand were prepared and presented in a format that practioners could use to make initial assessments regarding 4-3 conversion feasibility.

CHAPTER 1: INTRODUCTION

In 1999 Dan Burden and Peter Lagerway (Buden and Lagerway 1999) popularized the term “road diet” for the practice of converting a four-lane undivided road to a road with a three-lane cross-section, where the two travel lanes were separated by a two-way, left-turn lane (See Figure 1.1). In what follows, we will use the terms “road diet” and “4-3 conversion” as synonyms for this practice.

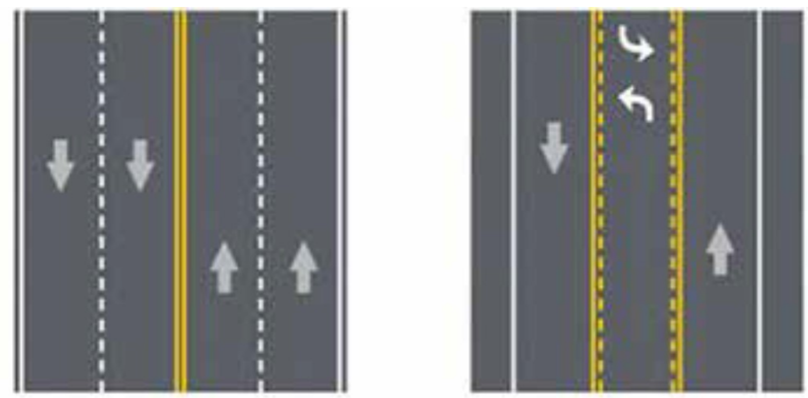


Figure 1.1 “Road Diet” Conversion of a Four-Lane Road to a Three-Lane Road

One potential benefit from a 4-3 conversion comes from the fact that this is a proven safety countermeasure. From Figure 1.1 it can be seen that in the three-lane cross-section vehicles waiting to make left-turns can be removed from conflicts with through traffic. The *Highway Safety Manual* (AASHTO 2010) gives a predicted reduction of 29% (i.e., a CMF=0.71) for this countermeasure. This is essentially an average effect based on estimates obtained by reanalyzing data from two earlier studies, one of roads in Iowa (Pawlovich et al 2006, CMF=.53) and one of roads in Washington state and California (Huang et al. 2002, CMF=0.89).

A second potential benefit from a 4-3 conversion is that space can be given to alternative modes, for example, by providing bikeways or transit lanes. Generally, though, if a given traffic flow currently spread over two lanes is shifted to a single lane, traffic density will increase, and other things being equal, traffic speeds will decrease. The underlying assumption then is that sufficient unused capacity exists on the four-lane road so that the loss of travel lanes does not lead to an unacceptable decline in level of service (LOS) provided for through traffic. Since traffic flow tends to vary throughout the day, the effect that a 4-3 conversion has on speed and delay will also vary, but, interestingly, guidance for identifying feasible situations for 4-3 conversions is often given in terms of average daily traffic (ADT) instead of hourly flow. For example, Burden and Lagerway stated, regarding road diets, “The ideal patient is often a four-lane road carrying 12-18,000 auto trips per day.” At present, a not uncommon criterion is to regard 4-3 conversions as feasible for main road ADTs below approximately 15,000 vehicles per day, but there is no universal consensus on this, and several authorities caution that detailed analysis of a road’s particular situation will often be required.

The ultimate goal of this project is to provide more nuanced guidance regarding 4-3 conversions that fall between simple ADT cutoffs and the need for detailed, site-specific, analyses. Chapter 2 describes our survey of existing literature regarding guidance on 4-3 conversions for a number of road design features. On completing this survey, in consultation with the project's Technical Advisory Panel (TAP), it was decided to focus on guidance regarding traffic demand. Chapter 3 describes the factorial simulation study we conducted to characterize the performance of three-lane cross-sections on three existing Minnesota road segments. Chapter 4 then synthesizes the results of the simulation study and provides a set of tables that can be used to assess the initial feasibility of a 4-3 conversion. Chapter 5 presents our conclusions.

CHAPTER 2: LITERATURE REVIEW AND NEXT STEPS

The objectives of this part of the project were:

(1) to review relevant literature regarding the effects of 3-lane geometric and operational characteristics,

(2) to identify gaps in the understanding of the impacts of 4-3 conversions, and

(3) with the assistance of the project's TAP, to determine priorities for further investigation.

2.1 LITERATURE SUMMARY

Work on objective (1) began with a literature search using the Transportation Research Board's TRID database. An initial list of sources then identified reports from three projects, Lyles et al (2012), Noyce et al (2006), and Stamatiadis et al (2011), each of which contained relevant literature reviews. From these, we identified a list of 48 relevant sources. Adding to this list two of the above reports (Lyles et al 2012 and Stamatiades et al 2011), along with two more recent documents (Knapp et al 2014 and Thomas 2013), completed our list of 52 documents. These are listed, along with abstracts, in Appendix B. Source documents that were available either electronically or from the University of Minnesota library were then obtained directly. Those not directly available were requested through Inter-Library Loan. As of May 31, 2019, 48 of the 52 identified documents had been obtained for review.

For objective (2), a review of the *Road Diet Information Guide* (Knapp et al 2014) produced an initial list of design features which was then distributed to the project's administrative (AL) and technical (TL) liaisons and for comment. Adding several elements suggested by the TL produced the final list. These elements, and their working definitions, are listed in Appendix A.

Project personnel then reviewed each of the 48 available sources to see what information, if any, they provided regarding the design elements. Of special interest was whether or not a source offered a guideline regarding a particular element. A guideline was defined broadly as an If-Then-type statement where the "If" part described observable features and the "Then" part gave a recommendation. These could be verbal, symbolic, graphical, or tabular expressions. In some cases the If-Then structure was explicit, and in other cases, it was inferred by us. For example, in Squires and Parsonen (1989, source #39) the statement "The report indicated that if stopping sight distance is less than AASHTO standards, a TWLTL should not be used" was treated as a guideline for the design element Main Road Stopping Distance. As another example, **Figure 2.1**, taken from Stamatiades et al (2011, source #50), was treated as a guideline for the design elements Main Road Traffic Volume and Minor Road Traffic Volume.

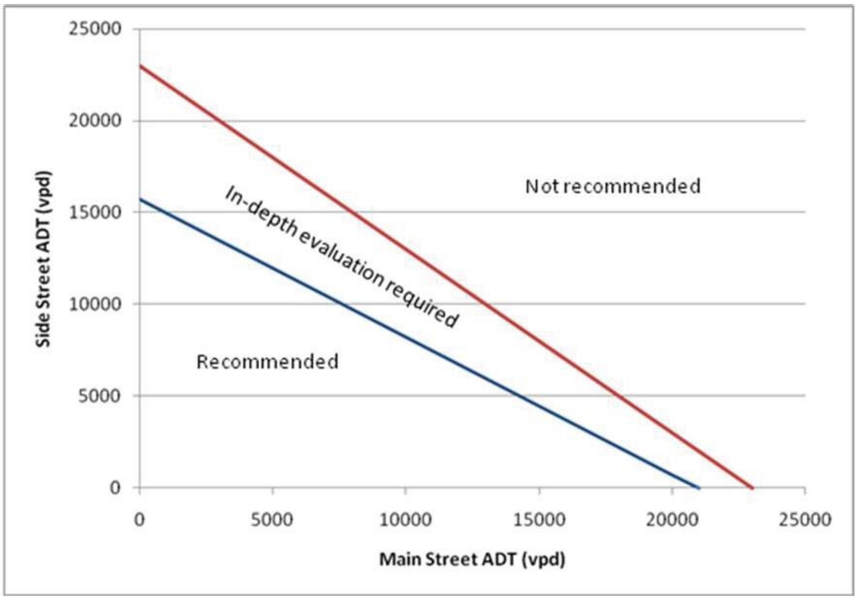


Figure 2.1 Graph compiled by Stamatiades et al (2011) relating feasibility of road-diet conversions to main and side street ADTs.

As a final example, in this case for Main Road Traffic Volume, Knapp and Rosales (2007, source #17) provided the statement "Successful roadway case study volumes (previously noted) ranged from 8,500 to 24,000 vpd."

For each design element, each source was classified as whether it appeared to offer guidance regarding that element, if it mentioned the element but did not appear to offer guidance, or if it appeared to be silent regarding that element. These characterizations were summarized in an Excel worksheet, which was delivered to the project's AL and TAP.

Based on our review we offered the following initial conclusions:

1. Table 2.1 lists our design elements and records Y(es) or N(o) depending on whether or not guidance about that element was found in at least one of the consulted sources. Interestingly, guidance on most of the design elements could be found somewhere in the literature. On the other hand, overall guidance on effectively integrating the design elements was lacking. One recurring theme in the literature was that the impacts of road-diet conversions can vary depending on particular circumstances, and that feasibility of road-diet conversions should be evaluated on case-by-case bases.

2. In some cases the available guidance was inconsistent. For example, regarding average daily traffic, Burden and Lagerway (1999, source #4) cited successful examples of road diet conversions with ADTs exceeding 20,000, while Knapp et al (2001, source #16) indicated that four-lane roads with ADTs greater than 15,000-17,500 could, if converted, suffer declines in intersection level-of-service. Lyles et al (2012, source #49) suggested that road diet conversions can become problematic at ADTs above 10,000.

3. Although ADT thresholds are often used to determine whether or not a proposed 4-3 conversion might be feasible, ADT by itself is a weak indicator of the likely performance of a conversion. This is in part because the same ADT can be consistent with different distributions of demand throughout the day, and because these different demand distributions can in turn interact with different intersection features.

4. Although crash experience was not identified as a design element for this study, we noted that road diet conversions are often recommended as safety countermeasures. Unfortunately, the estimates of crash reduction effects associated with road diet conversions are not consistent. Estimated reductions of 47%, 19%, and 9% have been given, and differences appear between studies using different data sets and between different studies using similar datasets. There is limited evidence that this range of outcomes could be due to differences in road and traffic conditions.

Table 2.1 Summary of Literature Review Regarding Guidance

Design Element	Guidance Offered at Least Once
Bike lanes	Y
Medians	Y
Turn pockets	N
Sidewalks/width	Y
Buffers/width	Y
Bus stops	Y
On-street parking	Y
Access spacing	Y
Shoulders/width	Y
Pedestrian islands	Y
Crosswalks	Y
Lane width	Y
Curb return	Y
Shy distance	N
Design speed	N
Bus turnouts	Y
Right turn lanes	Y
Roundabouts	Y
Side street control	Y
Intersection control	Y
Main road sight distance	Y
Crossroad sight distance	Y
Location (e.g. Urban/Suburban/Rural)	Y
Adjacent land use	Y
Operating speed	Y
Main road traffic volume	Y
Minor road(s) traffic volume	Y

Lane widths: Through lanes	Y
Lane widths: TWLTL	Y
Lane widths: left turn (with median)	Y
Adjacent feature	Y
Overall width	Y
Target Speed	N
Distracted Driving	N
Driveway left-turn conflicts (overlapping movements)	Y
Driveway volumes	Y

In summary, the terms “road-diet” and “4-3 conversion” are generic terms that cover a wide range of actual designs. There is an impressive literature of individual case studies indicating that road-diet conversions can reduce traffic speeds, can reduce crash frequencies, and can make roads more friendly to non-automotive users, without seriously compromising the levels of service provided to drivers. When looking at the more rigorous efforts at quantifying these effects, however, the situation is less clear-cut. Differences in recommended ADT thresholds and in estimated crash reductions are especially salient.

Table 2.2 Summary of Priority Ratings for Design Elements

		Priority					
Design Feature	**Guidance**	**Very Low**	**Low**	**Moderate**	**High**	**Very high**	**Not Relevant**
Bike lanes	Y			x	xxx		
Medians	Y			x	xx	X	
Turn pockets	N			xx	xx		
Sidewalks/width	Y			xx	x	x	
Buffers/width	Y			xxx	x		
Bus stops	Y		x	xx		x	
On-street parking	Y		x	xx	x		
Access spacing	Y			xx	xx		
Shoulders/width	Y			xxx	x		
Pedestrian islands	**Y**				**xxx**	**x**	
Crosswalks	Y		x	x	xx		
Lane width	**Y**				**xxx**	**x**	
Curb return	Y		xx	x	x		
Shy distance	N		xx	xx			
Design speed	N			xx	x	x	
Bus turnouts	Y		xx	xx			
Right turn lanes	Y		xx	xx			
Roundabouts	Y		x	xx	x		
Side street control	Y		x	xxx			
Intersection control	Y		x		xxx		
Main road sight distance	Y		x	xx	x		
Cross road sight distance	Y		x	x	xx		
Location (e.g. Urban/Suburban/	Y			xx	x	x	
Adjacent land use	Y		x	x	x	x	
Operating speed	**Y**				**xxxx**		
Main road traffic volume	**Y**				**xxx**	**x**	
Minor road(s) traffic volume	Y			x	xx	x	
Lane widths: Through lanes	Y			x	x	xx	
Lane widths: TWLTL	Y			x	x	xx	
Lane widths: left turn (with med	Y			x	x	xx	
Adjacent feature	Y		x	xx			
Overall width	Y		x	x	x	x	
Target Speed	N			x	x	xx	
Distracted Driving	N		xx			xx	
Driveway left turn conflicts (ove	Y		x	xx	x		
Driveway volumes	Y		x	xx	x		
Crash Modification Factors	Y		xx	x	x		

A summary of our literature review was provided to project's TAP and the TAP members were asked to rate the different design elements regarding priority of further investigation. Table 2.2 summarizes the TAP's response, and it should be noted that four of the design elements, pedestrian islands, lane widths, operating speed, and main road traffic volume, were rated by all four TAP members as having either High or Very High priority. These results were presented at a meeting between the TAP and project staff, and at that meeting it was decided to focus on developing guidelines for main road traffic volumes.

2.2 DETAILED REVIEW REGARDING LITERATURE ON MAIN ROAD TRAFFIC VOLUMES

Our literature review identified three important reports that offered guidance concerning the effects of traffic volumes on the performance of 4-3 conversions.

2.2.1 Knapp and Giese (2001)

Using CORSIM and Synchro, Knapp and Giese (2001) simulated the performance of a hypothetical ¼-mile section highway, bounded by signalized intersections, before and after a conversion from a four-lane undivided road to three-lane road with a two-way left-turn lane. Figure 2.2 and Figure 2.3 show the lanes and turning movements for the four-lane and three-lane configurations.

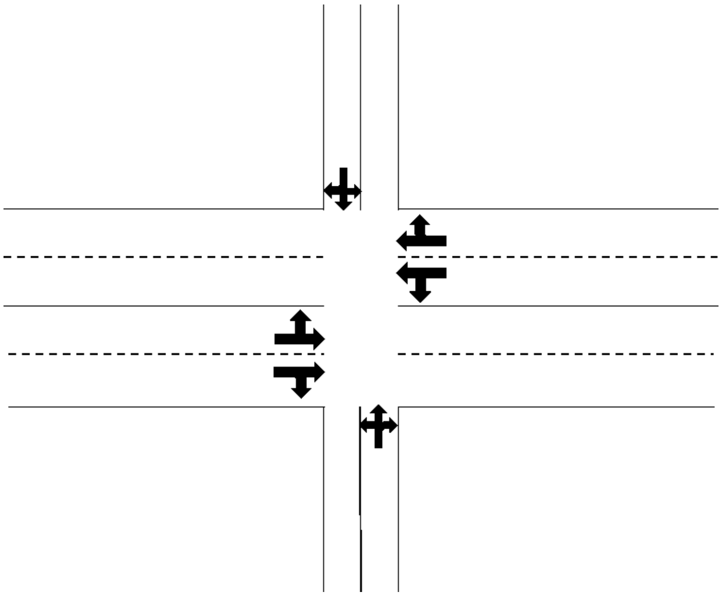


Figure 2.2 Intersection Layout for 4-Lane Undivided Highway

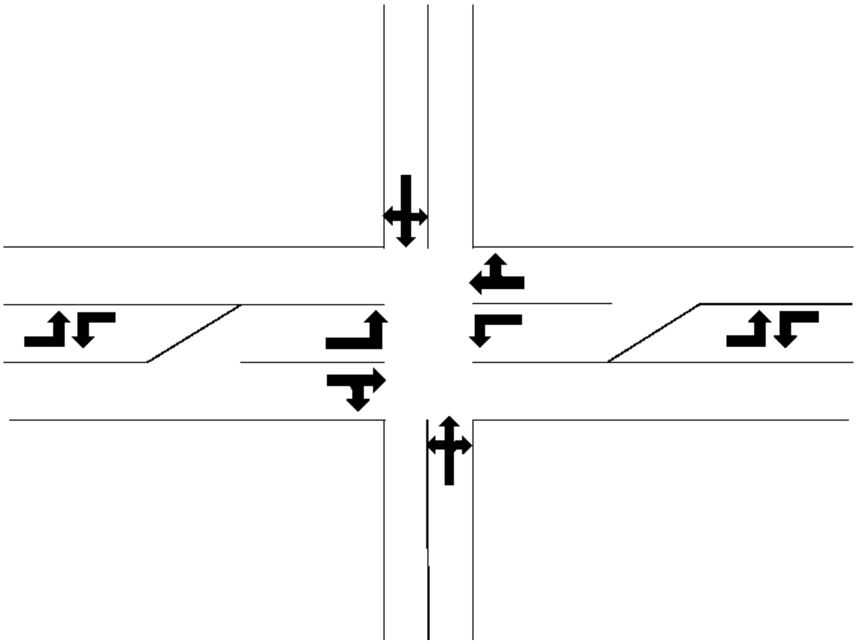


Figure 2.3 Intersection Layout for Three-Lane Highway

Intersection and corridor performances were simulated for main-road hourly flows of 500, 750, 875, and 1000 vehicles/hour/direction (vphpd), leading the authors to the following recommendations:

Flow <=750 vphpd (feasibility probable)
Flows between 750 and 875 vphpd (exercise caution)

Flows >=875 vphpd (feasibility less likely)

Hourly directional flows were converted to approximate ADTs using the rule ADT=(2)(10)(vphpd) to produce ADT-based guidance:

ADT <=15,000 vpd (feasibility probable)
ADT between 5,000 and 17,500 vpd (exercise caution)
ADT >=17,500 vpd (feasibility less likely)

2.2.2 Stamatiadis et al (2011)

Using CORSIM, Stamadiadis et al (2011) simulated the performance of a hypothetical signalized intersection for both four-lane and three-lane configurations. The intersection layouts were similar to those shown in Figure 2.2 and Figure 2.3. Main road volumes, in vphpd, ranged from 300 to 1200, crossroad volumes varied from 150 vphpd to 650 vphpd, and main road left-turn percentages varied from 5% to 40%. Using the simulation results, the authors developed a statistical model relating the difference between three-lane and four-lane delay to main and cross-street volumes and to left-turn percentages

3-lane and 4-lane Delay Difference = -29.113 + 0.013(main street volume (vphpd)) + 0.025*(cross street volume (vphpd)) + 0.313*(left-turn percent).*

Converting main road flows to ADT using the rule ADT = (2)(10)(vphpd), the authors then divided the combinations of main and crossroad volumes into three regions, as depicted in **Figure 2.4**. The red line in **Figure 2.4** shows the volume combinations where the total entering ADT = 23,000 vehicles per day, and the blue line defines combinations where the statistical model gives equal delay for a 4-lane and 3-lane cross-sections.

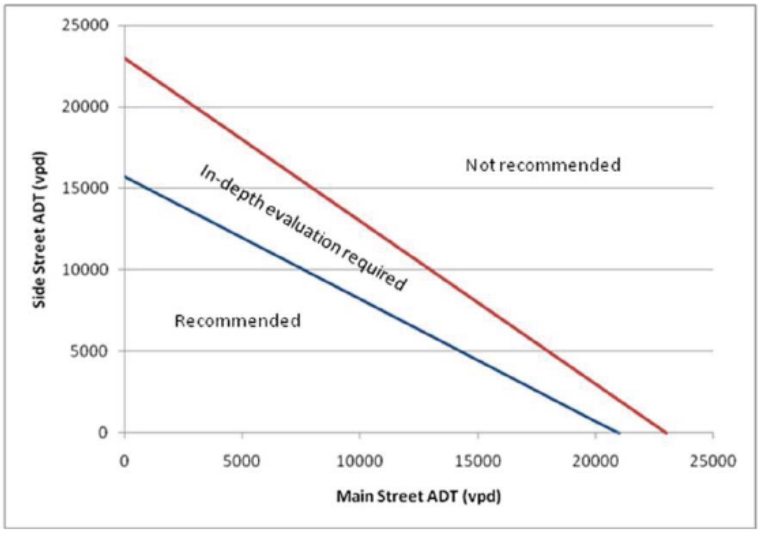


Figure 2 Operational performance guideline for road diet implementation

Figure 2.4 Example of Guidance Provided in Stamatiades et al (2011).

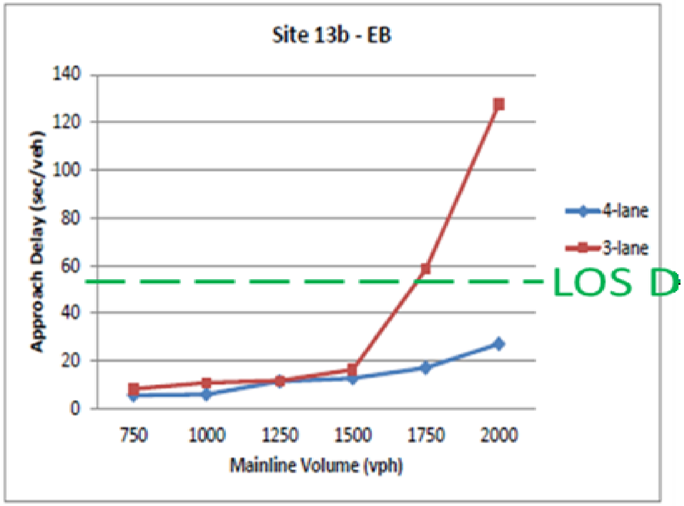
2.2.3 Lyles et al (2012)

Using Synchro and VISSIM, Lyles et al (2012) simulated the effects of 4-3 conversions for 9 existing signalized intersections. Results were summarized in Figures such as those shown in Figure 2.5. Based on their results, the authors suggested the following guidelines:

The ADT threshold for considering such road diets should be changed to 10,000 vehicles per day.

More importantly, detailed operational analysis should be done when ADTs are 10,000 or more OR when peak hour volumes exceed 1,000 vehicles/hour.

Finally, because of the variation in intersection geometry, turning volumes, and signal timing from site to site, detailed operations analysis should always be done.



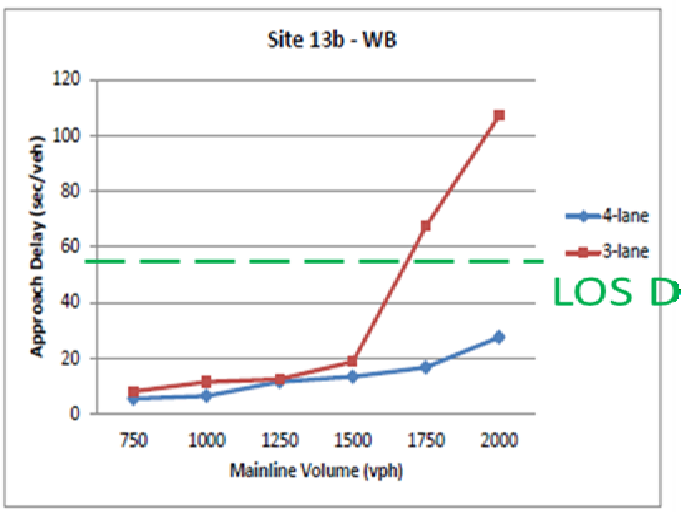


Figure 2.5 Example of Figures Provided in Lyles et al. (2012).

2.2.4 Anecdotal Reports

As noted above, there are anecdotal reports in the literature where 4-3 conversions were successfully accomplished on roads with ADTs greater than 20,000 vehicles per day. We identified three; two of these, Lake Washington Blvd, in Kirkland, WA, and Grand River Ave, in East Lansing, MI were described in Burden and Lagerway (1999). The third, Ocean Park Blvd, in Santa Monica, CA, was described in FHWA (2015).

Figure 2.6 Overhead view of Lake Washington Boulevard.

Figure 2.6 shows an aerial view of a section of Lake Washington Blvd. Crossroads consist mainly of driveways and two-way stop-controlled intersections. Figure 2.7 shows a section of Grand River Ave, and again, cross-streets consist mainly of driveways, with few signalized intersections.

Figure 2.7 Overhead view of a section of Grand River Ave.

Figure 2.8 Overhead view of a section of Ocean Park Blvd.

Figure 2.8 shows Ocean Park Blvd. This is a more urbanized road segment, but note that both the main road and the crossroads appear to have exclusive left-turn lanes.

Based on our literature review, we suggest the following tentative conclusions:

The capacities at signalized intersections constrain the feasibility of 4-3 conversions.

Conversions could be feasible on roads with AADTs > 20,000 where there are mainly driveways or low-volume crossroads and few signalized intersections.

If the capacities at signalized intersections are sufficient, the capacities at stop-controlled intersections should then be considered.

CHAPTER 3: SIMULATION STUDY TO DEVELOP GUIDELINES

As noted in Chapter 2, we identified 36 design features relevant to 4-3 road conversions and reviewed the state of knowledge regarding these. Summaries of our findings were sent to the project's TAP along with a poll for ranking the 36 features as to priority. Four features, pedestrian islands, lane width, operating speed, and main road traffic volume, were identified as the most important. At the September 2019 TAP meeting project staff presented summaries of available research regarding these features, and following a discussion it was decided to focus on identifying conditions that could justify 4-3 conversions when ADTs were higher 15,000 vehicles per day. This was to be done by simulating traffic conditions at one or more selected road sections, for a range of main road and crossroad demand levels, and then summarizing the LOS of 3-lane conversions as functions of traffic demand.

After reviewing simulation software packages, it was found that recent versions of TransModeler supported explicit specification of two-way left-turn lanes as roadway features. A single work-station license for TransModeler SE was purchased and installed on a computer at the University of Minnesota. After installing/testing the Transmodeler SE software, project personnel began reviewing possible sites for a simulation study.

After reviewing the list of TWLT lane sites in Minnesota, 50th Street in Minneapolis was identified as having turning movement data available for its signalized intersections. The section of 50th Street between Chowen and Zenith, with two internal stop-controlled intersections, was identified as a candidate site, and this was presented to the TAP. After discussion, it was suggested by the TAP that two additional sites that were being considered for 4-3 conversions could also be of interest: Minnetonka Blvd between MNTH 100 and Inglewood, and Baker Road between CSAH 62 and Valleyview. These sites are especially interesting because Minnetonka Blvd is currently operating at ADTs greater than 15,000 vehicles per day while Baker Road offers a relatively long interval without signalized intersections. Summary information for the three candidate sites is presented in Table 3.1.

Table 3.1 Summary of Road Sections Selected for Simulation

Street	From	To	Length(miles)	AADT (year)	Intersections	
					Signalized	Stop-Controlled
50th Street	Chowen	Zenith	0.2	11,400 (2019)	2	2
Minnetonka Blvd	Highway 100	Inglewood	0.7	25,500 (2018)	3	9
Baker Road	Valley View	CSAH 62	1.7	10,200 (2016)	2	14

In summary, it was decided to:

(1) Conduct a simulation study of the 50th Street site, at a range of main road traffic volumes corresponding to main road ADTs ranging from 10,000 vehicles per day to 25,000 vehicles per day.

(2) Conduct a simulation study of a 4-3 conversion of the Minnetonka Blvd site, at a range of main road traffic volumes corresponding to ADTs ranging from 10,000 vehicles per day to 25,000 vehicles per day.

(3) Conduct a simulation study of the Baker Road site, at a range of main road traffic volumes corresponding to ADTs ranging from 10,000 vehicles per day to 25,000 vehicles per day.

3.1 STUDY DESIGN

The simulation study was designed as a factorial study, with four levels of main road traffic volume, three levels of crossroad volume at the signalized intersections, and three levels of crossroad volume at the unsignalized intersections. This design is summarized in Table 3.2.

The four levels of major road flow were 500 vehicles per hour per lane (vphpl), 750 vphpl, 1000 vphpl, and 1250 vphpl, which correspond roughly to AADTs of 10,000 vehicles per day, 15,000 vehiclesper day, 20,000 vehicles per day, and 25,000 vehicles per day. At the signalized intersections it was assumed that 10% of the major road traffic would turn right and 10% would turn left, while the flows on the signalized minor roads were set at 20%, 40%, or 60% of the major road flow. The minor road turning volumes were then set so that the major road flow was constant throughout the study section. Figure 3.1 shows the turning movement volumes at the signalized intersections for the case where the major road flow was 750 vphpl and the minor road flow was set at 40% of the major road flow.

At the unsignalized intersections, the minor road flow was keyed to the MnMUTCD Peak Hour Volume warrant for signalization. That is, given the major road flow, the minor road flow was set at 50%, 75%, and 100% of the signalization threshold. For a major road flow of 750 vphpl (1500 vehicles/hour for both directions) the MnMUTCD signalization threshold is 100 vehicles/hour/direction on the minor road, so the range of directional minor road volumes was 50 vehicles/hour, 75 vehicles/hour, and 100 vehicles/hour. For most scenarios, it was assumed that 2.5% of the major road vehicles would turn right and 2.5% would turn left, while the minor road turning movements were set so that the major road flow was constant throughout the segment. However, for the main road flow=1250 vphpl scenario the turning movement percentages were reduced to 2% in order to maintain a constant main road flow. Figure 3.2 illustrates the minor road turning for the case where the major road flow was 750 vehicles/hour/lane and the minor road flow was 100% of the MnMUTCD threshold, 100 vehicles/hour.

For each set of turning movements, the signalized intersections were retimed by applying Webster's method to a three-phase timing plan that included a protected left-turn phase for major road left turns. However, when Webster's cycle length formula indicated oversaturation no timing plan was computed and no simulations were done.

Table 3.2 Factorial Structure of Simulation Study

Major Road Directional Hourly Flow (vphpl)	Signalized Minor Road Directional Hourly Flow (% of Major Road Flow)	Unsignalized Minor Road Directional Hourly Flow (% of MUTCD Limit)
	20	50
		75
		100

500	40	50
		75
		100
	60	50
		75
		100
750	20	50
		75
		100
	40	50
		75
		100
	60	50
		75
		100
1000	20	50
		75
		100
	40	50
		75
		100
	60	50
		75
		100
1250	20	50
		75
		100
	40	50
		75
		100
	60	50
		75
		100

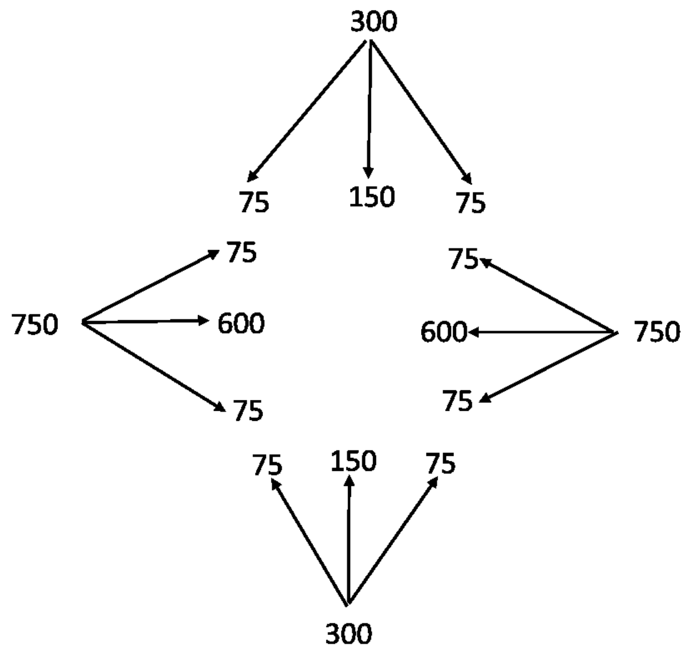


Figure 3.1 Signalized Intersection Turning Movements: Major Road Flow = 750 vehicles/hour/lane, Minor Road Flow = 40% of Major Road Flow.

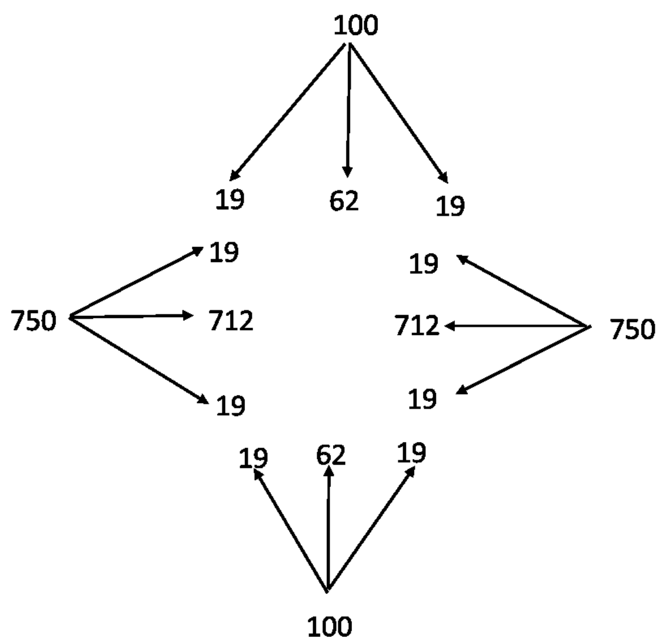


Figure 3.2 Unsignalized Intersection Turning Movements: Major Road Flow = 750 vehicles/hour/lane, Minor Road Flow = 100% of MUTCD Threshold.

For each feasible combination of turning movement volumes (each cell of Table 3.2) four TransModeler SE simulations were run starting with different random number seeds, and the average intersection delays for each intersection approach and the average corridor speeds were recorded. The results of each run were then averaged and entered into summary tables. Figure 3.3 shows an example summary table, for westbound traffic at the intersection of 50th Street and Chowen Ave, in Minneapolis.

WB @ Chowen Ave

Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)	Corridor Avg. Speed in mph (LOS)
500	20	50	5.2 (A)	25.2 (B)
		75	5.1 (A)	25.1 (B)
		100	5.4 (A)	24.9 (B)
	40	50	6.8 (A)	24.4 (B)
		75	6.7 (A)	24.3 (B)
		100	6.7 (A)	24.3 (B)
	60	50	12.2 (B)	18.7 (C)
		75	12.7 (B)	18.7 (C)
		100	12.4 (B)	18.7 (C)
750	20	50	7.3 (A)	23.8 (B)
		75	7.2 (A)	23.9 (B)
		100	7.2 (A)	23.7 (B)
	40	50	11.6 (B)	19.7 (C)
		75	10.9 (B)	19.9 (C)
		100	11.1 (B)	19.7 (C)
	60	50	21.0 (C)	14.9 (D)
		75	22.0 (C)	14.8 (D)
		100	15.9 (B)	17.1 (D)
1000	20	50	11.3 (B)	17.1 (D)
		75	15.0 (B)	16.9 (D)
		100	15.1 (B)	16.9 (D)
	40	50	21.0 (C)	12.1 (E)
		75	21.4 (C)	12.3 (E)
		100	20.3 (C)	11.8 (E)
	60	50	26.0 (C)	10.1 (F)
		75	26.0 (C)	10.7 (F)
		100	25.7 (C)	10.4 (F)
1250	20	50	13.1 (B)	13.6 (E)
		75	14.2 (B)	13.8 (E)
		100	13.7 (B)	13.3 (E)

Figure 3.3 Example Performance Summary, for Traffic Westbound at Chowen Avenue.

3.2 50TH STREET

Figure 3.4 and Figure 3.5 show overhead views of the study site, while Table 3.1 gives descriptive information. The road segment is 0.2 miles long, the intersections at Zenith and at Chowen are controlled by traffic signals, while the intersections at Beard Ave and at Abbott Ave are two-way stop-controlled. In 2019 the ADT for this segment was estimated at 11,400 vehicles per day. 50th Street has a fairly common three-lane configuration, with one lane each for eastbound and westbound traffic separated by a TWLTL. The TWLTL is replaced by a dedicated left-turn lane at each intersection.

Figure 3.4 Aerial Image of 50th Street Study Site.

Figure 3.5 Representation of 50th Street Study Site in TransModeler SE.

Table 3.3 summarizes how the delay-based LOS for eastbound traffic at Zenith varied with the different combinations of major and minor road traffic. Like the westbound traffic at Chowen, LOS remained acceptable even for major road traffic volumes corresponding to ADTs above 15,000 vehicle/day.

Table 3.3 Level of Service Based on Intersection Delay, Eastbound Traffic at Zenith.

Eastbound at Zenith Ave				
		Minor Flow (percent of major flow)		
		20%	40%	60%
Major Flow (ADT)	500 (10000)	A	A	B
	750 (15000)	A	A	B
	1000 (20000)	A	B	C
	1250 (25000)	B	X	X

Overall, the LOS for main road drivers generally remained acceptable even at high demands, but this was not the case for crossroad drivers at either the signalized or the unsignalized intersections. Table 3.4 summarizes the delay-based LOS for northbound traffic at Chowen. Acceptable LOS occurred when the main road flow was 500 vphpl, while at 750 vphpl LOS=F occurs when crossroad flow was 40% or more of major road flow. When the main road flow was greater than 1000 vphpl LOS=F occurred for all levels of crossroad flow. Table 3.5 shows a similar performance summary for northbound traffic at the two-way stop-controlled intersection at Abbott. Here we see acceptable LOS for main road flows of less than or equal to 750 vphpl and LOS=F for the higher main road flows, at all levels of crossroad flow.

Table 3.4 Level of Service Based on Intersection Delay for Northbound Traffic at Chowen, Initial Simulation Runs

Northbound at Chowen Ave				
		Minor Flow (percent of major flow)		
		20%	40%	60%
Major Flow (ADT)	500 (10000)	B	C	E
	750 (15000)	C	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

Table 3.5 Level of Service Based on Intersection Delay for Northbound Traffic at Abbott, Initial Simulation Runs

Northbound at Abbott Ave				
		Minor Flow (% of MUTCD Signal Warrant)		
		50%	75%	100%
Major Flow (ADT)	500 (10000)	B	C	D
	750 (15000)	C	D	E
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

The patterns shown in Table 3.4 and Table 3.5 were typical of what was seen at other approaches, with a rather definite break in crossroad LOS occurring at a main road flow of 750 vphpl (ADT=15,000) level. To try to localize this transition from acceptable to unacceptable performance we conducted an additional factorial experiment for main road volumes of 800, 850, 900, and 950 vphpd, corresponding roughly to

ADTs of 16,000, 17,000, 18,000, and 19,000 vehicles per day. The results for the original and supplemental simulation turns for northbound traffic at Chowen, and northbound traffic at Abbott, are shown in Table 3.6 and Table 3.7, respectively.

Table 3.6 Level of Service Based on Intersection Delay for Northbound Traffic at Chowen, Including Supplemental Simulation Runs

Northbound at Chowen Ave				
		Minor Flow (percent of major flow)		
		20%	40%	60%
Major Flow (ADT)	500 (10000)	B	C	E
	750 (15000)	C	**F**	**F**
	800 (16000)	C	**F**	**F**
	850 (17000)	C	**F**	**F**
	900 (18000)	D	**F**	**F**
	950 (19000)	**F**	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

Table 3.7 Level of Service Based on Intersection Delay for Northbound Traffic at Abbott, Including Supplemental Simulation Runs

Northbound at Abbott Ave				
		Minor Flow (% of MUTCD Signal Warrant)		
		50%	75%	100%
Major Flow (ADT)	500 (10000)	B	C	D
	750 (15000)	C	D	E
	800 (16000)	C	D	E
	850 (17000)	C	E	E
	900 (18000)	D	E	**F**
	950 (19000)	E	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

For 50^{th} Street, our simulation study suggested the following conclusions:

(1) For main road traffic, at both the signalized and unsignalized intersections, the three-lane configuration showed acceptable delay-based LOS even at hourly volumes greater than 750 vphpl, which correspond roughly to ADTs greater than 15,000 vehicles per day.

(2) At the minor road approaches on the signalized intersections, substantial deterioration in LOS tended to occur when main road flows exceeded 750 vhphpl. The supplemental simulation runs indicated that acceptable LOS was possible for main road flows up to 900 vphpl as long as the minor flows did not exceed 20% of the major road flow.

(3) A roughly similar pattern was seen for minor road traffic at the unsignalized intersections, with LOS=F conditions appearing as major road flow increased from 750 vphpl to 1000 vphpl, depending on the level of minor road flow.

3.3 MINNETONKA BOULEVARD

Figure 3.6 and Figure 3.7 show overhead views of the Minnetonka Boulevard site, while Table 3.1 gave descriptive information. The road segment is 0.7 miles long, and the boundary intersections at MNTH 100 and Inglewood are controlled by traffic signals. The internal intersection at Ottawa is also signalized. The site has 9 internal intersections that are two-way stop-controlled. In 2018 the AADT for this segment was estimated at 25,500 vehicles per day. This section currently has four travel lanes, two for eastbound traffic and two for westbound traffic.

Figure 3.6 Aerial Image of Minnetonka Blvd. Site.

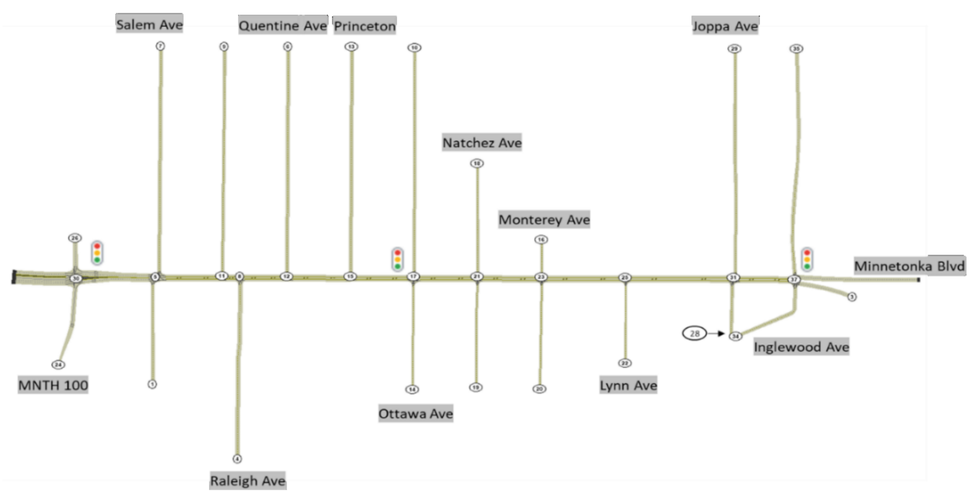


Figure 3.7 Representation of Minnetonka Blvd Site in TransModeler SE.

WB @ MNTH 100				
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)	Corridor Avg. Speed in mph (LOS)
500	20	50	4.9 (A)	22.4 (C)
		75	4.6 (A)	22.3 (C)
		100	2.6 (A)	22.2 (C)
	40	50	10.4 (B)	20.8 (C)
		75	10.1 (B)	20.8 (C)
		100	10.7 (B)	20.6 (C)
	60	50	13.3 (B)	19.6 (C)
		75	12.6 (B)	19.9 (C)
		100	11.5 (B)	19.8 (C)
750	20	50	2.7 (A)	21.2 (C)
		75	2.6 (A)	21.0 (C)
		100	4.7 (A)	21.1 (C)
	40	50	8.3 (A)	21.2 (C)
		75	9.2 (A)	21.1 (C)
		100	10.6 (B)	21.3 (C)
	60	50	7.0 (A)	18.8 (C)
		75	6.5 (A)	18.7 (C)
		100	13.9 (B)	18.3 (C)
1000	20	50	9.3 (A)	19.2 (C)
		75	9.1 (A)	19.2 (C)
		100	8.9 (A)	19.3 (C)
	40	50	15.3 (B)	16.1 (D)
		75	14.2 (B)	16.1 (D)
		100	14.2 (B)	16.1 (D)
	60	50	22.4 (C)	13.5 (E)
		75	21.2 (C)	13.9 (E)
		100	21.4 (C)	13.8 (E)
1250	20	50	6.8 (A)	18.1 (C)
		75	6.4 (A)	18.3 (C)
		100	6.6 (A)	18.0 (C)

Figure 3.8 Example Performance Summary, for Traffic Westbound at MNTH 100.

A factorial simulation study similar to that used for 50th Street was conducted to relate LOS to different combinations of main road and crossroad traffic demand. Figure 3.8 summarizes results for westbound traffic at MNTH 100 while Figure 3.9 summarizes results for eastbound traffic at Inglewood. Delay-based LOS remained acceptable even for major road traffic volumes corresponding to ADTs above 15,000 vehicle/day for both approaches.

EB @ Inglewood Ave				
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)	Corridor Avg. Speed in mph (LOS)
500	20	50	9.3 (A)	21.7 (C)
		75	8.5 (A)	22.0 (C)
		100	8.5 (A)	22.0 (C)
	40	50	11.1 (B)	21.1 (C)
		75	11.1 (B)	21.0 (C)
		100	11.8 (B)	21.2 (C)
	60	50	15.3 (B)	19.9 (C)
		75	15.2 (B)	19.9 (C)
		100	14.3 (B)	19.5 (C)
750	20	50	7.7 (A)	22.0 (C)
		75	8.2 (A)	22.0 (C)
		100	7.8 (A)	22.0 (C)
	40	50	10.8 (B)	21.1 (C)
		75	10.8 (B)	21.1 (C)
		100	11.3 (B)	21.9 (C)
	60	50	13.5 (B)	17.7 (D)
		75	13.8 (B)	17.8 (D)
		100	14.5 (B)	17.7 (D)
1000	20	50	10.6 (B)	20.2 (C)
		75	10.4 (B)	20.3 (C)
		100	19.9 (A)	20.5 (C)
	40	50	18.3 (B)	15.3 (D)
		75	18.8 (B)	15.5 (D)
		100	18.9 (B)	15.7 (D)
	60	50	30.3 (C)	10.2 (F)
		75	30.2 (C)	10.7 (F)
		100	29.6 (C)	11.6 (E)
1250	20	50	15.3 (B)	14.5 (D)
		75	14.7 (B)	15.5 (D)
		100	15.7 (B)	16.6 (D)

Figure 3.9 Level of Service Summary, Eastbound Traffic at Inglewood.

EB @ Ottawa Ave			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	7.0 (A)
		75	6.8 (A)
		100	6.5 (A)
	40	50	8.6 (A)
		75	8.7 (A)
		100	9.2 (A)
	60	50	9.9 (A)
		75	9.9 (A)
		100	11.1 (B)
750	20	50	7.7 (A)
		75	7.9 (A)
		100	7.8 (A)
	40	50	9.1 (A)
		75	9.5 (A)
		100	11.6 (B)
	60	50	20.0 (B)
		75	19.3 (B)
		100	19.0 (B)
1000	20	50	11.8 (B)
		75	11.9 (B)
		100	11.6 (B)
	40	50	21.0 (C)
		75	21.1 (C)
		100	20.4 (C)
	60	50	29.9 (C)
		75	30.0 (C)
		100	27.3 (C)
1250	20	50	15.5 (B)
		75	14.9 (B)
		100	15.0 (B)

Figure 3.10 Level of Service Based on Intersection Delay, Eastbound Traffic at Ottawa.

Figure 3.10 shows the delay-based LOS for eastbound traffic at Ottawa, the internal signalized intersection, while Figure 3.11 and Figure 3.12 summarize performance for main road flow at two main-road approaches at unsignalized intersections. As with the boundary intersections, acceptable delay-based LOS occurs for almost all levels of demand.

EB @ Raleigh Ave (SB)			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	4.0 (A)
		75	3.6 (A)
		100	4.2 (A)
	40	50	2.6 (A)
		75	4.2 (A)
		100	3.5 (A)
	60	50	2.7 (A)
		75	3.2 (A)
		100	5.2 (A)
750	20	50	7.3 (A)
		75	8.8 (A)
		100	10.0 (A)
	40	50	9.1 (A)
		75	9.5 (A)
		100	6.2 (A)
	60	50	12.6 (B)
		75	10.2 (B)
		100	10.3 (B)
1000	20	50	16.8 (C)
		75	16.3 (C)
		100	15.6 (C)
	40	50	15.2 (C)
		75	20.9 (C)
		100	14.1 (B)
	60	50	10.0 (A)
		75	10.4 (B)
		100	8.3 (A)
1250	20	50	20.3 (C)
		75	17.3 (C)
		100	16.6 (C)

Figure 3.11 Level of Service Based on Intersection Delay, Eastbound Traffic at Raleigh.

WB @ Natchez Ave			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	3.3 (A)
		75	4.1 (A)
		100	4.7 (A)
	40	50	3.3 (A)
		75	4.5 (A)
		100	4.8 (A)
	60	50	3.6 (A)
		75	3.5 (A)
		100	3.5 (A)
750	20	50	5.9 (A)
		75	7.0 (A)
		100	6.1 (A)
	40	50	7.8 (A)
		75	7.3 (A)
		100	4.9 (A)
	60	50	4.8 (A)
		75	4.7 (A)
		100	7.2 (A)
1000	20	50	14.3 (B)
		75	14.0 (B)
		100	11.6 (B)
	40	50	13.1 (B)
		75	11.4 (B)
		100	12.1 (B)
	60	50	43.0 (E)
		75	12.6 (B)
		100	15.6 (C)
1250	20	50	24.0 (C)
		75	25.2 (D)
		100	17.5 (D)

Figure 3.12 Level of Service Based on Intersection Delay, Westbound Traffic at Natchez.

While the LOS for major road drivers generally remained acceptable even at high demands, this was not the case for crossroad drivers at either the signalized or the unsignalized intersections. Table 3.8 summarizes the delay-based LOS for northbound traffic at Inglewood. Acceptable LOS occurred when the main road flow is 500 vphpl, while at 750 vphpl LOS=F occurs when minor road flow is 40% or more of major road flow. Table 3.9 shows similar performance for southbound traffic at the Ottawa, the internal signalized intersections. When major road flow is greater than 1000 vphpl LOS=F occurs for all levels of minor road flow.

Table 3.8 Level of Service Based on Intersection Delay for Northbound Traffic at Inglewood, Initial Simulation Runs

Northbound at Inglewood Ave				
		Minor Flow (percent of major flow)		
		20%	40%	60%
Major Flow (ADT)	500 (10000)	B	C	E
	750 (15000)	C	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

Table 3.9 Level of Service Based on Intersection Delay for Southbound Traffic at Ottawa, Initial Simulation Runs

Southbound at Ottawa Ave				
		Minor Flow (% of MUTCD Signal Warrant)		
		50%	75%	100%
Major Flow (ADT)	500 (10000)	B	C	D
	750 (15000)	C	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**F**	**F**

Table 3.10 shows a performance summary for northbound traffic using the two-way stop-controlled intersection at Raleigh. Here we see acceptable LOS for main road flows of less than or equal to 750 vphpd and LOS=F for the higher main road flows, at all levels of crossroad flow.

Table 3.10 Level of Service Based on Intersection Delay for Northbound Traffic at Raleigh, Initial Simulation Runs

Northbound at Raleigh Ave				
		Minor Flow (% of MUTCD Signal Warrant)		
		50%	75%	100%
Major Flow (ADT)	500 (10000)	B	C	C
	750 (15000)	C	D	D
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**F**	**F**

The patterns shown above were typical of what was seen at other approaches, with a rather definite break in minor approach LOS occurring at a main road flow of 750 vphpl (ADT=15000) level. To try to localize this transition from acceptable to unacceptable performance we conducted an additional factorial experiment for major road volumes of 800, 850, 900, and 950 vphpl, corresponding roughly to ADTs of 16,000, 17,000, 18,000, and 19,000 vehicles per day. The results for the original and supplemental simulation turns for northbound traffic at Inglewood, and northbound traffic at Raleigh, are shown in Table 3.11 and Table 3.12, respectively.

Table 3.11 Level of Service Based on Intersection Delay for Northbound Traffic at Inglewood, Including Supplemental Simulation Runs

Northbound at Inglewood Ave				
		Minor Flow (percent of major flow)		
		20%	40%	60%
Major Flow (ADT)	500 (10000)	B	C	E
	750 (15000)	C	**F**	**F**
	800 (16000)	**F**	**F**	**F**
	850 (17000)	**F**	**F**	**F**
	900 (18000)	**F**	**F**	**F**
	950 (19000)	**F**	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

Table 3.12 Level of Service Based on Intersection Delay for Northbound Traffic at Raleigh, Including Supplemental Simulation Runs

Northbound at Raleigh Ave				
		Minor Flow (% of MUTCD Signal Warrant)		
		50%	75%	100%
Major Flow (ADT)	500 (10000)	B	C	D
	750 (15000)	C	D	E
	800 (16000)	D	E	E
	850 (17000)	D	E	**F**
	900 (18000)	**F**	**F**	**F**
	950 (19000)	**F**	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

For the Minnetonka Boulevard example, our simulation study suggested the following tentative conclusions:

(1) For major road traffic, at both the signalized and unsignalized intersections, the three-lane configuration showed acceptable LOS even at hourly volumes greater than 750 vphpl, which correspond roughly to ADTs greater than 15,000 vehicles per day.

(2) At the crossroad approaches on the signalized intersections, substantial deterioration in LOS tended to occur when main road flows exceeded 750 vphpl. This was probably in part because these were single-lane approaches.

(3) A roughly similar pattern was seen for minor road traffic at the unsignalized intersections, with LOS=F conditions appearing as major road flow increased from 750 vphpl to 1000 vphpl, depending on the level of minor road flow.

3.4 BAKER ROAD

Figure 3.13 and Figure 3.14 show overhead views of the Baker Road site, while as before Table 3.1 gives descriptive information. This road segment is 1.7 miles long, and the boundary intersections at CSAH 62 and Valley View are controlled by traffic signals. The site also has 14 intersections that are two-way stop-controlled. In 2016 the AADT for this segment was estimated at 10,200 vehicles per day. This section currently has four travel lanes, two for eastbound traffic and two for westbound traffic.

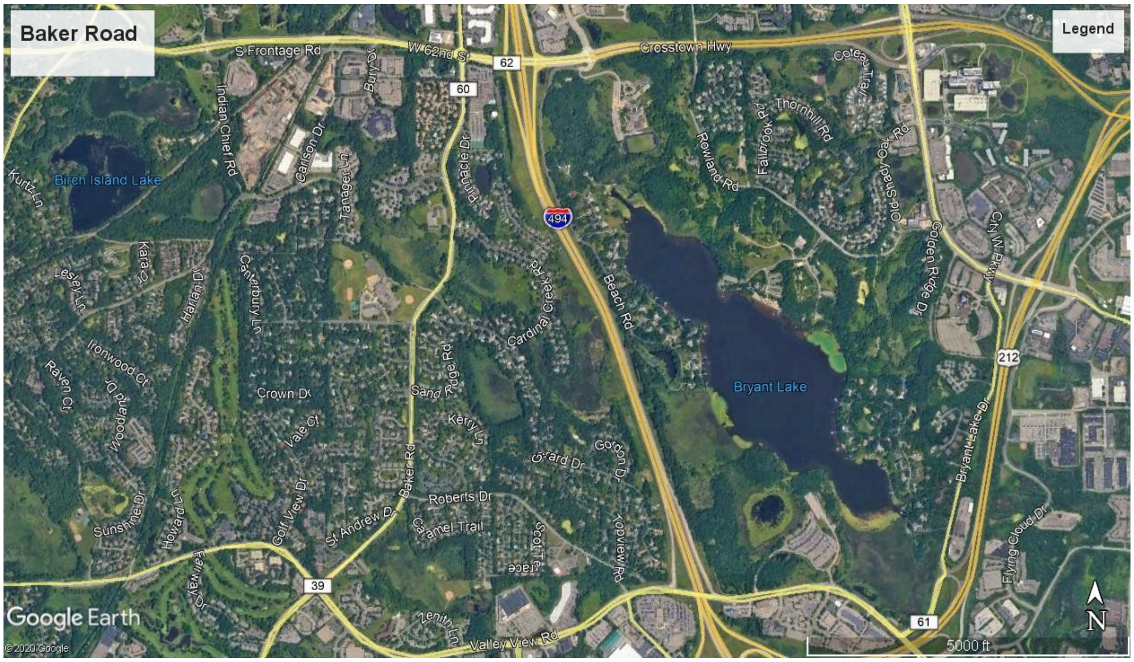


Figure 3.13 Aerial Image of Baker Road Site.

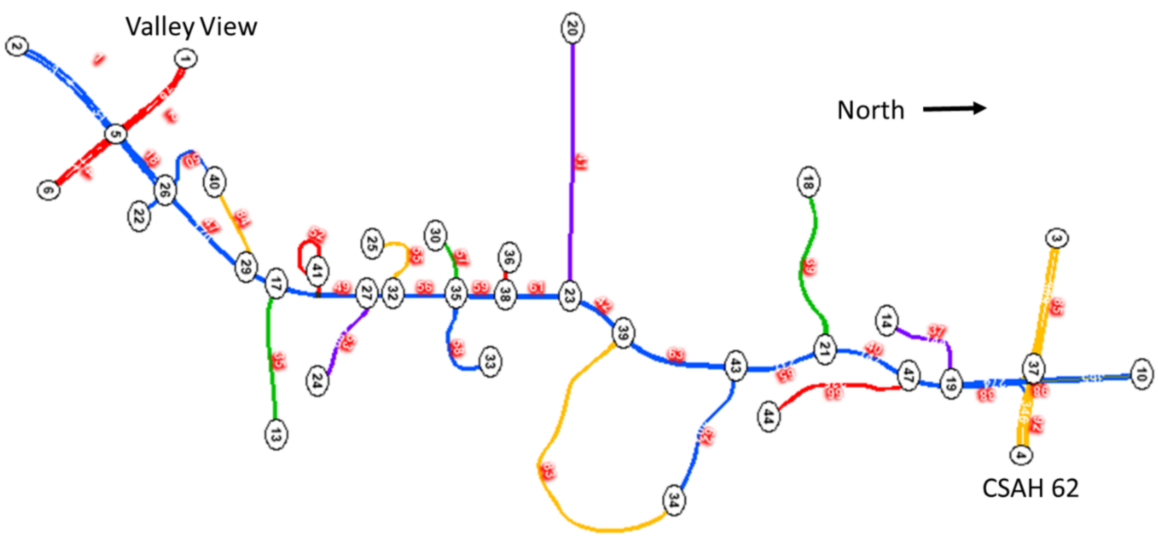


Figure 3.14 TransModeler SE Model of Baker Road.

Table 3.13 Correspondence between TransModeler SE Nodes in Figure 3.12 and Baker Road's Intersections.

Node #	Main Road	Crossroad
37	Baker Rd	CSAH 62
19		St John's Dr
47		Pinnacle Dr
21		Edenvale Blvd
43		Promontory Dr
39		Cardinal Creek Rd
23		Holly Rd
38		James Pl
35		Theresa Pl & Sand Ridge Rd
32		Candice Ln
27		Arbor Glen Dr
31		Fenwich Cir
17		Roberts Dr
29		St Andrew Dr 2
26		St Andrew Dr 1
5		Valley View Rd

As with the preceding two sites, for each feasible combination of turning movement volumes (each cell of Table 3.2) four TransModeler SE simulations were run starting with different random number seeds, and the average intersection delays for each intersection approach and the average corridor speeds were recorded. Figure 3.15 shows the summary table prepared for northbound traffic at CSAH 62. For this approach, the LOS based on approach delay were, for the most part, between A and C.

NB @ CSAH 62			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	14.8 (B)
		75	14.1 (B)
		100	13.4 (B)
	40	50	15.6 (B)
		75	15.7 (B)
		100	14.8 (B)
	60	50	16.1 (B)
		75	17.6 (B)
		100	16.4 (B)
750	20	50	15.9 (B)
		75	14.9 (B)
		100	15.4 (B)
	40	50	20.2 (C)
		75	20.2 (C)
		100	20 (B)
	60	50	20.1 (C)
		75	19.8 (B)
		100	21.2 (C)
1000	20	50	17.3 (B)
		75	18.4 (B)
		100	18.2 (B)
	40	50	27.4 (C)
		75	27.6 (C)
		100	25.3 (C)
	60	50	36.2 (D)
		75	34 (C)
		100	31.6 (C)
1250	20	50	26 (C)
		75	24.7 (C)
		100	22.7 (C)

Figure 3.15 Performance Summary for Traffic Northbound at CSAH 62.

Figure 3.16 summarizes how the delay-based LOS for southeastbound traffic at Valley View varies with the different combinations of major and minor road traffic. Like the northbound traffic at CSAH 62, LOS remains acceptable even for major road traffic volumes corresponding to ADTs above 15,000 vehicle/day.

SEB @ Valley View Rd			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	15.1 (B)
		75	14.6 (B)
		100	15.8 (B)
	40	50	20.8 (C)
		75	20 (C)
		100	19.8 (B)
	60	50	20.8 (C)
		75	20.9 (C)
		100	20.8 (C)
750	20	50	19.1 (B)
		75	18.7 (B)
		100	17.7 (B)
	40	50	27.7 (C)
		75	26 (C)
		100	26.4 (C)
	60	50	26.4 (C)
		75	27.4 (C)
		100	27.3 (C)
1000	20	50	24.4 (C)
		75	24.5 (C)
		100	24.4 (C)
	40	50	38 (D)
		75	38.6 (D)
		100	38.7 (D)
	60	50	42.7 (D)
		75	42.8 (D)
		100	43.5 (D)
1250	20	50	39 (D)
		75	36.2 (D)
		100	37 (D)

Figure 3.16 Level of Service Based on Intersection Delay, Southeastbound Traffic at Valley View.

Figure 3.17 shows delay experienced by drivers making left turns from Baker Road onto Holly Road. As with the major road traffic at the signalized intersections we see acceptable LOS even at fairly high major road flows. Finally, Figure 3.18 shows delay experience by eastbound (non Baker Road) traffic at the CSAH 62 intersection. Again, we see acceptable LOS at the higher demand levels.

NB LT @ Holly Rd			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	7 (A)
		75	7.3 (A)
		100	7.3 (A)
	40	50	6.2 (A)
		75	7.5 (A)
		100	7.3 (A)
	60	50	6.3 (A)
		75	6.2 (A)
		100	7.5 (A)
750	20	50	8.6 (A)
		75	8.6 (A)
		100	10.8 (B)
	40	50	10.1 (B)
		75	9.7 (A)
		100	10.2 (B)
	60	50	9.9 (A)
		75	11.3 (B)
		100	10.5 (B)
1000	20	50	13.8 (B)
		75	13.8 (B)
		100	16.5 (C)
	40	50	17.6 (C)
		75	15.7 (C)
		100	17.9 (C)
	60	50	17.1 (C)
		75	14.4 (B)
		100	16.9 (C)
1250	20	50	21.3 (C)
		75	23.2 (C)
		100	21.5 (C)

Figure 3.17 Level of Service Based on Intersection Delay, Northeastbound Left Turns at Holly Road.

EB @ CSAH 62			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	20.6 (C)
		75	19.4 (B)
		100	19.5 (B)
	40	50	26.1 (C)
		75	27.1 (C)
		100	27 (C)
	60	50	29.7 (C)
		75	29.4 (C)
		100	29.3 (C)
750	20	50	22.9 (C)
		75	22.6 (C)
		100	23.1 (C)
	40	50	34.9 (C)
		75	34.3 (C)
		100	35.1 (D)
	60	50	38.2 (D)
		75	38.1 (D)
		100	39.1 (D)
1000	20	50	27.9 (C)
		75	27.5 (C)
		100	28.7 (C)
	40	50	49.6 (D)
		75	48.6 (D)
		100	48.7 (D)
	60	50	56.6 (E)
		75	57 (E)
		100	57.1 (E)
1250	20	50	39.2 (D)
		75	38.6 (D)
		100	41.3 (D)

Figure 3.18 Level of Service Based on Intersection Delay, Eastbound Traffic at CSAH 62.

The situation is less encouraging when we look at minor road traffic at the unsignalized intersections. Figure 3.19 summarizes delay experienced by eastbound traffic at Holly Road, while Figure 3.20 shows similar information for westbound traffic at Cardinal Creek Road. For both approaches, LOS appears acceptable for main road flows up to 750 vphpl, but we see LOS F becoming more frequent at the higher main road flows.

EB @ Holly Rd			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	10.9 (B)
		75	16.3 (C)
		100	20 (C)
	40	50	10.4 (B)
		75	16.7 (C)
		100	24 (C)
	60	50	12.3 (B)
		75	14.7 (B)
		100	21.3 (C)
750	20	50	16.6 (C)
		75	20.6 (C)
		100	26.6 (D)
	40	50	17.5 (C)
		75	21.8 (C)
		100	25.3 (D)
	60	50	21.1 (C)
		75	23.4 (C)
		100	26.8 (D)
1000	20	50	44.9 (E)
		75	50.3 (F)
		100	92.1 (F)
	40	50	36.6 (E)
		75	36.8 (E)
		100	115 (F)
	60	50	32 (D)
		75	48.1 (E)
		100	138.1 (F)
1250	20	50	106.8 (F)
		75	313.6 (F)
		100	650.4 (F)

Figure 3.19 Delay Experienced by Eastbound Traffic at Holly Road.

WB @ Cardinal Creek Rd			
Main Flow (vhe/h/dir)	Minor Signal (%)	Minor Unsignal (%)	Avg. Delay in sec/veh (LOS)
500	20	50	14.6 (B)
		75	18.4 (C)
		100	21.2 (C)
	40	50	13.4 (B)
		75	17.4 (C)
		100	18.7 (C)
	60	50	15.7 (C)
		75	15.3 (C)
		100	23.2 (C)
750	20	50	16.3 (C)
		75	20 (C)
		100	27.9 (D)
	40	50	19.2 (C)
		75	25.3 (D)
		100	26.7 (D)
	60	50	20.3 (C)
		75	25.1 (D)
		100	28.9 (D)
1000	20	50	35.4 (E)
		75	53.7 (F)
		100	111.8 (F)
	40	50	34.7 (D)
		75	44.4 (E)
		100	66.6 (F)
	60	50	34.5 (D)
		75	54.8 (F)
		100	82.6 (F)
1250	20	50	123 (F)
		75	272.9 (F)
		100	392.2 (F)

Figure 3.20 Delay Experienced by Westbound Traffic at Cardinal Creek Road.

Table 3.14 Level of Service Based on Intersection Delay for Eastbound Traffic at Holly Road, Including Supplemental Runs

Eastbound at Holly Rd (Minor Signalized = 40%)				
		Minor Flow (% of MUTCD Signal Warrant)		
		50%	75%	100%
Major Flow (ADT)	500 (10000)	B	C	C
	750 (15000)	C	C	D
	800 (16000)	C	C	D
	850 (17000)	C	E	**F**
	900 (18000)	C	E	**F**
	950 (19000)	D	E	**F**
	1000 (20000)	E	E	**F**
	1250 (25000)	**F**	**F**	**F**

As with the 50th Street and Minnetonka Boulevard sites, we conducted supplemental runs to identify the boundaries between acceptable and unacceptable LOS at the unsignalized intersections. Table 3.14 and Table 3.15 summarize these results for the two approaches presented above. For the eastbound traffic at

Holly Road, major road flows up to 1000 vphpl (AADT=20000) gave LOS better than F as long the crossroad flow was not greater than 75% of the MUTCD signal warrant. Table 3.15 shows a roughly similar pattern for the westbound traffic at Cardinal Creek Road.

Table 3.15 Level of Service Based on Intersection Delay for Westbound Traffic at Cardinal Creek Rd, Including Supplemental Simulation Runs

Westbound at Ave Cardinal Creek Rd (Minor Signalized = 40%)				
		Minor Flow (percent of major flow)		
		20%	40%	60%
Major Flow (ADT)	500 (10000)	B	C	C
	750 (15000)	C	D	D
	800 (16000)	C	D	D
	850 (17000)	D	D	E
	900 (18000)	D	E	**F**
	950 (19000)	D	E	**F**
	1000 (20000)	D	E	**F**
	1250 (25000)	**F**	**F**	**F**

For the Baker Road site, our simulation study suggested the following conclusions:

(1) For major road traffic, at both the signalized and unsignalized intersections, the three-lane configuration showed acceptable LOS even at hourly volumes greater than 750 vphpl, which correspond roughly to ADTs greater than 15,000 vehicles per day.

(2) At the cross-street approaches for the signalized intersections, acceptable LOS was present even at higher demand levels. This is likely due to the greater capacity at these intersections compared to those on 50th Street or Minnetonka Boulevard.

(3) For minor road traffic at the unsignalized intersections, LOS=F conditions appeared as major road flow increased above 750 vphpl, depending on the level of minor road flow.

CHAPTER 4: GUIDELINES FOR 4-3 CONVERSIONS

As noted in Chapter 1 and Chapter 3, in consultation with the project's TAP it was decided to focus on identifying conditions that could justify 4-3 conversions for ADTs higher than 15,000 vehicles per day. Our review of the literature found that the capacities at a road's signalized intersections have been identified as hard constraints, and these depend on the traffic volumes on the intersections' crossroads. Our goal here is to add to the existing understanding by making initial identifications of how delay-based LOS on 3-lane configurations varies as both main road and crossroad volumes vary, for both signalized and unsignalized intersections. Chapter 3 described how we used microsimulation to study performance 4-3 conversions of three example road sections, having a total of seven signalized and 25 unsignalized intersections. Here we have selected eight intersections and 16 approaches as representative of our results.

A guideline can be reasonably interpreted as a presumption that, in the simplest version, divides relevant cases into two categories with respect to the predicted outcomes of an action. The first category contains those cases where, absent more specific information, it is predicted that the action should be successful, while the second category identifies those cases where, absent case-specific information, it is predicted that the outcomes will be unsuccessful. To use our guidelines, a user should first identify which of our exemplars is similar to an intersection of interest, then identify the LOS category defining the boundary between acceptable and unacceptable performance, and finally use our tables to divide combinations of main road and crossroad traffic flow into those having acceptable versus unacceptable predicted performance.

As an example, suppose it is decided that an intersection of interest is similar to our first exemplar, the signalized intersection between 50th and Chowen Ave, in Minneapolis. A graphic shows the intersection geometry assumed by our simulation model, and two tables summarize the predicted level of service for two representative approaches, one approach having the 3-lane design and one being an existing crossroad. If we accept LOS=C as defining the boundary of acceptable performance then our guideline predicts that the 3-lane configuration should work for 3-lane demand flows as high as 850 vehicles/hour/direction, corresponding to an approximate ADT of 17,000 vehicles per day, as long as the cross-street flow does not exceed 20% of 3-lane road's flow. If LOS=E is acceptable, then the prediction is that ADTs up to 18,000 vehicles per day could be accommodated, again as long as the cross-street flow does not exceed 20% of the 3-lane road flow. If the crossroad flow equals 40% of the 3-lane road's flow then AADTs above 10,000 vehicles per day become problematic. An unacceptable predicted performance indicates that mitigation of capacity problems should be considered in addition to the 4-3 conversion.

Exemplar Intersection #1: 50th St and Chowen Ave, Minneapolis

Figure 4.1 50th and Chowen

Configuration:
Boundary Signalized Intersection
EB/WB: 1 through lane in each direction plus 1 left-turn lane
NB/SB: 1 through lane in each direction, no left-turn lanes

Table 4.1 Main Approach: Westbound at Chowen				
		Minor Flow (Percent of Major Flow)		
		20%	40%	60%
Major Peak Hour Directional Flow (ADT)	500 (10000)	A	B	B
	750 (15000)	A	B	B
	1000 (20000)	B	B	C
	1250 (25000)	B	**X**	**X**

Table 4.2 Cross Approach: Northbound at Chowen				
		Minor Flow (Percent of Major Fow)		
		20%	40%	60%
Major Peak Hour Directional Flow (ADT)	500 (10000)	B	C	E
	750 (15000)	C	**F**	**F**
	800 (16000)	C	**F**	**F**
	850 (17000)	C	**F**	**F**
	900 (18000)	E	**F**	**F**
	950 (19000)	**F**	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

Exemplar Intersection #2: 50th St and Abbott Ave, Minneapolis

Figure 4.2 50th and Abbott

Configuration:
Internal Four-legged, Two-Way Stop Controlled Intersection
EB/WB: 1 through lane in each direction plus 1 left-turn lane
NB/SB: 1 through lane in each direction, no left-turn lanes

Table 4.3 Main Approach: Westbound Left Turns at Abbott				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	A	A	A
	750 (15000)	A	A	A
	800 (16000)	A	A	A
	850 (17000)	A	A	A
	900 (18000)	A	A	A
	950 (19000)	B	B	B
	1000 (20000)	B	B	B
	1250 (25000)	D	**X**	**X**

Table 4.4 Cross Approach: Northbound at Abbott				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	B	C	D
	750 (15000)	C	D	F
	800 (16000)	D	D	F
	850 (17000)	D	E	F
	900 (18000)	D	**F**	**F**
	950 (19000)	E	**F**	**F**
	1000 (20000)	**E**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

Exemplar Intersection #3: Minnetonka Blvd and Ottawa Ave, St. Louis Park

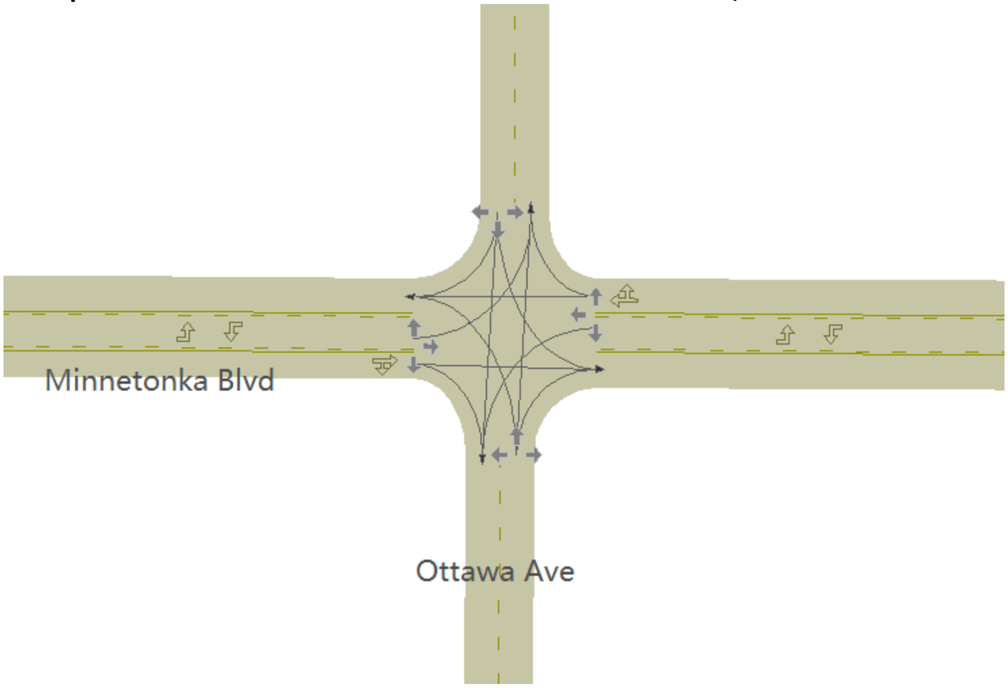


Figure 4.3 Minnetonka Blvd and Ottawa Ave

Configuration:
Internal Signalized Intersection
EB/WB: 1 through lane in each direction plus 1 left-turn lane
NB/SB: 1 through lane in each direction, no left-turn lanes

Table 4.5 Main Approach: Eastbound at Ottawa				
		Minor Flow (Percent of Major Flow)		
		20%	40%	60%
Major Peak Hour Directional Flow (ADT)	500 (10000)	A	A	A
	750 (15000)	A	A	B
	1000 (20000)	B	C	C
	1250 (25000)	B	**X**	**X**

Table 4.6 Cross Approach: Southbound at Ottawa				
		Minor Flow (Percent of Major Fow)		
		60%	40%	60%
Major Peak Hour Directional Flow (ADT)	500 (10000)	B	C	D
	750 (15000)	C	**F**	**F**
	800 (16000)	C	**F**	**F**
	850 (17000)	D	**F**	**F**
	900 (18000)	D	**F**	**F**
	950 (19000)	E	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**X**	**X**

Exemplar Intersection #4: Minnetonka Blvd and Natchez Ave, St Louis Park

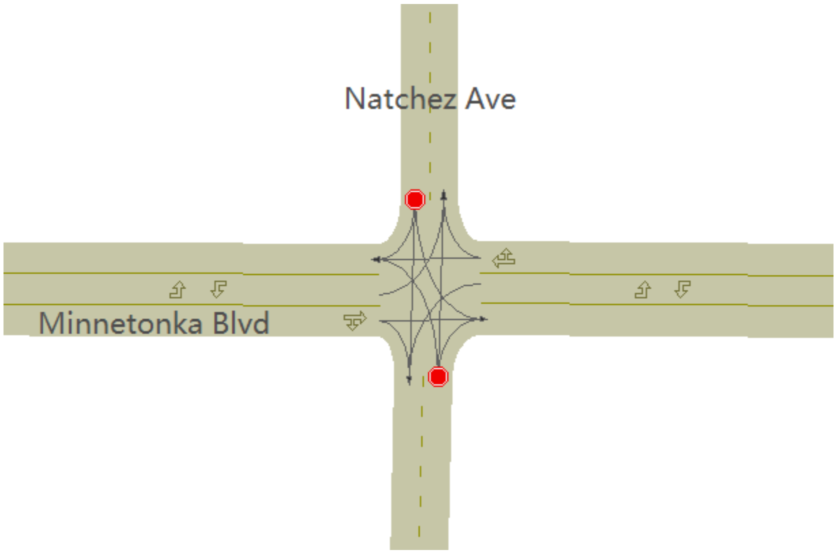


Figure 4.4 Minnetonka Blvd and Natchez Ave.

Configuration:
Internal Four-legged, Two-Way Stop-Controlled Intersection
EB/WB: 1 through lane in each direction plus 1 left-turn lane
NB/SB: 1 through lane in each direction, no left-turn lanes

Table 4.7 Main Approach: Eastbound Left Turns at Natchez				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	A	A	A
	750 (15000)	A	A	A
	800 (16000)	A	A	A
	850 (17000)	A	A	B
	900 (18000)	B	B	B
	950 (19000)	B	B	B
	1000 (20000)	C	C	C
	1250 (25000)	D	D	D

Table 4.8 Cross Approach: Southbound at Natchez				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	C	C	E
	750 (15000)	D	E	**F**
	800 (16000)	E	E	**F**
	850 (17000)	E	**F**	**F**
	900 (18000)	E	**F**	**F**
	950 (19000)	**F**	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**F**	**F**

Exemplar Intersection #5: Minnetonka Blvd and Quentin Ave, St. Louis Park

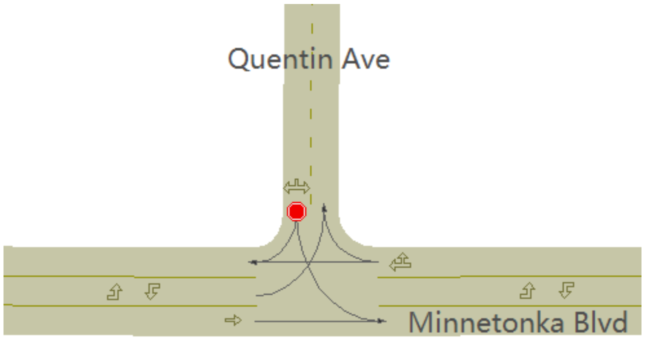


Figure 4.5 Minnetonka Blvd and Quentin Ave.

Configuration:
Internal Three-legged, Two-Way Stop-Controlled Intersection
EB/WB: 1 through lane in each direction plus 1 left-turn lane
SB: 1 lane for right-turn and left-turn lane

Table 4.9 Main Approach: Eastbound Left Turns at Quentin				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	A	A	A
	750 (15000)	A	A	A
	800 (16000)	A	B	B
	850 (17000)	B	B	B
	900 (18000)	B	B	B
	950 (19000)	C	C	C
	1000 (20000)	C	C	C
	1250 (25000)	C	C	C

Table 4.10 Cross Approach: Southbound at Quentin				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	B	C	C
	750 (15000)	C	D	D
	800 (16000)	C	D	E
	850 (17000)	D	E	**F**
	900 (18000)	E	**F**	**F**
	950 (19000)	E	**F**	**F**
	1000 (20000)	**F**	**F**	**F**
	1250 (25000)	**F**	**F**	**F**

Exemplar Intersection #6: Baker Rd and CSAH 62, Eden Prairie/Minnetonka

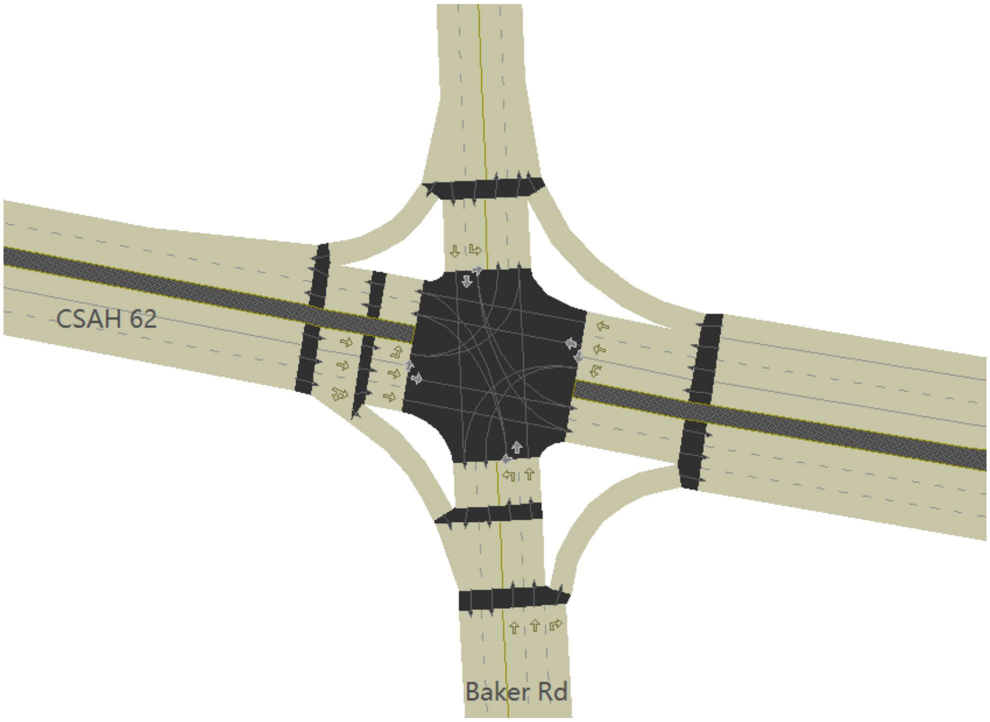


Figure 4.6 Baker Road and CSAH 62

Configuration:
Boundary Signalized Intersection
EB/WB: 2 through lanes in each direction plus 1 left-turn lane
NB/SB: 1 through lane in each direction plus 1 left-turn lane

Table 4.11 Main Approach: Northbound Baker at CSAH 62				
		Minor Flow (Percent of Major Flow)		
		20%	40%	60%
Major Peak Hour Directional Flow (ADT)	500 (10000)	B	B	B
	750 (15000)	B	C	C
	1000 (20000)	B	C	C
	1250 (25000)	C	**X**	**X**

Table 4.12 Cross Approach: Westbound CSAH 62 at Baker				
		Minor Flow (Percent of Major Fow)		
		20%	40%	60%
Major Peak Hour Directional Flow (ADT)	500 (10000)	C	C	C
	750 (15000)	C	C	D
	800 (16000)	C	D	D
	850 (17000)	C	D	D
	900 (18000)	C	D	D
	950 (19000)	C	D	D
	1000 (20000)	C	D	D
	1250 (25000)	D	**X**	**X**

Exemplar Intersection #7: Baker Rd and St. Andrew Dr, Eden Prairie

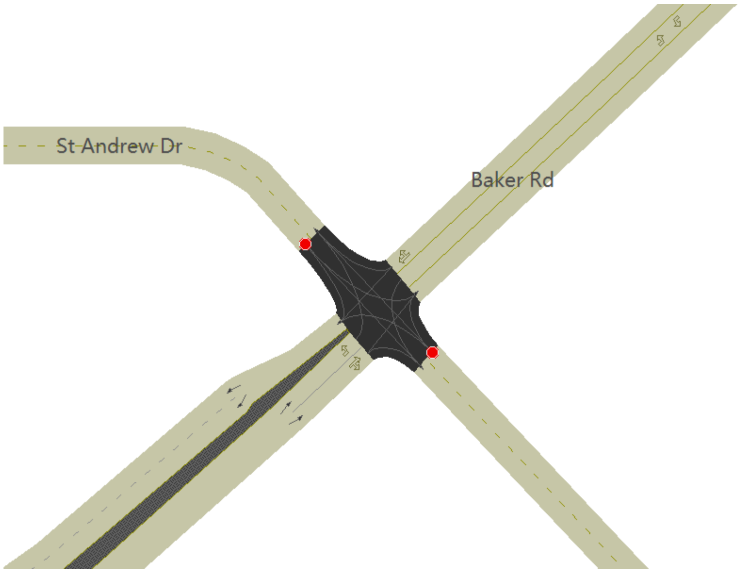


Figure 4.7 Baker Road and St. Andrew Drive

Configuration:
Internal Four-legged, Two-Way Stop-Controlled Intersection
NEB/SWB: 1 through lane in each direction plus 1 left-turn lane
NWB/SEB: 1 through lane in each direction, no left-turn lanes

Table 4.13 Main Approach: Southwestbound Left Turns at St. Andrew Drive				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	A	A	A
	750 (15000)	A	A	A
	800 (16000)	A	A	A
	850 (17000)	A	B	B
	900 (18000)	B	B	B
	950 (19000)	B	C	C
	1000 (20000)	B	C	C
	1250 (25000)	D	E	E

Table 4.14 Cross Approach: Northwestbound at Baker				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	C	E	**F**
	750 (15000)	D	E	**F**
	800 (16000)	D	E	**F**
	850 (17000)	D	**F**	**F**
	900 (18000)	E	**F**	**F**
	950 (19000)	E	**F**	**F**
	1000 (20000)	E	**F**	**F**
	1250 (25000)	**F**	**F**	**F**

Exemplar Intersection #8: Baker Rd and Holly Rd, Eden Prairie

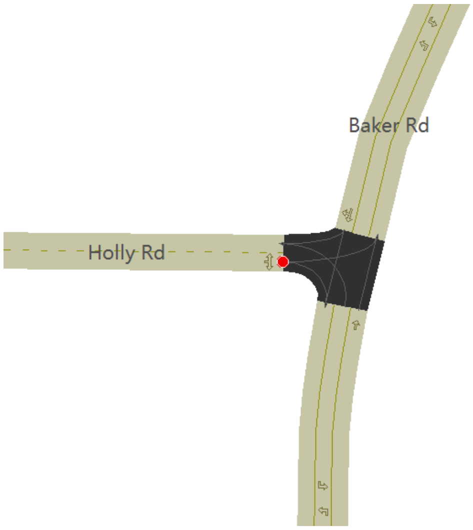


Figure 4.8 Baker Road and Holly Road

Configuration:
Internal Three-legged, Two-Way Stop-Controlled Intersection
NB/SB: 1 through lane in each direction plus 1 left-turn lane
WB: 1 lane for right-turn and left-turn

Table 4. 15 Main Approach: Northbound Left Turns at Holly Road				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	A	A	A
	750 (15000)	A	A	B
	800 (16000)	B	B	B
	850 (17000)	B	B	B
	900 (18000)	B	B	B
	950 (19000)	B	B	B
	1000 (20000)	C	C	C
	1250 (25000)	C	C	C

Table 4.16 Cross Approach: Eastbound on Holly Road				
		Minor Flow (Percent of MUTCD Signal Warrant)		
		50%	75%	100%
Major Peak Hour Directional Flow (ADT)	500 (10000)	B	C	C
	750 (15000)	C	C	D
	800 (16000)	C	C	D
	850 (17000)	C	D	E
	900 (18000)	C	D	**F**
	950 (19000)	D	E	**F**
	1000 (20000)	E	E	**F**
	1250 (25000)	**F**	**F**	**F**

CHAPTER 5: SUMMARY AND CONCLUSIONS

Converting a four-lane road to one where a two-way, left-turn lane separates single directional lanes is a recognized safety countermeasure and can provide space for alternative uses such as shoulders, parking, bikeways, and transit lanes. The feasibility of a 4-3 conversion will depend on whether or not the capacity provided by a three-lane cross-section remains sufficient to accommodate traffic demand, and it has been suggested that when average daily traffic (ADT) volumes on the candidate road are below 15,000 vehicles per day, then such a conversion should be feasible. Several authorities have pointed out however that: (1) differences within a day’s traffic patterns can produce the same ADT, so demand during peak periods can affect feasibility, and (2) traffic demand on crossroads should also be taken into account.

In this project, we conducted simulation experiments to relate level-of-service on three-lane cross-sections to both main-road and crossroad hourly flows, for both signalized and two-way, stop-controlled intersections. A main goal was to identify demand conditions where a 4-3 conversion might be feasible when main road demand exceeded an ADT of 15,000. Generally, we found that 4-3 conversions can be feasible for ADTs greater than 15,000 as long as demands on crossroads remain low enough. The results from our simulation studies were then summarized in a set of two-way tables that show LOS ratings for different demand combinations for eight exemplars that cover the range of intersections included in our study. The tables can be used to separate the main and crossroad demand combinations into feasible and unfeasible regions. A user considering a 4-3 conversion can select the exemplar(s) having geometries similar to intersections in the proposed conversion, and then use our tables to get an initial assessment of feasibility.

Several authorities have pointed out that the variety in the different conditions that can be encountered on existing roads makes it difficult to provide broad, low-dimensional recommendations regarding the feasibility of 4-3 conversions. We agree with this view, and recommend that our guidelines are best applied initially to identify those situations where, although main road ADTs exceed 15,000, the crossroad demands are low enough that a 4-3 conversion could remain possible. More detailed evalution of the actual design, including particulars like bicycle lanes, transit access, peak spreading, driver and pedestrian safety, and possible capacity improvments on crossroads, should still be considered. A final decision would also involve balancing these consideratins with other goals such as those associated with complete streets and the accommodation of multiple modes on a road.

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APPENDIX A

ROAD DIET DESIGN ELEMENTS

Bike lanes: Presence of marked or signed bicycle lanes on main (road diet) roadway

Medians: Presence of median separating directional movements on main (road diet) roadway

Turn pockets: Presence of short turn lanes separating right turns from bus, bike, or vehicle traffic

Sidewalks/width: Presence and/or width of sidewalks along main (road diet) roadway

Buffers/width: Presence and/or width of strips separating sidewalks from roadways

Bus stops: Presence/location of bus stops along main (road diet) roadway

On-street parking: Presence of permitted parking places along main (road diet) roadway

Access spacing: Distances between driveways/access roads along main (road diet) roadway

Shoulders/width: Presence, width, and type of shoulders along main (road diet) roadway

Pedestrian islands: Presence, width, and length of pedestrian islands in main (road diet) roadway

Crosswalks: Location, size, and type of crosswalks across main (road diet) roadway

Curb return: Radii of curbs connecting tangent curbs at intersections

Shy distance: Distances needed, by pedestrians or drives, to comfortable pass structures or other features

Design speed: Design speed for main (road diet) roadway and/or crossroads

Bus turnouts: Presence or location of pavement widening to accommodate bus stops

Right turn lanes: Presence and/or design of right-turn lanes from main (road diet) roadway

Roundabouts: Presence and/or design of roundabouts at intersections between main and crossroads

Side street control: Type of traffic control for side roads intersecting main (road diet) roadway

Intersection control: Type and design of control at intersections between main and crossroads

Main road sight distance: Available or required sight distances for left or right turns from major road

Crossroad sight distance: Available or required sight distances for turning or crossing movements from side roads

Location (e.g. Urban/Suburban/Rural): Considerations regarding road diets in urban versus suburban versus rural conditions

Adjacent land use: Considerations regarding effects of particular land uses on road diet performance

Operating speed: Considerations regarding actual speeds on candidates for road diet conversions

Main road traffic volume: Considerations regarding main road traffic volumes on road diet effectiveness

Minor road(s) traffic volume: Considerations regarding crossroad traffic volumes on road diet effectiveness

Lane widths: Through lanes: Considerations regarding width of through lanes on road diet effectiveness

Lane widths: TWLTL: Considerations regarding width of TWLT lanes of road diet effectiveness

Lane widths: left turn (with median): Considerations regarding sizing of left-turn lanes on main (road diet) roadway

Adjacent feature: Considerations regarding effect of features along main roadway that could affect road diet effectiveness

Overall width: Considerations regarding overall main roadway width both before and after conversion

Target Speed: Considerations regarding speeds that conversion seeks to achieve

Distracted Driving: Considerations regarding effect of distracted drivers on road diet effectiveness

Driveway left-turn conflicts (overlapping movements): Considerations regarding effect of opposing left-turn movements on road diet effectiveness

Driveway volumes: Considerations regarding traffic volumes entering or exiting from driveways accessing main (road diet) roadway.

APPENDIX B

LITERATURE SOURCES, WITH ABSTRACTS

Most of the following abstracts were taken either from the original documents or from the TRID database. These are shown in italics. Those that were written by project personnel are shown in regular type.

1 Turner-Fairbank Highway Research Center (2010). Evaluation of Lane Reduction "Road Diet" Measures on Crashes. McLean, VA: U.S. Department of Transportation, Federal Highway Administration, Research, Development, and Technology, Turner-Fairbank Highway Research Center.

This Highway Safety Information System (HSIS) summary replaces an earlier one, Evaluation of Lane Reduction "Road Diet" Measures and Their Effects on Crashes and Injuries (FHWA-HRT-04-082), describing an evaluation of "road diet" treatments in Washington and California cities. This summary reexamines those data using more advanced study techniques and adds an analysis of road diet sites in smaller urban communities in Iowa. A road diet involves narrowing or eliminating travel lanes on a roadway to make more room for pedestrians and bicyclists. While there can be more than four travel lanes before treatment, road diets are often conversions of four-lane, undivided roads into three lanes—two through lanes plus a center turn lane. The fourth lane may be converted to a bicycle lane, sidewalk, and/or on-street parking. In other words, the existing cross-section is reallocated. This was the case with the two sets of treatments in the current study. Both involved conversions of four lanes to three at almost all sites. While potential crash-related benefits are cited by road diet advocates, there has been limited research concerning such benefits. Two prior studies were conducted using data from different urbanized areas. The first, conducted by HSIS researchers, used data from treatment sites in eight cities in California and Washington. The second study analyzed data from treatment sites in relatively small towns in Iowa. While the nature of the treatment was the same in both studies (four lanes reduced to three), the settings, analysis methodologies, and results of the studies differed. Using a comparison of treated and matched comparison sites before and after treatment and the development of negative binomial regression models, the earlier HSIS study found a 6 percent reduction in crash frequency per mile and no significant change in crash rates at the California and Washington sites. Using a long-term (23-year) crash history for treated and reference sites and the development of a hierarchical Poisson model in a Bayesian approach, the later Iowa study found a 25.2 percent reduction in crash frequency per mile and an 18.8 percent reduction in crash rate. Because of these differences, researchers from the National Cooperative Highway Research Program (NCHRP) 17-25 project team obtained and reanalyzed both data sets using a common methodology. This summary documents the results of that reanalysis.

2 Bonneson, James A., Patrick T. McCoy, American Association of State Highway Transportation Officials, and National Research Council. Transportation Research Board. Capacity and Operational Effects of Midblock Left-Turn Lanes. Washington, D.C.: National Academy Press, 1997.

The objective of this research project was to develop a methodology for evaluating alternative midblock left-turn treatments on urban and suburban arterials. This methodology is applicable to three commonly found midblock left-turn treatments: the raised-curb median, the flush median with two-way left-turn lane (TWLTL) delineation, and the undivided cross-section. The approach taken in conducting this research was to develop a comprehensive midblock left-turn treatment evaluation methodology, collect field data to

calibrate this methodology, and then use the calibrated methodology to develop treatment selection guidelines. This approach was applied to the parallel development of three models that comprise the evaluation methodology. These three models can be used to evaluate the operational effects, safety effects, and the access impacts associated with a specific midblock left-turn treatment. The operations and safety models were used to develop midblock left-turn treatment selection guidelines based on a benefit-cost analysis approach. The following conclusions have been reached as a result of this research. First, the raised-curb median and the TWLTL yield similar delays to arterial drivers while the undivided cross-section yields significantly higher delays than either the raised-curb median or TWLTL. Second, any of the left-turn treatment types can function without congestion to the arterial traffic movements at average daily traffic demands of 40,000 vpd or less. Third, the difference in safety between the undivided and TWLTL treatments is highly dependent on whether parallel parking is permitted; however, the raised-curb median treatment appears to be associated with fewer accidents than either the undivided cross-section or the TWLTL, when all other factors are equal. Fourth, business owners believe that the conversion from an undivided cross-section to either a raised-curb median (with frequent median openings) or a TWLTL will improve arterial traffic conditions and business conditions; however, they also believe that a raised-curb median with infrequent median openings will not improve business opportunities.

3 Bowman, B. L., R. W. Paulk, and W. C. Zech (2005). Analysis of Cross-Median Crashes on Divided Partial Control of Access Arterial for the State of Alabama. In Accessed from TRB 2005 Annual Meeting CD-ROM.

4 Burden, Dan, and Peter Lagerway (1999). Road diets: fixing the big roads. Walkable Communities, Inc. Minneapolis, MN.

This article is primarily a rhetorical exercise in favor of road diets, touted as a cure for "sick" roads. Four-lane road with ADTs in the range of 12,000-18,000, with "excessive" vehicle speeds are recommended candidates for road diets. Cases of successful conversions with higher ADTs are presented. The importance of preserving intersection capacity and density of driveways are mentioned.

5 City of Orlando – Transportation Planning Bureau (2002). Edgewater Drive Before & After Re-Striping Results.

This article describes a before/after evaluation of a conversion of Edgewater Drive. in Orlando FL. Before conversion, the target road had four lanes with "approximately 20,000 Average Daily Trips." Decreases in crash rates and frequencies were reported, as were decreases in the fractions of drivers going faster than 35 mph. Some reductions in main road ADTs were reported, but no obvious change in side-road volumes.

6 City of Seattle – Department of Transportation (2010). Stone Way N Rechannelization: Before and After study.

This article describes a before/after evaluation of conversion on Stone Way, in Seattle WA. Initial ADTs in the range of 5,000-7500 tended to decline after conversion, as did crash frequencies. A substantial decrease in fraction of drivers exceeding the speed limit by 10 mph was reported.

7 Committee 4A-2 (1981). Design and Use of Two-Way Left-Turn Lanes. ITE Journal, pp 30-37.

This article presents ITE's 1981 recommended practice regarding two-way left-turn lanes.

8 Cynecki, M. J., & Sparks, J. (1992). A study of two-way left-turn lane pavement markings. ITE journal, 62(6), 38-42.

The city of Phoenix recently completed a study designed to measure the effectiveness of 2-way left-turn lanes (TWLTL) throughout the city. TWLTL provides a sheltered storage area for left-turning vehicles on high-volume streets. The TWLTL offers many benefits including a substantial reduction in accidents, increased capacity, reduced delay and congestion, separation of oncoming traffic, and space for construction detours and other emergency uses. The concept has been expanded to include a sheltered storage area to facilitate left turns onto a major street. The study found that TWLTL in Phoenix is very effective in reducing accidents and improving service to driveways and side streets. TWLTLs also have been helpful serving as a limited refuge area for pedestrians and for improving overall street capacity.

9 Fang, F. C., Rimiller, J. H., & Habesch, N. O. (2007). Safer Streets: The Measured Effectiveness of Hartford's Citywide Traffic Calming Program. ITE Journal, 18(1).

The City of Hartford, Connecticut made an innovative move in 2005 when it developed a comprehensive citywide traffic calming master plan. This plan, the first of its kind in the United States, and the process used to develop it were presented at the 2005 Institute of Transportation Engineers (ITE) Technical Conference and Exhibit. Two years later, as this ambitious plan is gradually implemented, the city is collecting "before" and "after" data for many of the traffic calming devices so that their impact on vehicular safety can be measured and so that future deployments may be validated. This paper presents a case study on the effects of deploying road diets on crash frequency. Roads that were placed on road diets were compared to similar roads that did not receive any treatments. The Empirical Bayesian (EB) method was used to predict the "expected" crash rate during the "after" period without implementation based on the control sites. The observed "before" crash rates, the crash rate expected without improvement, and the observed "after" crash rate were compared and discussed in this paper.

10 Genesee County Metropolitan Planning Commission. "Complete Streets Technical Report."

This is an informational report prepared by Genesee County planning agency, with some interesting guidance on when road-diets might be appropriate

"Average Daily Traffic Count (ADT) of under 10,000 is highly likely as feasible. ADT of 10,000 to 20,000 may be feasible depending on other factors. ADT over 20,000 typically is not appropriate for a road diet."

"When narrow lane widths prohibit correct use of 4-lane roadway. 12 ft lane width is standard, less than 12 ft lane width can prohibit cars from passing safely."

"When land use on a corridor produces lots of turning movements such as a block-style street grid, shopping areas along a corridor, school zones, etc."

"When rates of traffic accidents for head on, head on – left turn, angle, rear end, and rear end – left turn crashes are higher than average for similarly functionally classified roadways."

"When bike lanes are needed in the area."

"When a parallel route exists with a higher capacity (5-lane road)"

"When traffic calming is needed"

"When on-street parking is needed"

11 Giese, K., Knapp, K., & Welch, T. (2001, August). CORSIM Sensitivity Analysis of Four To Three-Lane Cross-Section Conversion Operational Impacts. In ITE 2001 Annual Meeting and ExhibitInstitute of Transportation Engineers (ITE) (No. CD-013).

This study investigated and compared the simulated operational measures of effectiveness for similar traffic volumes and access densities for a case study roadway with a four-lane undivided and a three-lane cross-section. The objectives of this study were to quantify and define the operational impacts and feasibility of this type of conversion. The CORSIM model was used to complete a sensitivity analysis that included five simulations for each combination of four peak-hour volumes, and six access point densities. In general, a statistically significant decrease in average arterial travel speed was found when the roadway was converted from a four-lane undivided to a three-lane cross-section. The magnitude of the decrease, however, ranged only from 0.5 to 3.9 miles per hour. The arterial level of service (LOS) decreased from LOS C to D when the bidirectional peak-hour volume was 2,000 vehicles per hour (the largest volume considered). The timing of the two-phase signalized intersections within the simulated corridor was optimized and did not experience a change of more than 5.5 seconds per vehicle in average stopped delay (i.e., no overall intersection LOS change). The portion of the decrease in average arterial speed that occurred on the roadway segments and at the signalized intersections is currently under investigation. Actual four-lane to three-lane conversions have decreased crashes and crash rates, produced small reductions in average travel speed (similar to the CORSIM results), and resulted in large reductions in the number of speeding vehicles.

12 Harwood, D. (1986). Multilane Design Alternatives for Improving Suburban Highways (National Cooperative Highway Research Program Report 282). Transportation Research Board, National Research Council, Washington, D.C.

The objective of this research was to investigate and compare the safety, operational, and cost characteristics of selected multilane design alternatives for suburban highways. Operational characteristics of interest to the study included capacity, level of service, and accessibility. Safety characteristics included the frequency, severity, and type of accidents. The multilane design alternatives that were the major focus of the research included: three-lane divided including a two-way left-turn lane in the median; four-lane undivided; four-lane undivided; four-lane divided with a raised-median; and five-lane divided including a two-way left-turn in the median. Other multilane design alternatives that were considered in the study included: five-lane divided with a continuous alternating left-turn lane in the *median; six-lane divided with a raised median; and seven-lane divided with a two-way left-turn in the median. A two-lane undivided suburban highway served as the base condition for the study. A safety database was assembled for suburban highways on the state highway systems of California and Michigan to quantify the safety performance of multilane design alternatives. Accident rate estimates and the percentage of accidents involving a fatality or injury and the percentage of accidents susceptible to correction by median treatments were also quantified by design alternative and type of development. Traffic operational comparisons of suburban highway sections with and without two-way left-turn lanes were made using a computer traffic simulation model. The research provides a comparison of the advantages, disadvantages, and relative merits of the various design alternatives for suburban highways, including both their traffic operational and safety performance, as well as the less quantitative aspects such as the impacts on land use and development, abutting businesses, and pedestrians and bicycles. A stepwise process for selecting an appropriate design alternative for use on a suburban highway is suggested.*

13 Harwood, D., American Association of State Highway Transportation Officials, & National Research Council. Transportation Research Board. (1990). Effective Utilization of Street Width on Urban Arterials, (Aleph) 002060351UMN01 no:326-332.

The objective of this research was to determine the effectiveness of various alternative strategies for reallocating the usage of street width on urban arterials without changing the total curb-to-curb width. The research evaluated improvement strategies for urban arterial streets with curb-and-gutter cross-sections and speeds of 45 mph or less. The design alternatives that were evaluated ranged from a two-lane undivided cross-section to cross-sections with as many as eight lanes for through traffic. Evaluations were performed on the safety effectiveness of 35 improvement projects that involved use of lane widths of 10 ft or less. Field observations of passenger car and truck operations on selected sites were also conducted. The evaluation concluded that improvement strategies that involve installation of a center two-way left-turn lane are likely to reduce accident rates even when narrower lanes for through traffic must be used. Improvement strategies to provide additional through lanes without the addition of a two-way left-turn lane may increase intersection accidents, but generally do not affect midblock accidents. None of the strategies involving narrower lanes affected accident severity. The report includes a recommended process for selecting appropriate improvement strategies for urban arterials based on their traffic operational and safety effects. Guidelines for implementation and evaluation of projects are presented.

14 Huang, H. F., Stewart, J. R., & Zegeer, C. V. (2005). Evaluation of Lane Reduction" Road Diet" Measures and Their Effects on Crashes and Injuries. Transportation Research Record, 1784, 80-90.

“Road diets” are often conversions of four-lane undivided roads into three lanes (two through lanes plus a center turn lane). The fourth lane may be converted to bicycle lanes, sidewalks, or on-street parking. Road diets are sometimes implemented with the objective of reducing vehicle speeds as well as the number of motor vehicle crashes and injuries. A study was conducted to investigate the actual effects of road diets on motor vehicle crashes and injuries. Twelve road diets and 25 comparison sites in California and Washington cities were analyzed. Crash data were obtained for these road diets (2,068 crashes) and comparison sites (8,556 crashes). A “before” and “after” analysis using a “yoked comparison” study design

found that the percent of road diet crashes occurring during the "after" period was about 6% lower than that of the matched comparison sites. However, a separate analysis in which a negative binomial model was used to control for possible differential changes in average daily traffic, study period, and other factors indicated no significant treatment effect. Crash severity was virtually the same at road diets and comparison sites. There were some differences in crash type distributions between road diets and comparison sites, but not between the "before" and "after" periods. Conversion to a road diet should be made on a case-by-case basis in which traffic flow, vehicle capacity, and safety are all considered. It is also recommended that the effects of road diets be further evaluated under a variety of traffic and roadway conditions.

15 Hummer, J.E., and C.F. Lewis. (2000). Operational Capacity of Three-Lane Cross-Sections (Report Number FHWA/NC/2000-003). Center for Transportation Engineering Studies, North Carolina State University, Raleigh, NC. (Not in zip-file)

16 Knapp, K. K., & Giese, K. (2001). Guidelines for the conversion of urban four-lane undivided roadways to three-lane two-way left-turn lane facilities.

The primary objective of this research project was to develop a set of guidelines to assist in the selection of candidate roadways for urban four-lane undivided to three-lane cross-section conversions. The authors evaluated and assessed the physical, operational, and safety characteristics that appear to be compatible with the consideration and/or feasibility of this type of conversion. These characteristics were evaluated qualitatively, with simulation software, and through an interpretation of subjective and objective before-and-after study results from four-lane undivided to three-lane conversions throughout the United States and Iowa. Some of the roadway characteristics investigated were roadway function and environment, overall traffic volume and level of service, turning volumes and patterns, weaving/speed/queues, crash types and patterns, pedestrian and bicycle activity, right-of-way availability/cost/acquisition, and several other general characteristics (e.g., parallel parking).

17 Knapp, K. K., & Rosales, J. A. (2007). Four-lane to three-lane conversions: An update and a case study. In 3rd Urban Street Symposium: Uptown, Downtown, or Small Town: Designing Urban Streets That Work. Transportation Research Board. Institute of Transportation Engineers (ITE) US Access Board.

A presentation at the first Urban Street Symposium promoted the more widespread consideration and examination of four- to three-lane roadway cross-section conversions. At the second Urban Street Symposium a set of guidelines for their implementation, along with other relevant ongoing and completed projects, were summarized. Several additional four- to three-lane conversion analyses have been completed since that time. This paper summarizes some of the key text from the conversion guidelines mentioned above and also presents the results of several recently completed projects that add to the current state-of-the-knowledge in this subject area. The feasibility determination factors for a potential four- to three-lane case study conversion location are then described and evaluated. The factors of special interest along this case study roadway were its desired and actual roadway function and vehicle speed, intersection operations and design, business access, truck traffic, pedestrians, right-of-way availability, and a nearby parallel railroad track. The characteristics of these and other factors are discussed and a list *of observations and lessons learned from this case study application are provided. Some of the roadway factors and characteristics that should be considered early in the cross-section comparison process (before more detailed design, etc.) are noted.*

18 Knapp, K. K., Giese, K. L., & Lee, W. (2003, July). Urban minor arterial four-lane undivided to three-lane conversion feasibility: An update. In 2nd Urban Street Symposium, Anaheim, California.

At the first Urban Street Symposium in June 1999, the feasibility of converting urban four-lane undivided roadways to three-lane cross-sections was introduced. Several successful examples of this type of conversion were discussed. It was found that in some cases this type of conversion might be able to improve safety with only a small reduction in operations. A significant amount of work has been done related to the potential safety and operational impacts of four-lane undivided to three-lane conversions since 1999. This paper summarizes the content of some guidelines and research completed by the authors. Data from case study conversions are presented and feasibility determination factors are described. A CORridor SIMulation (CORSIM) software package sensitivity analysis approach was used in two projects to support the discussion of the factors related to the traffic flow differences of similar four-lane undivided and three-lane roadways. The variables considered in the analyses were total entering traffic volume (up to 1,150 vehicles per hour per direction), different levels of left-turn traffic, access point densities, percent heavy vehicles, and bus stop activities (e.g., bus dwell times and headways). Investigations of the difference in signalized side-street vehicle delays and off-peak average arterial travel speed were also completed. The results of all the work recently completed in this area should help urban street designers decide whether a four-lane undivided to three-lane conversion is feasible at a particular location, and whether it will help improve their situation.

19 Knapp, K., Giese, K., & Welch, T. (2002). Comparison of Simulated Average Arterial Travel Speeds Along Four-Lane Undivided and Three-Lane Roadways with Similar Traffic Flow and Access Density Characteristics. In 81st Annual Meeting TRB.

The operational benefits of widening cross-sections have been the focus of numerous studies. Almost no research has been completed to quantify the operational impacts of urban four-lane undivided to three-lane conversions. This research investigated the changes in simulated average arterial travel speeds for a pre-defined corridor with either a four-lane undivided or three-lane urban cross-section. CORridor SIMulation software was used to determine the average arterial travel speed for 64 combinations of roadway characteristics. Four bi-directional peak-hour volumes, three access point left-turn percentages, and six access point densities were considered. The corridor was 0.4-kilometer (1/4-mile) long with two signalized intersections and had evenly distributed access points. The simulation results show little difference between urban four-lane undivided and three-lane roadway average arterial travel speeds. Overall, the average arterial travel speed differences ranged from 0 to 6.3 kilometers per hour (kph) (0 to 3.9 miles per hour (mph)). For general comparison purposes, the before-and-after speed studies reviewed for this research along converted roadways has typically shown a decrease in spot speeds up to 11.3 kph (7 mph). A Wilcoxon signed-rank test indicated that most of the differences simulated, although small, were statistically significant. The minimum difference occurred when total entering volume was 1,500 vehicles per hour and access point densities high. This result supports the idea that urban four-lane

undivided and three-lane roadways may begin to operate in a similar manner as volumes and access densities increase. The simulation speed results are summarized in this paper, and findings and recommendations are documented. Future research ideas are suggested along with how some of the study results might be used.

20 Kueper, D. A. (2007). Road diet treatment in Ocean City, NJ, USA. ITE Journal (Institute of Transportation Engineers), 77(2), 18-22.

West Avenue in Ocean City, NJ, USA, historically has consisted of four travel lanes, two parking lanes and a striped median. In accordance with a new circulation plan, a six-block section of West Avenue was placed on a Trial "road diet" and re-striped to include two through lanes, a median lane for left turns, pedestrian refuges, two bike lanes and two parking lanes. Ocean City has decided to extend the road diet over a greater length of West Avenue….An extensive before-and-after data analysis was not conducted because the road diet was recommended as part of the city's circulation element, which, in New Jersey, is comprehensive by definition. The Ocean City circulation element focused on conceptual strategies to improve conditions for all travel modes in various parts of the city, and resources were not available to conduct a major data collection effort at any one site. Although the conclusions on the effect of the road diet treatment in Ocean City are limited, the intent of this feature is to focus on the process followed in implementing the treatment, which proved satisfactory to municipal officials and residents alike.

21 Lee, W. (2002). High Volume, Heavy Vehicle, and Bus Stop Impacts on Four Lane to Three-Lane Conversion. Master of Science Thesis, Department of Civil & Environmental Engineering, University of Wisconsin-Madison.

Some of the operational and safety impacts of converting four-lane undivided (4LUD) roadways to three lanes have been considered in the past. The study described in this thesis supplements and expands upon the previous operational analyses. The differences in the traffic flow and vehicle operation along similar 4LUD and three-lane (3L) roadways are simulated, investigated, and presented. Unlike past studies, however, the operational differences that result from a range of large peak-hour volumes, heavy vehicle percentages, and bus stop activities are investigated, and the impacts on side-street vehicle delay and non-peak-hour traffic flow are evaluated. The operation of similar 4LUD and 3L roadways for these input variables were approximated with the CORridor SIMulation (CORSIM) software package and then compared as part of the sensitivity analysis completed in this research. A total of 680 simulations were done.

The large peak-hour volumes investigated as part of this research ranged from 1,000 vehicles per hour per direction (vphpd) to 1,250 vphpd. In general, the average arterial through-vehicle travel speeds (AATTSs) calculated from the simulation results decreased along both the 4LUD and 3L roadways as traffic volume increased. The AATTSs from the 4LUD simulations were also always higher than those from the 3L cross-section simulations. Overall, the AATTSs of the simulated 4LUD and 3L roadways decreased by 4.5 miles per hour (mph) and 3.4 mph, respectively, for peak-hour volumes from 1,000 vphpd to 1,150 vphpd. The 4LUD simulation results for volume levels above 1,150 vphpd were not considered to be reliable and were ignored. The change in 3L AATTS primarily occurred between peak-hour volumes of 1,000 vphpd and 1,050 *vphpd, and this change resulted 4LUD roadways operated at an arterial LOS C, but the 3L roadways operated at LOS D. These results indicated that a traffic volume between 1,000 vphpd to 1,050 vphpd should be considered a decision point in the feasibility evaluation of 4LUD to 3L roadway conversions.*

The heavy vehicle percentages considered in this research ranged from 0 to 30 percent of the total entering vehicles (750 vphpd) at 5 percent increments. The AATTS calculated from the simulations for the 3L roadways decreased 8.3 mph as the heavy vehicle percentage increased from Oto 30 percent, but decreased by only 2.8 mph for the 4LUD roadways. The arterial LOS for the simulated 3L roadways changed from LOS C to LOS D when the HV percentage increased from 20 to 25 percent, and from LOS D to LOS E when it increased from 25 to 30 percent. Overall the LOS of the 4LUD corridors remained at LOS C throughout. It is recommended from these results that HV percentage above 20 percent of total traffic flow be considered a decision point in the feasibility evaluation of 4LUD to 3L conversions is evaluated.

The impacts of several bus stop activities along similar 4LUD and 3L roadways were also investigated as part of this research. The difference in the impacts of one and two bus stops, and a range of bus dwell times and bus headways (i.e., the number of buses in an hour) were considered for an overall roadway volume of 750 vphpd. In general, the impact of the bus stop activities along the 3L roadway cross-section was much larger than those simulated for a similar 4LUD cross-section. In fact, the operational impacts of the bus stop activities along the simulated 4LUD roadways (at the traffic volume considered) were practically nothing. For the 3L simulations, the operational impact increased with the number of bus stops, bus dwell time, and the number of buses per hour. It is recommended that the impact of bus stop activities should be strongly considered for the operational feasibility of a 4LUD to 3L conversion.

Side-street vehicle delay and non-peak-hour operation were also evaluated for the corridor model used in this research. The side-street vehicle delay evaluation for similar 4LUD and 3L roadways was completed for main arterial traffic volumes from 1,000 vphpd to 1,150 vphpd. It was found that the side-street proportion of the average intersection stopped delay from the 3L simulations increased with traffic volume, but decreased with traffic volume for the 4LUD simulations. It would appear the optimization timing of the two-phase signals at the intersections was not able to properly serve the left-tum vehicles on the 4LUD roadway and the delay on the main arterial approaches increased proportionally more than the delay experienced on the side-street approaches. The addition of a left-tum lane along the 3L roadway reduced the impact of the left-tum vehicles on the main arterial approaches and the delay of the vehicles on the side-street approaches increased disproportionately. It is recommended that the delay impact on side-street be recognized and considered in the feasibility evaluation of the 4LUD to 3L roadway conversions.

Finally, The AATTS of the 4LUD and 3L roadway models were also calculated for typical hourly traffic flows between 5:00 AM and 8:00 PM. As expected, the 4LUD AATTSs were always higher than the AATTSs calculated along similar 3L roadway. The difference between the 4LUD and 3L AATTSs was the largest during non-peak-hours and the smallest during the morning and evening peak hours. It is recommended that the cumulative impacts of a 4LUD to 3L conversion during non-peak-hours should be considered when the feasibility of this type of improvement is being evaluated. These impacts may be unacceptable to the community.

22 Li, W., & Carriquiry, A. (2005). The effect of four-lane to three-lane conversion on the number of crashes and crash rates in Iowa roads. Department of Statistics, Iowa State University.

The authors analyze crash data collected by the Iowa Department of Transportation using Bayesian methods. The data set includes monthly crash numbers, estimated monthly traffic volumes, site length and other information collected at 30 paired sites in Iowa over more than 20 years during which an intervention experiment was set up. The intervention consisted in transforming 15 undivided road segments from four-lane to three lanes, while an additional 15 segments, thought to be comparable in terms of traffic safety-related characteristics were not converted. The main objective of this work is to find out whether the intervention reduces the number of crashes and the crash rates at the treated sites. The authors fitted a hierarchical Poisson regression model with a change-point to the number of monthly crashes per mile at each of the sites. Explanatory variables in the model included estimated monthly traffic volume, time, an indicator for intervention reflecting whether the site was a "treatment" or a "control" site, and various interactions. The authors accounted for seasonal effects in the number of crashes at a site by including smooth trigonometric functions with three different periods to reflect the four seasons of the year. A change-point at the month and year in which the intervention was completed for treated sites was also included. The number of crashes at a site can be thought to follow a Poisson distribution. To estimate the association between crashes and the explanatory variables, the authors used a log link function and added a random effect to account for overdispersion and for autocorrelation among observations obtained at the same site. The authors used proper but non-informative priors for all parameters in the model, and carried out all calculations using Markov chain Monte Carlo methods implemented in WinBUGS. The authors evaluated the effect of the four to three-lane conversion by comparing the expected number of crashes per year per mile during the years preceding the conversion and following the conversion for treatment and control sites. The authors estimated this difference using the observed traffic volumes at each site and also on per 100,000,000 vehicles. The authors also conducted a prospective analysis to forecast the expected number of crashes per mile at each site in the study one year, three years, and five years following the four to three-lane conversion. Posterior predictive distributions of the number of crashes, the crash rate, and the percent reduction in crashes per mile were obtained for each site for the months of January and June one, three, and five years after completion of the intervention. The model appears to fit the data well. The authors found that in most sites, the intervention was effective and reduced the number of crashes. Overall, and for the observed traffic volumes, the reduction in the expected number of crashes per year and mile at converted sites was 32.3% (31.4% to 33.5% with 95% probability) while at the control sites, the reduction was estimated to be 7.1% (5.7% to 8.2% with 95% probability). When the reduction in the expected number of crashes per year, a mile and 100,000,000 AADT was computed, the estimates were 44.3% (43.9% to 44.6%) and 25.5% (24.6% to 26.0%) for converted and control sites, respectively. In both cases, the difference in the percent reduction in the expected number of crashes during the years following the conversion was significantly larger at converted sites than at control sites, even though the number of crashes appears to decline over time at all sites.

23 Margiotta, R., & Chatterjee, A. (1995). Accidents on Suburban Highways-Tennessee's Experience. Journal of Transportation Engineering, 121(3), 255-261.

This technical paper describes a safety analysis of median design that was performed using data compiled from the Tennessee Roadway Information Management System. Two median designs were investigated: two-way left-turn lanes (TWLTLs) and raised medians. All study sections had four basic through lanes and were located in areas with varying degrees of typical suburban commercial development. Analysis of covariance and multiple regression analysis were employed to determine the relative safety of the two designs. The study was limited to locations (highways) where average daily traffic volumes were less than or equal to 32,500 vehicle per day. The authors determined that medians are generally safer than TWLTLs; however, TWLTLs are more favorable under certain circumstances (high driveway densities and low to medium traffic volumes). Regression analysis revealed that driveway density is an important contributor to accidents for medians but not for TWLTLs. This study was part of a larger effort to develop guidelines for the design of arterial roads in areas undergoing suburbanization.

24 Mukherjee, D., A. Chatterjee, and R. Margiotta. (1993). Choosing between a Median and a TWLTL for Suburban Arterials. ITE Journal, pp 25-30.

This is an examination of the existing state of the art with regard to the choice between a non traversable median and a two-way, left-turn lane (TWLTL). The scope of the paper is limited to roads with two through lanes in each direction. The existing guidelines on the subject are reviewed, and a survey was made of state highway engineers and their decision-making regarding the use of a median or a TWLTL. The results of the survey, particularly as they relate to the use of a median and a TWLTL, are discussed. Survey results relating to hypothetical case studies are also presented. Inferences drawn from the survey results are discussed. It is noted that a choice between a median and a TWLTL involves trade-offs among safety, delay, and land development considerations, and in each case, the trade-offs should be identified clearly before a choice is made.

25 Nemeth, Z. A. (1978). Two-way left-turn lanes: state-of-the-art overview and implementation guide. Transportation Research Record, 681, 62-69.

The results of a research project to synthesize existing information on continuous two-way left-turn median lanes and to conduct before-and-after studies to evaluate the effectiveness of such lanes as an access control measure are presented. Recommendations were prepared for the traffic engineer concerned with the evaluation of a situation in which a two-way left-turn median lane is a potential solution to existing capacity and safety problems. The research approach included studies in three distinct areas: a nationwide expert opinion survey, a literature review, and before-and-after field studies. Both the literature review and the survey indicated that two-way left-turn median lanes work well in spite of a wide variety of methods of signing and marking. There is uniform agreement that these lanes have excellent safety records; specifically, head-on collisions in the lanes are extremely rare. The before-and-after studies demonstrated that the effectiveness of the lanes and public reaction depend on proper engineering. A step-by-step decision-making strategy has been developed for the implementation of two-way left-turn median lanes.

26 Noyce, D. A., Talada, V., & Gates, T. J. (2006). Safety and Operational Characteristics of Two-Way Left-Turn Lanes (No. MN/RC 2006-25).

The purpose of this research was to evaluate the safety and operational characteristics of two-way left-turn lanes (TWLTLs) compared to four-lane undivided roadways in Minnesota. Research tasks to achieve this purpose consisted of a comprehensive literature review, data collection from the identified study sites, and statistical data analysis.

Nine study sites were selected, located throughout the state of Minnesota. Operational and crash data were analyzed before and after the conversion from a four-lane undivided roadway to a three-lane roadway with a TWLTL. The results of a yoked/group comparison analysis showed statistically significant reductions in total crashes, PDO crashes and left-turn crashes. The percentage reductions in total crashes, PDO crashes and left-turn crashes after the conversion were approximately 37 percent, 46 percent, and 24 percent, respectively. The reductions in crash rates for total crashes and PDO crashes were found statistically significant and the percentage reductions were 46 percent and 45 percent, respectively. Additionally, the change in the mean speed and 85th percentile speed were found statistically significant, but in both cases, the change was less than two miles per hour. The results of this research show that safety characteristics of a roadway are improved when a four-lane undivided roadway is converted to a three-lane roadway with a TWLTL when daily traffic volumes are less than 17,500 vehicles per day.

27 Parsonson, P. S., Waters III, M. G., & Fincher, J. S. (2000, January). Two-way Left-turn Lane with a Raised Median: Atlanta's Memorial Drive. In Third National Access Management Conference Committee on Access Management, Transportation Research Board; and Office of Technology Applications, Federal Highway Administration.

In 1990, the Georgia Department of Transportation replaced a two-way left-turn lane (TWLTL) with a raised median separation along 4.34 miles of Memorial Drive in greater Atlanta. In the year after completion, the project prevented about 300 crashes and 150 injuries. There was a 37% reduction in total accident rate and a 48% drop in the injury rate. Left-turn accidents between intersections were virtually eliminated. However, after the project, traffic volumes dropped 12% within the project and only 5.5% outside it (1991 was a recession locally and nationwide). Articles appeared in the local newspapers quoting merchants as saying that the median project has hurt business by eliminating left-turns into and out from their establishments. The project did not include any measures to improve inter-parcel access by providing frontage roads or rear alleyways or joint parking lots. The authors concluded that the project probably did have a negative effect on stores at mid-block locations and those that must do a large-volume business because of a small profit on each sale. These results were presented and published at the First National Access Management Conference, in 1993. It was reported there that, as of May of 1993, after over 2.5 years of the median, not a single fatality had occurred, whereas in the 11.6 years preceding the project there were 15 fatalities, including six pedestrian deaths. The present paper updates the Memorial Drive experience, reporting the longer-term impacts on both safety and abutting-business activity after eight years of the raised median. As of the date of this presentation in early October, 1998, there still has not occurred the first fatality, either motorist or pedestrian. However, the enormous percentage reductions in crashes experienced during the first year have not been found to hold up over time, at least on a project-wide basis. The annual number of crashes has been increasing since 1992, despite the fact that traffic volumes are gradually decreasing. However, the paper suggests that this increase is not significantly different from the county-wide increase during the same period and therefore is not attributable to the

median. Interviews with the traffic police in the area revealed strong opinions that driver inattention is to blame for the upward trend in crash frequency. There is a perception that in earlier times, before the invention of the cell phone, drivers were much less distracted from the task at hand and more likely to take their driving seriously. Memorial Drive, once prosperous with leading retail stores and automobile dealers, now has retail-vacancy rates of 15%, twice the Atlanta average. Newspaper accounts of the decline cite the raised median as one factor of several, but the paper shows that, in fact, the demographics of the corridor were weakening years before the median was built, due to socioeconomic influences such as court-ordered desegregation and the construction of a rapid-rail system.

28 Parsonson, P. S., Waters, M. G., & Fincher, J. S. (1993). Effect on Safety of Replacing an Arterial Two-Way Left-Turn Lane with a Raised Median. In First National Access Management Conference. Colorado Department of Transportation, Federal Highway Administration, and the Transportation Research Board.

This paper describes the safety effectiveness of replacing a two-way left-turn lane with a raised median on a high-volume, six-lane arterial in Atlanta. In the year after completion, the Memorial Drive median project prevented about 300 accidents and 150 injuries. There was a 37 percent reduction in total accident rate and a 48 percent drop in the injury rate. Left-turn accidents between intersections were virtually eliminated. Over the 4.34-mile section, a number of less-significant public-road intersections were not given median breaks. On similar retrofit projects, wehre narrow raised medians are used, all remaining median openings should be strongly considered for signalization. Also, adequately designed U-turn capability should be provided at each opening, if possible, with right-turn-on-red prohibition considered on cross-street approaches. Well designed, double left-turn lanes should be included where needed. A mountable curb allows the median to be driven on by emergency vehicles and reduces the possibility of an errant vehicle losing control upon striking it.

29 Pawlovich, M., Li, W., Carriquiry, A., & Welch, T. (2006). Iowa's experience with road diet measures: Use of Bayesian approach to assess impacts on crash frequencies and crash rates. Transportation Research Record: Journal of the Transportation Research Board, 1953, 163-171.

A before-and-after study implemented from a Bayesian perspective to assess crash history reduction due to road diets in Iowa was conducted by the Iowa State University Department of Statistics in cooperation with the Iowa Department of Transportation's Office of Traffic and Safety. The study used both monthly crash data and estimated volumes obtained from TAS for 30 sites—15 treatment and 15 comparison—over 23 years (1982 to 2004). The sites had volumes ranging from 2,030 to 15,350 during this period and were largely located in smaller urbanized areas. The research objective was to assess whether road diets appear to result in crash reductions on Iowa roads. Crash data were analyzed at each site before and after the conversions were completed. Given the random, rare nature of crash events, a hierarchical Poisson model was fitted, such that log mean rate was expressed as a piecewise linear function of time period, seasonal effects, and a random effect corresponding to each site. Monthly traffic volumes were incorporated as exposures. Estimation of model parameters was conducted within a Bayesian framework. Results indicate a 25.2% reduction in crash frequency per mile and an 18.8% reduction in crash rate. This differs from a previously publicized study that reported a 6% reduction in crash frequency per mile and an

insignificant indication for crash rate effects. The results from the Iowa study fit practitioner experience and agree with another Iowa study that used a simple before-and-after approach on the same sites.

30 Persaud, Lan, Lyon, & Bhim. (2010). Comparison of empirical Bayes and full Bayes approaches for before–after road safety evaluations. Accident Analysis and Prevention, 42(1), 38-43.

The empirical Bayes approach has now gained wide acceptance among researchers as the much preferred one for the before-after evaluation of road safety treatments. In this approach, the before period crash experience at treated sites is used in conjunction with a crash prediction model for untreated reference sites to estimate the expected number of crashes that would have occurred without treatment. This estimate is compared to the count of crashes observed after treatment to evaluate the effect of the treatment. This procedure accounts for regression-to-the-mean effects that result from the natural tendency to select for treatment those sites with high observed crash frequencies. Of late, a fully Bayesian approach has been suggested as a useful, though complex alternative to the empirical Bayes approach in that it is believed to require less data for untreated reference sites, it better accounts for uncertainty in data used, and it provides more detailed causal inferences and more flexibility in selecting crash count distributions. This paper adds to the literature on comparing the two Bayesian approaches through empirical applications. The main application is an evaluation of the conversion of road segments from a four-lane to a three-lane cross-section with two-way left-turn lanes (also known as road diets). For completeness, the paper also summarizes the results of an earlier application pertaining to the evaluation of conversion of rural intersections from unsignalized to signalized control. For both applications, the estimated safety effects from the two approaches are comparable.

31 Phillips, S. L., Carter, D. L., Hummer, J. E., & Foyle, R. S. (2004). Effects of increased U-turns at intersections on divided facilities and median divided versus five-lane undivided benefits. North Carolina Department of Transportation.

Highway projects involving access management strategies are among the most hotly debated transportation issues. In particular, the choice of midblock left turn treatment is a controversial issue. The two main competitors for midblock left-turn treatment on four-lane arterials are raised medians and two-way left-turn lanes (TWLTL). This research focused on determining the effects of median installation on midblock road segments and the adjacent signalized intersections. The areas of focus were vehicular safety and operational impacts. For the segment safety study, predictive collision models were calibrated using geometric, volume, land use, and collision data for 143 midblock segments. Analysis showed that collisions were significantly related to cross-section type, average daily traffic (AADT), segment length, predominant land use, and approach density (two-way total). For predominantly residential and industrial land uses, the raised median design was always associated with fewer collisions than the TWLTL design. For predominantly business and office land uses, the raised median design had a safety advantage for low approach densities. For higher driveway densities, the raised median was slightly safer at high traffic volumes and the TWLTL was slightly safer at lower traffic volumes. The signalized intersection study dealt with the effects of U-turns in exclusive left-turn lanes. This included analyses of the safety of U-turns and the operational impacts of U-turns on saturation flow rate. The safety study examined a set of 78 intersections in North Carolina, one-third of which were chosen because they were known to be U-turn *"problem sites". Although the group of study sites was purposely biased toward sites with high U-turn percentages, the study found that 65 of the 78 sites did not have any collisions involving U-turns in the three-year study period, and the U-turn collisions at the remaining 13 sites ranged from 0.33 to 3.0 collisions per year. The intersection operational analysis involved measurements of vehicle headways in exclusive left-turn lanes at 14 intersections. Regression analysis of U-turn percentage versus saturation flow rate indicates a 1.8% saturation flow rate loss in the left turn lane for every 10% increase in U-turn percentage and an additional 1.5% loss for every 10% U-turns if the U-turning movement is opposed by protected right turn overlap from the cross street. Overall, this research found that many of the typically cited drawbacks to median-oriented designs are not justified. Raised medians may increase U-turns at adjacent intersections, but this was found to have minimal effects on safety and operational performance. Additionally, raised medians are generally safer than TWLTLs on midblock segments.*

32 (NA) Redinger, C. (2010).Technical Memorandum: Road Diet Project Review.

33 Rosales, J. (2007). Past Presidents' Award for Merit in Transportation Engineering: Road Diet Handbook. Institute of Transportation Engineers. ITE Journal, 77(11), 26-32,37-41.

This article summarizes a new book called Road Diet Handbook: Setting Trends for Livable Streets. A road diet entails removing a travel lane in each direction of a four-lane undivided roadway to create a two-lane roadway with a two-way left-turn lane. The remaining roadway width can be converted to bike lanes, on-street parking or sidewalks. The handbook provides an overall best practice for the planning, analysis, design and implementation of road diets. The individual chapters of the handbook summarize existing road diet research, highlight case study examples of road diet projects, and provide guidelines for practitioners. This handbook also assesses livability benefits of road diets that have not been previously evaluated, including improved mobility for all modes of transportation and enhanced street character.

34 Rosales, J. A., & Knapp, K. K. (2005). Livability impacts of geometric design cross-section changes from road diets. In 3rd International Symposium on Highway Geometric Design. In 3rd International Symposium on Highway Geometric Design, Chicago Illinois, United States.

A "road diet" entails converting a four-lane undivided roadway to a two-lane roadway plus a two-way left-turn lane by removing a travel lane in each direction. The remaining roadway width can be converted to bike lanes, on-street parking or sidewalks. In cities throughout the world, roadways have been put on "road diets," and these improvements have generated benefits to all modes of transportation including transit, bicyclists, pedestrians and motorists. These benefits include reduced vehicle speeds, improved mobility and access, reduced collisions and injuries, and improved livability and quality of life. This paper will explore the livability impacts of the geometric changes produced by road diet projects. These livability impacts have not been previously evaluated in any research effort or manner. The impacts of the road diet cross-section evaluated include improved quality of life, street character, and comfort and safety for pedestrians, bicycles, and transit. The content, application, and results of a public opinion livability survey will be presented. The survey was administered along four-lane undivided and three-lane streets with comparable width, character, and traffic flow. The livability survey solicited information from people living and working adjacent to the streets with factors directly related to its livability. Five sites were chosen for the survey

and data collection in Washington, Iowa, and Georgia, and in Canada and New Zealand. The focus of the paper will be on the impacts of geometric changes in roadway cross-section on livability and context sensitivity.

35 Russell, E. R., & Mandavilli, S. (2003, March). Analysis of a road diet conversion and alternative traffic controls. In Proceedings of the Institute of Transportation Engineers (ITE) 2003 Technical Conference and Exhibit.

Safety is a prime concern of transportation engineers and safety specialists in the United States. Traffic volumes have increased tremendously over the past years. Accommodating the increased demand, while improving traffic safety, has led transportation officials to utilize various lane configurations and intersection controls to operate the transportation system more efficiently and safely. The primary focus of this research is to evaluate the benefits of the Road Diet concept and the operational performance of alternative intersection controls at a site in University Place, Washington. The intersection controls studied are two-way stop control, a roundabout, and traffic signals. The operation of the roadways at the intersection was videotaped and the traffic flow data collected was extracted from these tapes and analyzed using SIDRA software. The software produces many Measures Of Effectiveness (MOEs) of which six were chosen in this project for evaluating the performance of the roadways and the intersection controls. All the MOEs were statistically compared to determine which roadway configuration and intersection control performed better. For the evaluation of the operational performance of the intersection controls studied, the actual traffic volumes were incremented by 25% and 50% and the MOEs from the SIDRA output for the three intersection controls were compared for the original and the incremented volumes. This research concludes that three-lane roadway configuration can be adopted as a viable, safer alternative to the problematic undivided four-lane roadway configurations and a single-lane modern roundabout would have been the best form of intersection control at the intersection studied.

36 Saak, Joshua E. (2007). Using Roadway Conversions to Integrate Land Use and Transportation– The East Boulevard Experience, Managing Congestion: Can We Do Better, ITE Technical Conference.

Communities across the country have had positive experiences in reducing the number of travel lanes on major thoroughfares. Often referred to as "road diets", ideal candidates are usually four-lane roadways without a center turn lane or provisions for separate left-turn bays that carry 12-18,000 vehicle trips per day, though some roads may carry up to 25,000 vehicles per day and still benefit from the conversion. The City of Charlotte (NC) recently converted East Boulevard, a four-lane arterial roadway with an average daily traffic volume of 21,400 vehicles, to a three-lane facility with a center turn lane, planted medians, pedestrian refuge islands, and bike lanes. The conversion was performed in order to promote the vision for the East Boulevard corridor as a balanced, multi-modal, tree-lined avenue with pedestrians on sidewalks filled with amenities including sidewalk cafes, public art, and smaller commercial development. In this type of environment, people should feel comfortable moving along the corridor on foot, by bicycle, on transit, or via private automobile. This paper is devoted to the process of road diet implementation, from the initial traffic study to community involvement, construction, and before/after studies of traffic flow. As road diets can be counterintuitive in purpose, it also details specific pitfalls that city or state agencies may experience in the conversion process.

37 Sohn, K. (2011). Multi-objective optimization of a road diet network design. Transportation research part A: policy and practice, 45(6), 499-511.

The present study focuses on the development of a model for the optimal design of a road diet plan within a transportation network, and is based on rigorous mathematical models. In most metropolitan areas, there is insufficient road space to dedicate a portion exclusively for cyclists without negatively affecting existing motorists. Thus, it is crucial to find an efficient way to implement a road diet plan that both maximizes the utility for cyclists and minimizes the negative effect on motorists. A network design problem (NDP), which is usually used to find the best option for providing extra road capacity, is adapted here to derive the best solution for limiting road capacity. The resultant NDP for a road diet (NDPRD) takes a bi-level form. The upper-level problem of the NDPRD is established as one of multi-objective optimization. The lower-level problem accommodates user equilibrium (UE) trip assignment with fixed and variable mode-shares. For the fixed mode-share model, the upper-level problem minimizes the total travel time of both cyclists and motorists. For the variable mode-share model, the upper-level problem includes minimization of both the automobile travel share and the average travel time per unit distance for motorists who keep using automobiles after the implementation of a road diet. A multi-objective genetic algorithm (MOGA) is mobilized to solve the proposed problem. The results of a case study, based on a test network, guarantee a robust approximate Pareto optimal front. The possibility that the proposed methodology could be adopted in the design of a road diet plan in a real transportation network is confirmed.

38 Sohrweide, T. A., Buck, B., & Wronski, R. (2002). Arterial Street Traffic Calming With Three-Lane Roads. In ITE 2002 Annual Meeting and ExhibitInstitute of Transportation Engineers (ITE).

Two cities, Burnsville, Minnesota and River Falls, Wisconsin, both had 4-lane arterial roadways that were having problems with excessive vehicle speeds, pedestrian crossing safety, and left-turning vehicle safety. The implemented solution in both cities was a conversion to a 3-lane roadway with a center 2-way left-turn lane. This article discusses the decision in these 2 cases to switch to a 3-lane roadway, and also addresses the additional concern of roadway traffic carrying capacity. Evaluation of the change found a decrease in accidents and in traffic volume. Vehicle delays have remained essentially the same, although initial public reaction has not been positive.

39 Squires, C. A., & Parsonson, P. S. (1989). Accident comparison of raised median and two-way left-turn lane median treatments. Transportation Research Record, 1239, 30-40.

It is accepted that the installation of a median will reduce accident occurrence along a previously undivided road. This report provides an accident comparison of raised medians and continuous two-way left-turn lanes used as median treatments on four- and six-lane roads. A statistical comparison of accident rates for the two section types and regression equations to model expected accident experience for each section were developed. Four- and six-lane roadway study sections in Georgia were analyzed separately. The accident rate of raised medians was found to be lower than the rate of two-way left-turn lanes for both four- and six-lane roadway sections. Regression equations were developed for raised median and two-way left-turn lane sections, four- and six-lane sections, total and midblock accidents, and accidents per million

vehicle miles and accidents per mile per year. Tables of expected accident rate values were developed from the regression equations. On the basis of expected total accidents per million vehicle miles, the tables indicated that for four-lane sections, raised medians had a lower accident rate over the range of data studied. Results from six-lane sections were mixed. The regression equations indicated that raised medians would have lower accident rates for most conditions. However, two-way left-turn lanes had a lower accident rate where few concentrated areas of turns, such as signalized intersections and unsignalized approaches, existed.

40 Stout, T. B. (2005). Matched Pair Safety Analysis of Four-Lane to Three-Lane Roadway Conversions in Iowa.

The safety impacts of the conversion of a number of 4-lane undivided roadways to three lanes are evaluated in a classical before and after study conducted on 11 sites in Iowa. The study included yoked control sites and a comparison to the cities in which the study sites are located. Iowa DOT databases were used to evaluate the changes in the frequency of crashes, rate of crashes, types of injuries, major causes of crashes, and key age groups. Five years of before and up to five years of after data were utilized. The analysis also evaluated the relationship of driveway density to crash risk. While previous studies have indicated that 4-lane to 3-lane conversions reduce crash rates by only six percent, the results of the present study indicated that the frequency and rate of crashes was reduced by 21 to 38 percent when adjusted for overall trends in crash performance. Serious injury crashes were reduced, older drivers had a reduced risk of crashing, and left turn and stopped traffic crashes were also significantly reduced. The results of the driveway density analysis indicate a small positive correlation between that density and potential benefits of conversion.

41 Stout, T. B., Pawlovich, M. D., Souleyrette, R. R., & Carriquiry, A. (2006). Safety impacts of" road diets" in Iowa. ITE Journal, 76(12), 24.

The term "road diet" usually refers to converting a road from four lanes to three lanes, with one through lane in each direction and a two-way continuous left-turn lane. In Iowa, 15 of these conversions have been completed. This article analyzes the safety impacts of these conversions. A full Bayes approach and a classical before-and-after study with yoked comparison sites are used. The two study methods produced similar results. Findings showed significant reductions in the crash frequency per mile, crash rate, number of injury crashes, and crash severity. Reductions were also shown in the crash involvement rate for drivers aged 25 and younger and 65 and older. Significant reductions were also found in the number of crashes related to left turns and stopped traffic. These results confirm the benefits of converting four-lane undivided roadways to three-lane cross-sections in selected locations.

42 Taylor, W. C., Lim, I. K., & Mahmood, M. (2001). Guidelines for 4-lane to 3-lane Conversions. Michigan State University, Department of Civil and Environmental Engineering.

Many urban areas in Michigan are implementing traffic calming measures on residential and arterial streets. One of these measures is the conversion of a four-lane to a three-lane cross-section. Unfortunately, there are no published guidelines to assist in determining when this treatment should be used. All of the reports found in the literature reported a reduction in the crash frequency or rate for road segments after converting from a four-lane to a three-lane cross-section. However, the experience varied from small changes that are well within the error rate for the sample size available, to large changes that are statistically significant. None of the articles provided details on the type of crashes that were reduced, or if there were any crash types that showed an increase in frequency after the conversion. A total of eight sites were identified for use in the analysis of the experience in Michigan. The number of reported crashes on each of the study sections was extracted from the Michigan Department of Transportation Crash files. All of the locations where this conversion was implemented since 1996 experienced a decrease in the average frequency of crashes per year. Thus, there appears to be a safety benefit that accrues from the conversion. The average daily traffic volume (ADT) on these roads ranged from 7500 to 20,000. A nomograph was developed to provide guidance in determining whether the conversion would result in an undesirable level of delay to the main street traffic at any given location. The variables included in the graph are the major street volume, the volume on the minor street (or driveway), the access point average spacing, and the percent of vehicles turning left from the major street. There is no significant queuing delay until the minor street approach volume reaches 180 vehicles per hour. The delay to traffic entering the major street would not be significant for volumes associated with residential streets, where the conversion is frequently used as a traffic calming measure. The delay to the major street traffic is also low for the volume levels of most residential streets.

43 Thakkar, J. S. (1984). Study of the effect of two-way left-turn lanes on traffic accidents. Transportation Research Record, 960, 27-33.

The purpose of this investigation was twofold: (a) to determine the safety-effectiveness of two-way left-turn lanes (TWLTLs) and (b) to determine the cost-effectiveness of TWLTLs. The study includes statistical as well as economic analyses. Accident data were collected for 31 roadway sections, 15 five-lane and 16 three-lane sections, for 2 years before and 2 years after the improvements (addition of the TWLTL) were made. Statistical tests were applied on total accidents as well as affected accidents (rear-end, left turn, and sideswipes), their rates, and their severity. Statistically significant reductions were found in accidents, their rates, and their severity. An economic analysis was also performed, including benefit-cost ratios and cost-effectiveness values (cost per accident reduced). The only benefit considered was saving in accidents. The results of economic analysis along with those of statistical analysis indicate that the TWLTL is an economic safety improvement to the conventional two and four-lane urban roadways along which extensive commercial development has taken place.

44 (NA) URS. (2004). US-12 Downtown Sturgis Traffic Study: Final Report

45 Venigalla, M. M., Margiotta, R., Chatterjee, A., Rathi, A. K., & Clarke, D. B. (1992). Operational Effects of Nontraversable Medians and Two-Way Left-Turn Lanes: A Comparison. Transportation Research Record, 1356, 37.

Two popular arterial highway cross-section designs--two-way left-turn lanes (TWLTLs) and non-traversable medians (NTMs, raised or depressed) on four-lane roads--are compared for operational efficiency under identical traffic and development situations. Two broad measures of operational effectiveness, delay and fuel consumption, are obtained through simulation performed using the TRAF-

NETSIM model. A three-way factorial design is used to compare and contrast the variables of interest. The results suggest that driveway density, traffic volume on the arterial, and type of design (TWLTL or NTM) have a significant effect on the performance measures such as total delay, fuel consumption, and delay to left-turning traffic and through traffic on the arterial. At low driveway density and low traffic volume, the difference in total delay between the two designs is not found to be significant. At higher driveway densities, no significant difference in delay to left-turning traffic on the arterial can be expected between TWLTL and NTM. However, TWLTL design is found to cause less delay to through traffic and be more fuel-efficient at all levels of driveway density and traffic volume.

46 Walton, C. M., Machemehl, R. B., Horne, T., & Fung, W. (1979). Accident and operational guidelines for continuous two-way left-turn median lanes (discussion and closure). Transportation Research Record, 737, 43-54.

An investigation was begun to provide highway designers and traffic engineers with more definitive information on the installation of left-turn median lanes. Primary emphasis was on documentation of experiences with continuous two-way left-turn median lanes; however, for purposes of comparison channelized one-way left-turn median lanes (raised and flush markings) were included. This paper presents a summary of the detailed investigation of the literature on left-turn lanes, the results of a survey of current practices and standards in Texas, results of field studies, and guidelines for use. A literature survey and analysis of questionnaires returned by representatives from Texas cities and the Texas State Department of Highways and Public Transportation suggested areas in which definitive guidelines were required. Based on the analysis of these two phases of the study, field studies were conducted that concentrated on operational characteristics, accident experience, and currently accepted practices. The analysis of the data collected on left-turn-lane sites revealed many characteristics, patterns, and relationships of accidents and operational experiences. A brief summary of the conclusions and findings is included, and recommendations are provided to improve current practices. In the operational characteristics phase of the study, emphasis was placed on the lateral placement of vehicles in the left-turn lane and the entering and maneuvering distances of vehicles within the lane. These suggest the characteristics of driver behavior that can be used by traffic engineers and highway designers in determining the optimum design elements for two-way left-turn lanes.

47 Welch, T. M. (1999). The conversion of four lane undivided urban roadways to three-lane facilities (pp. 28-30). Office of Transportation Safety, Iowa Department of Transportation.

In recent years, many traffic engineers have advocated converting four-lane undivided urban streets to three-lane two-way left-turn facilities. A number of these conversions have been successfully implemented. Accident rates have decreased while corridor and intersection levels of service remained acceptable. This conversion concept is yet another viable alternative "tool" to place in our urban safety/congestion toolbox.

Added sources

48 Knapp, K., Chandler, B., Atkinson, J., Welch, T., Hughes, H., Retting, R., Meekins, S., Widstrand, E., and Porter, R., (2014). Road Diet Informational Guide, FHWA-SA-14-028, Federal Highway Administration, Washington, DC.

A classic Road Diet converts an existing four-lane undivided roadway segment to a three-lane segment consisting of two through lanes and a center two-way left-turn lane (TWLTL). A Road Diet improves safety by including a protected left-turn lane for mid-block left-turning motorists, reducing crossing distance for pedestrians, and reducing travel speeds that decrease crash severity. Additionally, the Road Diet provides an opportunity to allocate excess roadway width to other purposes, including bicycle lanes, on-street parking, or transit stops. This Informational Guide includes safety, operational, and quality of life considerations from research and practice, and guides readers through the decision-making process to determine if Road Diets are a good fit for a certain corridor. It also provides design guidance and encourages post-implementation evaluation.

49 Lyles, R., Abrar-Siddiqui, M., Taylor, W., Malik, B., Siviy, G., and Haan, T. (2012) Safety and Operational Analysis of 4-Lane to 3-Lane Conversions (Road Diets) in Michigan, RC-1555, Michigan Department of Transportation, Office of Research and Best Practice, Lansing MI 48933.

Road diets, specifically 4-to-3 lane conversions, implemented in various locations in Michigan were studied to determine the safety- and delay-related impacts, develop crash modification factors (CMFs), and develop guidelines that would be useful in deciding when it might be desirable to implement such road diets. The results of the operational analysis support a guideline that suggests that 4-to-3 lane conversions result in significant delay when average daily traffic (ADT) exceeds 10,000 and, more importantly, when peak hour volumes exceed 1,000. A CMF of 0.91 (after adjustment for background citywide trends) for all crash types is recommended although the factor is not statistically different from 1.0. There was considerable site-to-site variation among the 24 sites studied, and this should always be considered when a road diet is contemplated. A study-by-study literature review and suggestions for implementation strategies are also included.

50 Stamatiadis, N., Kirk, A., Wang, C., and Cull., (2011) A. Guidelines for Road Diet Conversions, KTC-11-XX/SPR-415-11-1F, Kentucky Transportation Cabinet, Frankfort, KY.

Road diets, which convert four-lane highways to three-lane cross-sections, are an innovative solution to address mobility and safety concerns under budgetary constraints. These improvements can assist in the development of multimodal corridors with minimal impact on automobile mobility, while retaining the original right of way. Past research has focused on evaluating road diet safety, but minimal guidance exists on determining when such conversions are appropriate from an operational perspective. The proposed guidelines focused on evaluating and comparing the operation of three- and four-lane roads at signalized intersections to provide basic guidance as to when the road diet conversion is appropriate. One of the important findings of this research is the expansion of the usable range for road diets. Prior experience has limited road diet application to roadways with ADTs less than 17,000 vehicles per day. This research identifies the importance of side street volumes and supports the utilization of road diets on roadways with volumes up to 23,000 vehicles per day. This paper provides comprehensive guidance for road diet evaluation including operational performance, correctable safety problems and identifies a list of evaluation elements that should be examined when in-depth analysis of alternatives is required.

51 Thomas, L., Road Diet Conversions: A Synthesis of Safety Research, (2013) DTFH61-11-H-00024, Federal Highway Administration, Washington, DC.

The primary purpose of this review is to assess the available evidence regarding the safety effectiveness of reductions in the number of motorized traffic lanes, widely known as road diet conversions. Although road diets have been implemented since at least the 1970s, earlier reviews and a search of the literature identified no controlled safety evaluation studies conducted prior to the year 2002. A systematic search of literature dating from 2002 was conducted. Six studies in total were initially identified, with four serving as the basis for most conclusions in this review. Several of the studies have used overlapping data from many of the same implementation sites, with the more recent studies employing the more robust study methodologies. As a result, the strongest evidence comes from relatively few studies building on earlier ones. However, a sizeable number of sites have been encompassed in the studies. Studies using data from sites in California, Iowa, and Washington provide the strongest evidence of safety effects, with additional reports providing corroborating, but somewhat weaker evidence. Road diets can be seen as one of the transportation safety field's greatest success stories. Total crashes might be expected to decline by an average of29 percent by converting from four, undivided lanes to three lanes (plus other uses such as bike lanes). Additionally, the studies determined total crash reductions were higher (47 percent) for treated sections of more rural thoroughfares passing through smaller towns (Iowa sites) and lower (19 percent) for road diet corridors in large urban areas (California and Washington sites) (Harkey et al., 2008). Thus far, only a single study from New York City has examined effects on pedestrian crashes (Chen et al., 2013). Although the researchers were unable to use the most robust methodology due to a lack of traffic volume data, the inclusion of 460 road diet sites and a large number of comparison locations supports the findings of significant reductions in total crashes, significant reductions in injurious and fatal crashes, and a trend of lower pedestrian crashes at segments. Total crashes and injurious crashes also declined significantly at intersections abutting the road diet sections. Each potential road diet should be vetted on a case-by-case basis. Case study and modeling results suggest that added caution is warranted before implementing road diets when volumes approach 1,700 vehicles per peak hour or are in the range of 20,000 to 24,000 vehicles per day (HSIS, 2010; Knapp and Giese, 2001; Welch, 1999). However, high-quality disaggregate estimates of safety effects of road diets for different volume roadways are lacking. Further study of potential traffic and safety effects on surrounding roads and access from side streets.