Converting Four-Lane Undivided Roadways to a Three-Lane Cross Section: Factors to Consider

By: Keith K. Knapp, Thomas M. Welch, and John A. Witmer

INTRODUCTION

There are a large number of four-lane undivided roadways in the metropolitan areas of the United States. Many of these roadways operate at acceptable levels of service and safety. In other cases, however, changes in volume levels, traffic flow characteristics, and/or the corridor environment have degraded the service and/or safety of the roadway to such an extent that an improvement to its cross section is considered necessary.

Improvements to the cross section of an urban four-lane undivided roadway are often limited to alternatives that increase its existing curb-to-curb width. For example, a typical recommendation to improve the operation and/or safety of an urban four-lane undivided roadway is the addition of a raised median or two-way-left-turn-lane (TWLTL). A schematic of this approach is shown in Figure 1a. The safety and operational benefits of these improvements are generally accepted, and have been discussed by a number of researchers (*1*, *2*, *3*, *4*, *5*, *6*, *7*, *8*).

Recently, an alternative to widening the cross section of an urban four-lane undivided roadway has begun to be considered. In certain situations, many traffic engineers believe that the conversion of an urban four-lane undivided roadway to a three-lane cross section (i.e., one lane in each direction and a TWLTL) can have lower overall impacts than a widening option, and produce acceptable operational and improved safety results. A schematic of this approach is shown in Figure 1b. Unlike the addition of a raised median or TWLTL, however, there is little guidance available to determine the locations where a conversion of the type shown in Figure 1b might be successful.

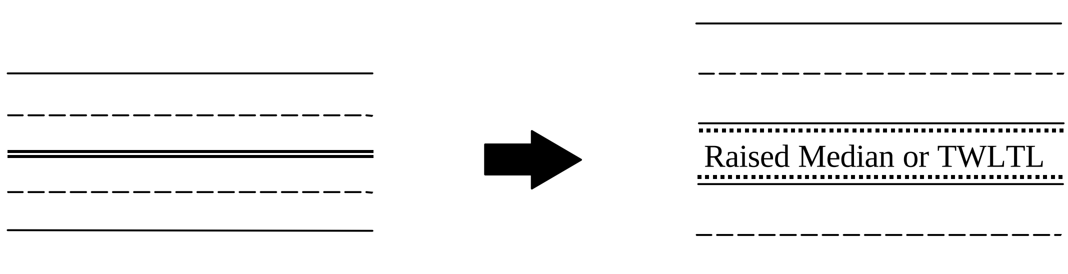

Figure 1a. Four-Lane Undivided Roadway Conversion to a Divided Cross Section.

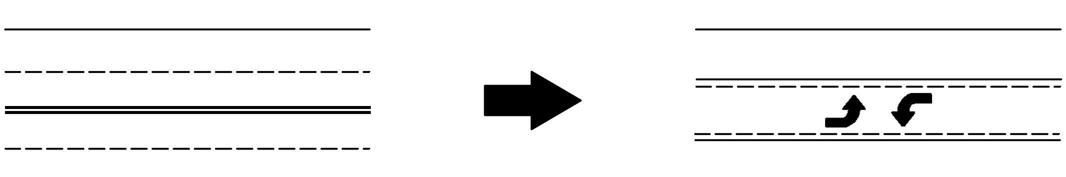

Figure 1b. Four-Lane Undivided Roadway Conversion to a Three-Lane Cross Section.

Purpose and Scope

The purpose of this paper is to discuss past research, case study experiences, and factors related to the conversion of urban four-lane undivided roadways to a three-lane cross section (See Figure 1b). First, the results of past research and the safety and operational benefits of TWLTLs or raised medians are discussed. Suggested approaches for the selection of cross section improvement alternatives are also presented. Then, the results from several case study locations are described, and several feasibility determination factors discussed. The authors believe that these factors should be investigated before a four-lane undivided to three-lane cross section conversion is considered a feasible improvement alternative. The factors discussed include roadway function; total traffic volume; turning volumes and patterns; weaving, speed, and queues; accident type and patterns; pedestrian and bike activity; and right-of-way availability and cost. A qualitative discussion of the factors, their characteristics, and the changes they may experience due to the conversion are documented.

The subject material of this paper is limited to the discussion of urban four-lane undivided roadways that have already been identified for a cross section improvement. In other words, the operation and/or safety conditions of the four-lane undivided roadway have degraded enough to require an evaluation of possible cross section improvements. The objective of this paper is to identify and discuss the factors that will help determine the feasibility of a four-lane undivided to three-lane cross section conversion. If the conversion is considered feasible, a more detailed engineering analysis should then be completed.

BACKGROUND

There has been very little formal research into the traffic flow or safety impacts of converting an urban four-lane undivided roadway to a three-lane cross section. The opposite is true, however, with respect to the safety and operational impacts of adding a TWLTL or raised median to an undivided two- or four-lane roadway. Past research about all three subjects is discussed in the following paragraphs.

Conversion of Four-Lane Undivided Roadways to a Three-Lane Cross Section

Two studies that evaluated the impacts of converting urban four-lane undivided roadways to a three-lane cross section were referenced by Harwood in *National Cooperative Highway Research Program (NCHRP) Report 282* and *NCHRP 330* (*1*, *2*). The results from one of these studies were published and are discussed in the following paragraph. The unpublished material documented the analysis of a converted roadway in Billings, Montana. Its contents are discussed later in this paper with other before-and-after case study results. Unfortunately, no additional published research on this particular subject was found during the literature review for this paper.

In the late 1970s, Nemeth completed a research study about TWLTLs and their implementation (*3*). As part of this study the author completed some before-and-after field studies of different cross section conversions. At one field study location a roadway within a commercial area and an average daily traffic (ADT) of approximately 16,000 vehicles per day (vpd) was converted from a four-lane undivided to a three-lane cross section. Nemeth concluded that the reduction in through lanes increased delay, but that the access function of the roadway was improved. Overall, the average speed in both directions decreased by approximately seven miles per hour (mph) while traffic increased by about seven percent (*3*). It was observed that traffic congestion and queuing during the peak periods was significant enough that some drivers used the TWLTL as a passing lane (*3*). The conversion also reduced brake applications by about 22 percent, but appeared to increase weaving dramatically (*3*). The weaving issue, however, was the result of some non-use or mis-use of the TWLTL, and some of the problem was eventually corrected by the proper removal of the old centerline (*3*). In the 1970s the use of TWLTLs was still relatively new. It is expected that the issue of nonuse or misuse of these facilities may now be less of a problem.

There has also been at least one suggestion about the ADT volumes most appropriate for three-lane cross sections (*4*). In their study of the operational and safety impacts of TWLTLs, Walton, et al. referenced a set of guidelines that suggested a 5,000 to 12,000 ADT range was appropriate for three-lane roadways (*4*). However, this suggestion appears to be based on what was considered acceptable several decades ago. The case study analyses and anecdotal information discussed in the next section of this report show that there have been successful conversions of four-lane undivided roadways to three-lane cross sections with daily traffic volumes much higher than the range suggested. In fact, some three-lane roadways in Minnesota are operating with an ADT as high as 20,000 vpd.

Overall, there is a general lack of published research or analysis about the impacts of converting a four-lane undivided roadway to three lanes. For this reason, most of the recommendations related to these types of conversions have been qualitative in nature. In *NCHRP Report 282* Harwood suggests that "[i]n some situations, with high left-turn volumes and relatively low through volumes, restriping of a four-lane undivided (4U) facility as a [three-lane] facility may promote safety without sacrificing operational efficiency (*1*)." In these cases, Harwood believed a three-lane cross section could be considered a lower cost alternative to widening. In the future, one source of guidance on these conversions may come from Dr. Joesph Hummer. Dr. Hummer is currently completing a research project on the operations and safety of two, three, and four-lane roadways on the fringe of urban areas and in small towns.

Safety Benefits of TWLTLs and Raised Medians

Most of the research related to the selection of a roadway cross section or left-turn treatment (e.g., raised median or TWLTL) has focused on the impacts of their addition to an existing cross section. Several investigators have summarized the research done on this subject, and/or modeled the expected safety benefits of TWLTLs and raised medians (*1*, *2*, *6*, *7*).

In the mid-1980s Harwood investigated the safety impacts of several cross section improvements to suburban highways (*1*). He found that the addition of a TWLTL to a two-lane undivided roadway could be expected to decrease overall accident rates by 11 to 35 percent (*1*). On average, he also found that accident rates decreased 19 to 35 percent when a TWLTL was added to a suburban four-lane undivided roadway. For urban four-lane undivided streets, however, the addition of a TWLTL (even when the roadway lanes were narrowed) reduced total accidents by approximately 44 percent (*2*). This urban data, however, varied substantially (*2*). The conversion of an urban two-lane undivided cross section to four lanes, on the other hand, typically produced a substantial increase in total accidents (*2*). Overall, angle, sideswipe, rear-end, and head-on accident rates are typically reduced the most by the addition of a TWLTL.

Two reports recently released by the NCHRP also address the safety benefits of TWLTLs and raised medians (*6*, *7*). In *NCHRP Report 395*, Bonneson and McCoy model annual accident frequency for undivided roadways and also those with a raised-curb median or TWLTL (*6*). They found a significant correlation between annual accident frequency and ADT, driveway density, the density of unsignalized public street approaches, left-turn treatment or median type, and adjacent land use (*6*). In addition, accidents can be expected to be more frequent along roadways with higher daily traffic demands, higher driveway and public street densities, and adjacent business and office land uses (versus residential and industrial land uses). In business and office areas, the model predicts that undivided roadways with parallel parking will have more accidents than cross sections with a TWLTL or raised median. When the parking is removed, however, the accident rate difference between undivided roadways and roadways with a TWLTL is relatively small (*6*). This similarity in accident rates was also found for residential and industrial areas, but only for an ADT less than 25,000 vpd (*6*). Above 25,000 vpd, undivided roadways (with or without parking) were predicted to have more accidents (*6*). In most cases, the model predicts the fewest accidents along roadways with a raised median (*6*).

NCHRP Report 395, along with *NCHRP Report 420*, also summarizes the results of past accident prediction models (*6*, *7*). As expected, most of these models produce similar results. For example, roadways with an undivided cross section are expected to have the highest accident rates (*6*, *7*). In addition, roadways with TWLTLs are predicted to have a lower accident rate than undivided roadways, and a higher rate than those roadways with a raised median (*7*). Harwood's model is an exception. It predicts the lowest accident rates on roadways with a TWLTL rather than a raised median (*1*, *7*). A summary of the results produced by past accident models (with the exception of Harwood's) are shown in Table 1 (*6*, *7*). Some of the reductions predicted are significant.

Table 1
Average Annual Accidents per Mile Predicted by Various Models (*6*, *7*)

Average Daily Traffic	Undivided Cross Section	Cross Section with TWLTL	Cross Section with Raised Median
10,000	48	39	32
20,000	126	60	55
30,000	190	92	78
40,000	253	112	85

Operational Benefits of TWLTLs and Raised Medians

Many of the studies previously described have also modeled and/or summarized the operational benefits of TWLTLs and raised medians. For example, Harwood concluded that a reduction in through vehicle delay results from the addition of a TWLTL to a previously undivided roadway (*1*). The reduction was primarily due to the removal of vehicles from the through lanes of vehicles turning left (*1*). More specifically, it was shown that the delay reduction per left-turn vehicle increased as total hourly volumes increased, but decreased as the number of driveways per mile decreased (*1*). Previous work by Harwood and St. John also found that the left-turn vehicle delay reduction effectiveness of TWLTLs was correlated to left-turn volume, through volume, opposing volume, and percent platooned traffic in the opposing direction (*8*). Opposing volume, however, had the strongest relationship with delay reduction per left-turn vehicle (*8*).

NCHRP Report 395 and *NCHRP Report 420* have also quantified or discussed the operational impacts of a raised median or TWLTL (*6*, *7*). In *NCHRP Report 395*, Bonneson and McCoy studied and modeled the through and left-turn vehicle delay expected for undivided and divided (i.e., TWLTL and raised-curb median) roadways (*6*). One model describes average through delay per roadway approach as a function of left-turn and right-turn volumes per access point, total volume in subject direction, opposing through lane flow rate, number of through lanes, and type of median treatment (e.g., undivided, TWLTL, or raised-curb) (*6*). Average total left-turn delay per approach, on the other hand, was related to opposing volume, average left-turn volume per access point, and number of through lanes (*6*). The models produced by Bonneson and McCoy have been described as ". . .a sound basis for assessing the through and left-turn approach delays associated with various median alternatives (*7*)."

Tables were provided in *NCHRP Report 395* that indicated the through, major street left-turn, and annual delays for different left-turn treatments (*6*). Table 2 is part of the annual delay tables for different left-turn treatments (*6*, *7*). These tables were also summarized in *NCHRP Report 420* (*6*, *7*). As expected, delays generally increase with higher ADT, percent major street left-turns, and access point density. Delays are also typically larger for undivided roadways versus those with a TWLTL or raised median.

Table 2
Annual Delay to Major Street Left-Turn and Through Vehicles (*6*, *7*)*

Access Points/Mile	**Undivided Cross Section**		**Cross Section with TWLTL**		**Cross Section with Raised Median**	
	10 Percent Left Turns	15 Percent Left Turns	10 Percent Left Turns	15 Percent Left Turns	10 Percent Left Turns	15 Percent Left Turns
Average Daily Traffic = 22,500						
30	2,200	2,900	1,300	1,700	1,300	1,700
60	2,200	3,000	1,400	1,800	1,400	1,800
90	2,200	3,000	1,400	1,800	1,400	1,800
Average Daily Traffic = 32,500						
30	7,100	9,100	3,000	4,000	3,100	4,000
60	7,800	10,200	3,200	4,200	3,500	4,800
90	8,000	10,800	3,200	4,200	3,400	4,700

*Delay is in seconds per vehicle per approach, and percent left-turns is for one direction of travel and a 1,320-foot roadway segment. Table is for four through lanes (both directions).

NCHRP Report 420 has also summarized the simulation and regression models developed (since 1982) for the operational analysis of median alternatives (*7*). In general, they produce results similar to those from the Bonneson and McCoy models. For example, lower delays are expected on roadways with TWLTLs or nontraversable medians versus undivided roadways (*7*). In high-volume situations, however, roadways with TWLTLs are typically expected to have lower delays than roadways with raised medians (*7*). This appears to be the result of modeled left-turn lane blockages, and the additional travel that may be necessary for traffic turning left at locations no longer provided a median opening (*7*). Usually, the modeled differences in delay along high-volume roadways with TWLTLs and raised medians are not significant (*7*).

Cross Section Selection Guidelines

All of the information discussed in the previous paragraphs is only useful if transportation professionals evaluating cross section design alternatives take it into account. In 1990, Harwood suggested the following eight-step process for the selection of cross section design alternatives (for an existing curb-to-curb width) on urban arterial roadways (*2*):

Step 1. Determine existing conditions
Step 2. Determine projected future conditions
Step 3. Identify constraints
Step 4. Identify feasible design alternatives
Step 5. Eliminate alternatives that do not address existing problems
Step 6. Examine possible geometric variations
Step 7. Determine benefits and disbenefits
Step 8. Select the preferred improvement strategy

This paper discusses the factors that determine whether or not a three-lane cross section could be a feasible design alternative to improve the operations and/or safety of an existing urban four-lane undivided roadway (i.e., Steps 4 and 5 above). These discussions should also help transportation professionals determine, at least qualitatively, how these factors might change with the subject conversion (i.e., Step 7 above).

The selection of an appropriate cross section design alternative is complex process, especially in urban areas. In *NCHRP Report 282* and *NCHRP Report 330*, Harwood discusses the many advantages and disadvantages of different urban and suburban roadway cross sections (*1*, *2*). In addition, Bonneson and McCoy have created tables to help transportation professionals with the proper selection of appropriate left-turn treatments (i.e., undivided, TWLTL, or raised-curb median). The tables are based on a benefit-cost analysis, and they suggest different left-turn treatments (i.e., conversions) for different combinations of total through lanes, ADT, access point density, land use (i.e., commercial and business or industrial and residential), and percent left-turns per 1,320 foot roadway segment (*6*). The results from *NCHRP Report 395* and past research are summarized in *NCHRP Report 420*, and recreated in Table 3 (*6*, *7*). The table identifies the "preferred" left-turn treatment for specific conversion alternatives and factors.

Table 3
Comparison of Left-Turn Treatment Types (*6*, *7*)

Comparison Factor	"Preferred" Midblock Left-Turn Treatment*

	Raised Curb vs. TWLTL	Raised Curb vs. Undivided	TWLTL vs. Undivided
Operational Effects			
Major –Street Through Movement Delay	n.d.	Raised Curb	TWLTL
Major-Street Left-Turn Movement Delay	n.d.	Raised Curb	TWLTL
Minor-Street Left & Through Delay (Two Stage Entry)	n.d.	Raised Curb	TWLTL
Pedestrian Refuge Area	Raised Curb	Raised Curb	n.d.
Operational Flexibility	TWLTL	Undivided	n.d.
Safety Effects			
Vehicle Accident Frequency	Raised Curb	Raised Curb	TWLTL
Pedestrian Accident Frequency	Raised Curb	Raised Curb	n.d.
Turning Driver Misuse/Misunderstanding of Markings	Raised Curb	Raised Curb	Undivided
Design Variations Can Minimize Conflicts (e.g., islands)	Raised Curb	Raised Curb	TWLTL
Positive Guidance (communication to motorist)	Raised Curb	Raised Curb	n.d.
Access Effects			
Cost of Access (access management tool)	Raised Curb	Raised Curb	n.d.
Direct Access to all properties along the arterial	TWLTL	Undivided	n.d.
Other Effects			
Cost of Maintaining Delineation	n.d.	Undivided	Undivided
Median Reconstruction Cost	TWLTL	Undivided	Undivided
Facilitate Snow Removal (i.e., impediment to plowing)	TWLTL	Undivided	n.d.
Visibility of Delineation	Raised Curb	Raised Curb	n.d.
Aesthetic Potential	Raised Curb	Raised Curb	n.d.
Location for Signs and Signal Poles	Raised Curb	Raised Curb	n.d.

*The “preferred” left-turn treatment is based on the findings of the source research and the more commonly found opinion from their review of the literature. n.d. = negligible difference or lack of consensus found in the literature on this factor. TWLTL = two-way-left-turn-lane.

Summary

In general, past research has focused on the operational and safety benefits of constructing TWLTLs or raised medians along previously undivided roadways. The conversion of an urban four-lane undivided roadway to a three-lane cross section has not been considered in any detail. Despite this fact, the information and selection guidelines/tools documented in past studies helped with the identification and discussion of the feasibility determination factors described later in this paper. For example, it can be concluded that accident type and patterns are important factors to consider because the expected accident reduction benefits of a TWLTL should occur whether there are one, two, or three lanes of traffic in each direction. Additional information has also been gathered from several case study conversion locations.

CASE STUDY ANALYSIS RESULTS

A number of jurisdictions have completed or are considering the conversion of urban four-lane undivided roadways to a three-lane cross section. This is true despite what appears to be a general lack of formal research on the impacts of this type of project, or any general guidance about when this type of conversion can be expected to be successful.

Some jurisdictions have examined the safety and/or operational impacts of a completed or proposed four-lane to three-lane conversion. In some cases, the impacts have only been documented qualitatively. The results from these analyses are presented in the following paragraphs.

Montana Examples

An unpublished before-and-after study report from Billings, Montana has been referenced in previous studies (*1*, *2*, *9*). In 1979, the City of Billings, Montana remarked 17th Street West from a four-lane undivided roadway to a three-lane cross section. The roadway was 40 feet wide, had a 35 mph posted speed limit, and an ADT of 9,200 to 10,000 vpd (*9*). A study of the conversion impacts indicated that there was no significant increase in delay after the roadway was converted, but that there was a decrease in vehicle accidents (*9*). In general, there were 37 reported accidents in the 20 months before the conversion, and 14 for the same time period after the conversion. The city traffic engineer of Billings, Montana has concluded that the conversion significantly decreased accidents with no notable increase in delay (*9*, *10*).

The city of Helena, Montana has also converted one of its urban roadways (i.e., U.S. 12). U.S. 12 is 48 feet wide in Helena and has a posted speed limit of 35 mph. The roadway is located in a commercial area, has numerous access points, and an ADT of 18,000 vpd (*10*). The conversion of this roadway to a three-lane cross section was suggested by the Montana Department of Transportation for safety reasons. It did not have a high overall accident rate, but the accidents that did occur were primarily of the rear-end and sideswipe type. When the conversion was initially proposed there was apprehension initially, but the change resulted in better operations and safety along the roadway. This fact alleviated most of the concerns previously expressed by city and some state officials. There also appears to be support for the conversion from the general public. The state traffic engineer for Montana has indicated that the number of accidents has decreased along the roadway segment, traffic flow has been maintained, and that the public prefers the new three-lane cross section (*10*).

Minnesota Examples

A similar change in community acceptance has been experienced in Duluth, Minnesota. Many people, and the local newspaper in Duluth, were opposed to the conversion of 21st Avenue East from a four-lane undivided roadway to a three-lane cross section. This roadway has an ADT of 17,000 vpd, and it was felt that traffic flow would suffer. This attitude changed, however, when the conversion was completed and the newspaper reported what appeared to be a reduction in congestion and vehicle speed, and a subsequent improvement in safety (*10*).

The safety impacts of converting a roadway from a four-lane undivided cross section to three lanes have been investigated in Ramsey County, Minnesota (*11*). In 1992, Rice Street (T.H. 49) was milled, overlayed, and remarked as a three-lane cross section from Hoyt Avenue to Demont Avenue. Three years of before-and-after accident data for this roadway corridor have been analyzed. During the three years before the construction the ADT on Rice Street was 18,700 vpd, and 162 accidents were reported (excluding those at the signalized intersections). During the three years after the construction the ADT on Rice Street decreased to 16,400 vpd, and there were 117 accidents reported (excluding those at the signalized intersections) (*11*). In other words, average daily volumes decreased by approximately 12 percent while the number of reported crashes decreased by approximately 28 percent. These changes are equal to a decrease of about 18 percent in the accident rate for the Rice Street roadway segments. Some of this decrease (possibly the majority) can be attributed to the conversion of the cross section.

Iowa Examples

Two cities in Iowa have also had positive experiences with the conversion of four-lane undivided roadways to a three-lane cross section. In 1996, the city of Storm Lake, Iowa converted a portion of Flindt Drive. This roadway was 40 feet wide and had an ADT of 8,500 vpd. No formal before-and-after analysis has been done, but there has generally been a positive public response to the conversion, and city officials are also pleased with the traffic flow and increased safety on the roadway (*10*). The city of Muscatine, Iowa had a similar experience with the conversion of Clay Street. City engineer, Ray Childs, has reported a large reduction in accidents due to the conversion (*10*).

In general, the Iowa Department of Transportation has begun to promote the *consideration* of four-lane undivided roadways to a three-lane cross section when safety is an issue. They have also used *Highway Capacity Manual* procedures to compare the possible operational impacts of cross section alternatives at two potential conversion locations. An arterial level of service (LOS) analysis was done for three possible cross section design alternatives along U.S. 75 in Sioux Center, Iowa (*10*). The ADT along this roadway is 14,500 vpd, and the arterial analysis for the corridor indicated that total delay would increase from 20.5 seconds to 29.4 seconds when the roadway was converted to a three-lane cross section. Average speeds are expected to decrease from 16.0 mph to 14.3 mph, but the overall arterial level of service would remain at LOS C (*10*). As expected, the conversion to a five-lane cross section would produce a lower total delay (i.e., 15.8 seconds) and a higher average speed (i.e., 17.1 miles per hour) than either of the two other cross sections. Again, however, the overall arterial level of service remained at LOS C (*10*).

A LOS analysis was also completed for the intersection of U.S. 65 and Brooks Road in Iowa Falls, Iowa (*10*). The analysis was done to determine the potential impacts on the operation of the intersection due to a cross section conversion of U.S. 65 (with a 1996 ADT of 8,700 vpd). First, the analysis assumed a four-lane undivided cross section along U.S. 65 and no left-turn or right-turn lanes at the intersection. The results of this analysis indicated that the intersection approaches on U.S. 65 and Brooks Road would operate at LOS A and LOS B, respectively. Overall, the intersection was expected to operate at a LOS B with an average stopped delay per vehicle of 6.2 seconds (*10*). Then, an analysis was done that assumed a three-lane cross section on U.S. 65 (i.e., a left-turn lane and through/right-turn lane on the U.S. 65 intersection approaches). This analysis produced LOS results similar to those for the intersection (without any turn lanes) on the four-lane undivided roadway. The LOS on one U.S. 65 approach, however, decreased from a LOS A to LOS B (although the average stopped delay only increased by 0.5 seconds). Overall, the intersection was still expected to operate at LOS B with an average stopped delay per vehicle of 6.7 seconds (*10*). This is an increase of only 0.5 seconds in the average stopped delay per vehicle for the two cross section designs considered. The results for this roadway generally show that an increase in delay can be expected, but that the increase will not be significant enough to change the intersection LOS.

California Examples

In the last two years four four-lane undivided roadways in Oakland, California have been converted to three-lane cross sections (*12*). A preliminary before-and-after comparison of vehicle speeds and accidents has been done by the city for one of the roadways (i.e., High Street). This roadway has an ADT between 22,000 and 24,000 vpd (*12*). The other converted roadways have an ADT of 6,000 vpd or 12,000 vpd.

The speeds of 100 vehicles on High Street were measured with a radar gun before-and-after the cross section was remarked. An analysis of this data did not show any significant change in vehicle speed (*12*). However, it has been concluded that this may have been due to the methodology used to collect the data (i.e., radar gun), the sample size, and/or the ability of a data collector to get more than one or two vehicles per platoon (*12*). The residential community adjacent to High Street believes that the cross section conversion has reduced speeds and some of the unsafe lane change maneuvers from the past (*12*). In addition, city transportation staff believes that the traffic has been "calmed" (*12*).

A preliminary analysis of the accidents along High Street has also been completed, and results are encouraging. There was an annual average of 81.5 reported accidents in the four years before the 1997 remarking of High Street, but in the year after the remarking there have been only 68 crashes reported (*12*). This is a 17 percent reduction in total crashes and may be attributable to the change in cross section. This conclusion would be consistent with the impacts experienced at the other previously discussed case study locations. However, additional analysis of a larger accident database is needed.

The City of San Leandro, California has also converted two four-lane undivided roadways to three-lane cross sections (*13*). The operation and safety of one roadway, East 14th Street, have been studied (*13*). First, it was found that spot speeds along this roadway decreased a maximum of three to four mph after the conversion. Daily volumes, on the other hand, ranged from approximately 16,000 to 19,300 vpd before the conversion to approximately 14,000 to 19,300 vpd after the conversion (*13*). Two years of before-and-after accident data also indicated that the total number of accidents along the roadway decreased by 52 percent, and that sideswipe and rear-end accidents decreased by over 60 percent (*13*). In addition, pedestrians said they felt safer and the city staff believe this is a significant benefit because the roadway passes through a downtown area and adjacent to several schools (*13*). Expected and perceived increases in delay at the unsignalized intersections along East 14th Street were also a concern for some citizens, but at the same time they recognized that crossing or turning maneuvers have become less complex (*13*). Finally, the high volumes along the roadway did require the city to widen East 14th Street to two lanes in each direction at one intersection. This capacity-related widening has maintained the intersection LOS, but also produced some safety and operational concerns related to its lane transition areas (*13*).

Summary

Table 4 summarizes the case study analysis results and anecdotal conclusions discussed in the previous paragraphs. In general, the results appear to support the conclusions reached in past research. In other words, the before-and-after study results and LOS analysis indicate that the conversion of a four-lane undivided roadway to a three-lane cross section can improve the safety of a roadway without dramatically decreasing the LOS provided. Vehicle speeds along the roadway may/can decrease somewhat and total delay increase, but safety is usually improved (sometimes dramatically). To achieve these results, however, this type of conversion must be done at the appropriate locations. The following section describes some of the environmental characteristics that determine the feasibility of converting an undivided four-lane roadway to a three-lane cross section.

Table 4
Case Study Analysis Results (*9, 10, 11, 12, 13*)*

Location	Approx. ADT	Safety	Operations
Montana			
Billings – 17th Street West	9,200 –10,000	62 Percent Total Accident Reduction (20 Months of Before/After Data)	No Notable Decrease**
Helena – U.S. 12	18,000	Improved**	No Notable Decrease**
Minnesota			
Duluth – 21st Avenue East	17,000	Improved**	No Notable Decrease**
Ramsey County – Rice Street	18,700 Before 16,400 After	28 Percent Total Accident Reduction (3 Years of Before/After Data)	NA
Iowa			
Storm Lake – Flindt Drive	8,500	Improved**	No Notable Decrease**
Muscatine – Clay Street	8,400	Improved**	NA
Sioux Center – U.S. 75	14,500	NA	Expected Average Arterial Speed Decrease of 1.7 mph
Iowa Falls – U.S. 65	8,700	NA	Expected Intersection Stopped Delay per Vehicle Increase of 0.5 seconds
California			
Oakland – High Street	22,000-24,000	17 Percent in Total Accident Reduction (1 year of Before/After Data)	No Notable Change in Vehicle Speed
San Leandro – East 14th Street	16,000-19,300 Before 14,000-19,300 After	52 Percent in Total Accident Reduction (2 years of Before/After Data)	Maximum of 3 to 4 mph Spot Speed Reduction

*ADT = Average daily traffic. NA = Not Available.
**Summarized results based on anecdotal information.

FEASIBILITY DETERMINATION FACTORS

A number of factors should be identified, estimated, and/or investigated to determine the feasibility of converting an urban four-lane undivided roadway to a three-lane cross section. In this paper, feasibility is defined by whether the conversion can be expected to maintain and/or improve the operation and safety of the existing four-lane undivided corridor. The authors have identified the following feasibility determination factors:

- Roadway Function
- Total Traffic Volume
- Turning Volumes and Patterns
- Weaving, Speed, and Queues
- Accident Type and Patterns
- Pedestrian and Bike Activity
- Right-of-Way Availability and Cost

Each of the factors above should be evaluated to determine the feasibility of a four-lane undivided to three-lane cross section conversion at a particular location. Their importance to the feasibility decision is based on the results of the research and case study analysis previously discussed. Undoubtedly, there are other factors that could and will be added to this list as more research and/or before-and-after studies are completed. The following paragraphs contain a qualitative discussion of the factors. In particular, the relevant characteristics of each factor are identified, and the changes they may experience due to a conversion (if any) described.

Roadway Function

The function of a roadway is currently defined by the amount of vehicular access and mobility activity it experiences and/or provides. In general, arterial roadways are expected to primarily serve a mobility function, local roadways an access function, and collector roadways a mixture of the two. The conversion of an urban four-lane undivided roadway to a three-lane cross section will impact how the corridor serves access and mobility.

The *intended* function of most four-lane undivided roadways was the movement or mobility of through traffic. Traffic turning into minor roadways or driveways was typically a secondary consideration. Roadways with a three-lane cross section, on the other hand, have a TWLTL for left-turning traffic and serve less of a mobility function. Roadways with each cross section often serve different levels of access and mobility, and are typically (but not always) labeled as minor arterials or major collectors. Issues related to safety and operations typically arise when the *actual* function of a roadway (e.g., minor arterial or major collector) does not match its *intended* or *designed* function (e.g., major arterial).

The objective of any design is to match the mobility and access served with the actual roadway function (i.e., the access and mobility demands). For example, an urban four-lane undivided roadway with a relatively small amount of access/turning activity may serve its major/minor arterial function efficiently and safely (and many do). In many cases, however, the turning volumes and/or frequency along these roadways have increased to such an extent that the four-lane undivided cross section is actually operating as a “defacto” three-lane roadway (i.e., most of the through flow is in the outside lane, and the inside lane is used almost exclusively by turning traffic). Figure 2 is an example of a roadway/intersection operating in a three-lane mode. The expected safety and operational impacts of this type of functional mismatch are described in the following paragraphs.

Figure 2. Four-lane Undivided Roadway/Intersection Operating as a "Defacto" Three-Lane Cross Section.

The *existing and intended* function of the candidate roadway must be seriously addressed and understood to determine the feasibility of a four-lane undivided to three-lane cross section conversion. The feasibility of this type of conversion, however, is more likely if the existing four-lane undivided cross section is already operating as a "defacto" three-lane roadway.

Total Traffic Volume

In the past, two-lane undivided roadways were widened to serve larger volumes of traffic. Some arguments for this type of improvement were that the new cross section would serve more through traffic and also allow it to bypass any turning traffic. Many urban four-lane undivided roadways operate both efficiently and safely in this manner. In other cases, unfortunately, the safety and operations have degraded with increased through and turning volumes.

A general knowledge of the existing and expected ADT along a roadway can provide a general idea of how its operations may change (both now and in the future) with a cross section conversion. As previously described, successful case study conversions of urban four-lane undivided roadways to three-lane cross sections have been done on roadways with ADT between 8,500 and 24,000 vpd. This ADT range is considerably wider than that suggested by Walton, et al. in the 1970s (i.e., 5,000 to 12,000 vpd), but it is not unexpected (*4*). Successful conversions of this type are typically measured by a comparison of how well the two cross sections serve the actual function of the roadway (from both an operational and safety point of view). In other words, a conversion can be successful (i.e., feasible) if the LOS along a four-lane undivided roadway is acceptable within a particular community and the proposed three-lane cross section produces an adequate LOS and improved safety. Achieving this type of result should not be problem if the ADT during the design period stays within a range that allows an acceptable (for the particular community) intersection and arterial LOS to be achieved. This type of stable or low-growth ADT characteristic typically occurs in well-established residential and commercial areas.

A preliminary intersection LOS analysis was completed as part of the background for this paper. The timing of two two-phase signals was optimized for two user-defined case study corridors. One of the corridors had a four-lane undivided cross section (i.e., no intersection turn lanes) and the other a three-lane cross section (i.e., intersection left-turn lane and through/right-turn lane). Based on series of traffic flow assumptions (e.g., 10 percent of the ADT occurring within the peak-hour), the analysis indicated that a signalized intersection on a roadway with a three-lane cross section begins to approach LOS F when the ADT is between 16,000 and 20,000 vpd (*14*). The results would appear to suggest that three-lane roadways (with no additional through lanes at the intersections) should be considered feasible for roadways with ADT below 20,000 vpd. This conclusion, however, is based on very preliminary analysis results. In addition, it is often the change in LOS expected from the conversion that determines its feasibility rather than the actual magnitude.

There has been at least one successful conversion (with the addition of through lanes at one signalized intersection) above 20,000 ADT (see the case study discussion). However, for capacity reasons one through-lane was added in each direction at one signalized intersection. The addition of through lanes for capacity reasons at intersections along high volume corridors must be considered carefully. The transition areas may produce safety and operational consequences that could impact the feasibility and overall success of the conversion to a three-lane cross section.

Turning Volumes and Patterns

Turning volumes and patterns (i.e., how many, when, and where turning movements occur) have a major impact on the operations and safety of a four-lane undivided roadway. The feasibility of converting this type of roadway to a three-lane cross section requires an estimation of those impacts (e.g. simulation and LOS analysis). In general, a four-lane undivided to three-lane conversion can be considered feasible if an increase in left-turn volumes and/or their frequency has produced “defacto” three-lane peak period operations (See Figure 2). However, like ADT, the stability of the turning volumes and patterns must be evaluated (i.e., are they expected to change dramatically within the design period). A different type of cross section conversion may be more appropriate if any major changes in total volumes or turning volume and patterns are expected within the design period considered. The safety concerns related to the “defacto” three-lane operation of a four-lane undivided roadway are discussed next.

Weaving, Speed, and Queues

The weaving, speed, and queuing of vehicles on a four-lane undivided roadway can be different than those on a three-lane roadway. Like some of previously discussed factors, however, the difference (especially for speed and queuing) is dependent upon the current operation of the four-lane undivided roadway. In other words, the impacts should be small if it is already operating as a “defacto” three-lane roadway.

Weaving or lane changing (other than vehicles entering the TWLTL) should not occur along a three-lane roadway. However, there is always the possibility of vehicles incorrectly using the TWLTL or bypassing right-turning vehicles on the left (marking the TWLTL properly is essential). Fortunately, neither of these maneuvers has been noted as a problem at the case study locations. Lane changing along four-lane roadways, on the other hand, is done for lane positioning purposes and to bypass turning vehicles. The ability to make these maneuvers decreases as volumes increase, and it can have significant safety impacts (discussed later in this paper).

The average speed and possibly speed variability can be expected to decrease when an urban four-lane undivided roadway is converted to a three-lane cross section. In addition, the delays related to left-turn traffic can be expected to decrease with the addition of a TWLTL. The reduction in the number of lanes, however, typically produces a greater impact on segment and intersection operations. Previous case study results, however, have shown that the overall decrease in average speed can be insignificant (e.g., an overall change of only a few miles per hour). Anecdotal observations from the case study locations also reveal that the inability to change lanes or pass along a three-lane roadway appears to result in lower vehicle speed variability (i.e., a more "calm" less "aggressive" traffic flow) than a four-lane undivided roadway. Again, as mentioned previously, the change in average speed will be determined by the difference in vehicle operations along a three-lane cross section and those of the existing four-lane undivided roadway.

The delay at signalized intersections may also increase with the conversion of a four-lane undivided roadway to a three-lane cross section. An increase in delay, in turn, may increase the queuing on the intersection approaches. Adjustments to signal timing will be needed to minimize this impact. The magnitude of any increase in delay or queuing depends on the current operation of the four-lane undivided roadway. Case study LOS analysis and observations, however, have shown that this delay increase can be relatively insignificant. Based on these results, any increase in queues can also be expected to be small. This is especially true if the signalized intersections along the existing four-lane undivided roadway are actually operating like a three-lane cross section (See Figure 2).

On high-volume three-lane roadways one concern is the delay and gap availability at unsignalized intersections and driveways. In these situations, the delay to minor street or private driveway traffic can increase because the number of acceptable gaps may decrease because all the traffic is now traveling along one lane in each direction rather than two. In most cases, however, this concern with increased delay is tempered by the improved safety that results from a reduction in complexity of the crossing or driveway maneuver. With a three-lane cross section only one lane of traffic in each direction needs to be considered by traffic on the minor street approaches.

Accident Type and Patterns

Based on past research and case study results, it is expected that a roadway with a three-lane cross section will have a lower accident rate than a four-lane undivided roadway. In fact, data from Minnesota indicate that three-lane roadways have an accident rate 27 percent lower than the rate for four-lane undivided roadways (*5*). Related research has also shown that that addition of a TWLTL can be expected to decrease accident rates by 10 to 40 percent (*1*, *2*, *7*).

The expected increase in safety resulting from a four-lane undivided to three-lane cross section conversion is primarily the result of a reduction in speed variability along the roadway, a decrease in the number of conflict points between vehicles, and improved sight distance for the major-street left-turn vehicles. A three-lane cross section removes left-turn vehicles from the through lane. This reduces the conflicts between these stopped vehicles and through traffic, and also any related lane changing conflicts that may result. The number of lanes that need to crossed by major-street left-turn and minor street crossing vehicles is also decreased (See Figures 3 and 4). The reduction in speed variability and conflict points decreases the probability of rear-end, sideswipe, and/or angle accidents related to left-turn and crossing vehicles on three-lane roadways. The major-street left-turn vehicle sight distance improvements that result from a four-lane undivided to three-lane cross section conversion are shown in Figure 5. These improvements are also expected to improve the safety of the corridor. The only increase in accidents that might be experienced when an urban four-lane undivided roadway is converted to a three-lane cross section would be related to an increase in right-turn and through vehicle stop/slow conflicts, and a general increase in overall congestion (e.g., increased volumes, intersection/segment delay, queues). In the case studies, however, this potential increase was far outweighed by the overall reduction in accidents.

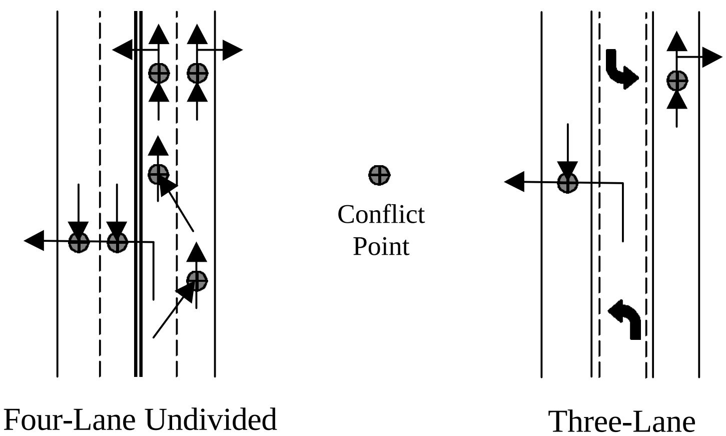

Figure 3. Mid-Block Conflict Points for Urban Four-Lane Undivided Roadway and Three-Lane Cross Section (*10*).

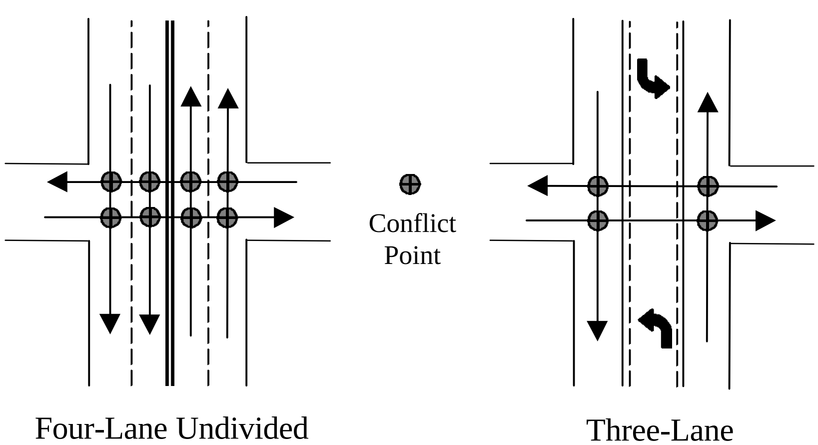

Figure 4. Crossing Through Traffic Conflict Points for Urban Four-Lane Undivided Roadway and Three-Lane Cross Section (*10*).

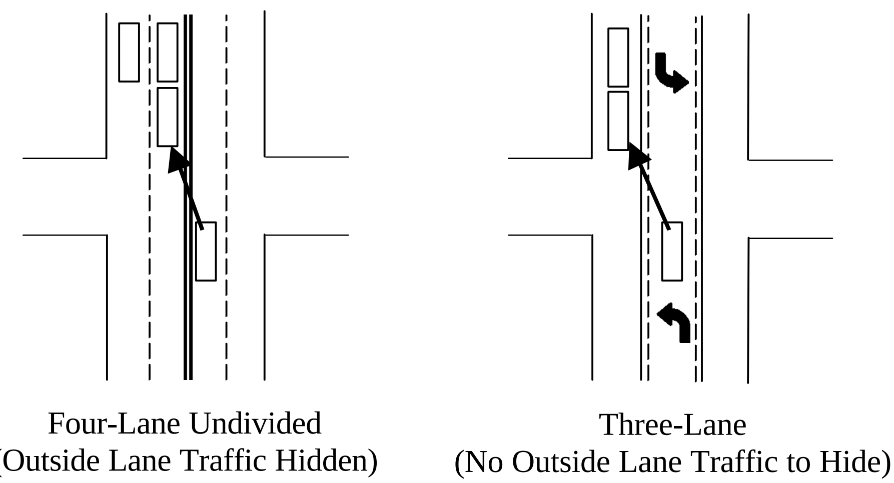

Figure 5. Major-Street Left-Turn Sight Distance for Urban Four-Lane Undivided Roadway and Three-Lane Cross Section (*10*).

The reduction in conflict points also decreases the complexity of left-turn and crossing maneuvers. This type of operation is safer for all drivers, but is especially preferable for areas with large populations of older drivers. As previously discussed, however, this decrease in complexity may be offset on high-volume roadways with an increase in delay for minor street approach and private driveway traffic (due to a decrease in acceptable major-street gaps).

Pedestrian and Bike Activity

The conversion of an urban four-lane undivided roadway to a three-lane cross section may have an impact on pedestrian and bike activity. These users (pedestrians and bicyclists) are not usually served well by urban four-lane undivided roadways. In fact, the case study results appear to support the conclusion that pedestrians, bicyclists, and adjacent landowners typically prefer the corridor environment of a three-lane cross section rather than a four-lane undivided roadway. The somewhat slower and more consistent speeds produced are more desirable to all three groups.

The safety of pedestrians and bicyclists is an important factor to consider. A three-lane cross section produces fewer conflict points between vehicles and crossing pedestrians. In addition, although the total roadway width does not change, the complexity of the pedestrian crossing maneuver is reduced. The conversion from four to three lanes also may allow the use of wider lanes or designated bike lanes to better accommodate bicyclists. Figure 6 is a photo of a three-lane roadway with bike lanes in Ames, Iowa. In general, the conversion of an urban four-lane undivided roadway to a three-lane cross section can be expected to benefit both pedestrians and bicyclists, and improve the overall roadway environment.

Figure 6. Three-Lane Cross Section with Bike Lanes.

Right-of-Way Availability and Cost

Many urban four-lane undivided roadways are located in areas that have a limited amount of right-of-way land available. If a roadway in this environment is widened (through the addition of a TWLTL or raised median) the impacts and costs could be significant. Fortunately, converting a four-lane undivided roadway to a three-lane cross section does not require any additional right-of-way. The existing curb-to-curb width is simply reallocated from four through lanes to two through lanes and a TWLTL. A three-lane cross section, therefore, is more feasible than widening along urban roadways with highly restricted right-of-way availability. Both the right-of-way impacts and costs can be significantly less than widening a roadway for a TWLTL or raised median.

Summary

The design period characteristics of certain feasibility determination factors (e.g., those discussed in the previous paragraphs) need to be investigated before the conversion of an urban four-lane undivided roadway to a three-lane cross section. The ability to estimate the expected change in these factors for both cross sections (during the design period) is essential in the determination of the conversion feasibility and subsequent impacts. These factors discussed in this paper included roadway function; total traffic volume; turning volumes and patterns; weaving, speed, and queues; accident type and patterns; pedestrian and bike activity; and right-of-way availability and cost. The design period characteristics of all these factors should be reviewed to determine the feasibility and possible success of converting a four-lane undivided roadway to a three-lane cross section. The four-lane undivided to three-lane cross section conversion should be considered feasible if the goals and objectives for the corridor match the existing and expected characteristics of the factors discussed. A detailed engineering study is then necessary to quantify and compare the impacts of all the feasible alternatives in order to determine the preferable mitigation measure.

The list of factors discussed in this paper is obviously not exhaustive. It does, however, provide a good starting point for the construction of guidance related to this type of conversion. More detailed guidance should be produced as experience with this type of conversion increases and more quantitative analysis and simulation is completed.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions resulted from the literature reviewed, case study results, and feasibility determination factors discussed in this paper.

- The addition of a TWLTL or raised median to an undivided roadway typically reduces vehicle delay
- The addition of a TWLTL or raised median to an undivided roadway typically reduces accident rates
- The three-lane cross section can easily be incorporated as a potentially feasible alternative in the cross section selection guidelines suggested in past research
- Some four-lane undivided roadways currently operate as “defacto” three-lane roadways (especially during the peak period)
- The present and future characteristics of several factors should be investigated to determine the design period feasibility of converting a four-lane undivided roadway to a three-lane cross section
- The increase in vehicle delay (or decrease in average speed) that results from the conversion of a four-lane undivided roadway to a three-lane cross section can be insignificant
- Accidents are usually reduced when a four-lane undivided roadway is converted to a three-lane cross section (left-turn related rear-end, right-angle, and sideswipe accidents are typically impacted the most)
- The conversion of a four-lane undivided roadway to a three-lane cross section can be feasible in certain circumstances but is not necessarily the preferable improvement

- The life-cycle costs and benefits, increased delay and decreased accidents, of an urban four-lane undivided to three-lane cross section conversion should be compared to the impacts from typical widening alternatives to determine the preferable improvement

- Four-lane undivided roadways are being successfully converted to three-lane cross sections in many areas of the United States

Recommendations

The following actions are recommended based on the discussions in this paper.

- The feasibility of replacing an urban four-lane undivided roadway with a three-lane cross section should be considered on a case by case basis

- The present and future characteristics of each of the factors discussed in this paper should be investigated to determine the design period feasibility of converting an urban four-lane undivided roadway to a three-lane cross section

- A four-lane undivided roadway should not be converted to a three-lane cross section if delays and/or accident rates are expected to increase dramatically

- A conversion of the type discussed in this paper will be most successful if the factors that define the roadway environment remain stable during the design period (e.g., traffic volumes won't increase dramatically) and the current four-lane undivided roadway is already operating as a "defacto" three-lane roadway

- More formal, consistent, and widespread before-and-after studies of this type of conversion should be completed and documented

- The expected operational impacts of converting an urban four-lane undivided roadway to a three-lane cross section should be modeled and documented

- Formal guidelines for the feasibility, installation, and evaluation of a three-lane cross section versus a four-lane undivided or wider cross section should be published

- If a three-lane cross section is determined to be feasible it should be considered, along with the other alternatives, within a detailed engineering study for comparison purposes

- Transportation professionals should consider the three-lane cross section as just one more possible improvement alternative for urban four-lane undivided roadways

AUTHORS INFORMATION

Primary Author and Presenter:
Keith K. Knapp

Co-Author:
Thomas M. Welch, P.E

Iowa State University
Center for Transportation Research and Education
2625 North Loop Drive, Suite 2100
Ames, IA 50010-8615
Phone: 515-294-7082
Fax: 515-294-0467
Email: kknapp@ctre.iastate.edu

Engineering Division
Iowa Department of Transportation
800 Lincoln Way
Ames, IA 50010
Phone: 515-239-1267
Fax: 515-239-1891
Email: twelch@iadot.e-mail.com

Co-Author:
John A. Witmer
Iowa State University
Center for Transportation Research and Education
2625 North Loop Drive, Suite 2100
Ames, IA 50010-8615
Phone: 515-294-8103
Fax: 515-294-0467
Email: jwitmer@ctre.iastate.edu

REFERENCES

1. Harwood, D.W. *Multilane Design Alternatives for Improving Suburban Highways*. National Cooperative Highway Research Program 282. Transportation Research Broad, National Research Council, Washington, DC, March 1986.

2. Harwood, D.W. *Effective Utilization of Street Width on Urban Arterials*. National Cooperative Highway Research Program 330. Transportation Research Broad, National Research Council, Washington, DC, August 1990.

3. Nemeth, Z.A. Two-Way Left-Turn Lanes: State-of-the-Art Overview and Implementation Guide. In *Transportation Research Record 681*. Transportation Research Board, National Research Council, Washington, DC, 1978, pp. 62-69.

4. Walton, C.M., et al. Accident and Operational Guidelines for Continuous Two-Way Left-Turn Median lanes. In *Transportation Research Record 923*. Transportation Research Board, National Research Council, Washington, DC, 1983, pp. 43-54.

5. Preston, H.R. Handout for *Workshop on Traffic Engineering Fundamentals – Accidents and Safety Issues*. BRW, Incorporated, Minneapolis, MN, 1998.

6. Bonneson, J.A. and P.T. McCoy. *Capacity and Operational Effects of Midblock Left-Turn Lanes*. National Cooperative Highway Research Program 395. Transportation Research Broad, National Research Council, Washington, DC, 1997.

7. Gluck J., H.S. Levinson, and V. Stover. *Impacts of Access Management Techniques*. National Cooperative Highway Research Program 420. Transportation Research Broad, National Research

Council, Washington, DC, 1999.

8. Harwood D.W. and A.D. St. John. *Passing Lanes and Other Operational Improvements on Two-Lane Highways*. Report Number FHWA/RD-85/028. Federal Highway Administration, Washington, DC, December 1985.

9. Jomini, P. City of Billings, Montana, Traffic Division, unpublished report (cited in Reference 1 and 2), 1981.

10. Welch, T.M. *The Conversion of Four Lane Undivided Urban Roadways to Three Lane Facilities*. Accepted for presentation at the Transportation Research Board/Institute of Transportation Engineers Urban Street Symposium, Dallas, TX, June 28-30, 1999. Transportation Research Broad, National Research Council, Washington, DC, 1999.

11. Kastner, B.C. Minnesota Department of Transportation, Metropolitan Division. Memorandum on Before and After Crash Study of T.H. 49 (Rice Street) from Hoyt Avenue to Demont Avenue. Unpublished report, 1998.

12. Cummings Kevin. City of Oakland, California Traffic Engineer. Email to Institute of Transportation Engineers Internet discussion group on traffic engineering (itetraffic@lists.io.com), March 1, 1999, and personal email communication on April 20, 1999.

13. Santiago, Raymond. City of San Leandro, California Traffic Operations Engineer. Phone conversation on April 20, 1999, and April 20, 1999 fax of TJKM report figures related to East 14th Street.

14. Cao, C. *The Conversion of a Four-Lane Undivided Roadway to a Three Lane with Center Two Way Left-Turn Lane (TWLTL) Cross Section*. Final Report for Civil Engineering 590 (Independent Study), Unpublished Paper, Iowa State University, May 1999.