Urban Four-Lane Undivided to Three-Lane Roadway Conversion Guidelines

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ABSTRACT

In April 2001 guidelines for the conversion of four-lane undivided roadways to three-lane facilities were developed. The content of these guidelines are summarized in this paper. Several successful examples of this type of conversion are identified in the guidelines along with the expected operational impacts and factors that should be considered in the conversion of four-lane undivided to three lanes. The focus of this paper is the factors and the operational analysis results in the guidelines. In addition, results from a University of Wisconsin extension of the guideline operational analysis are discussed. A CORridor SIMulation (CORSIM) software package sensitivity analysis approach was used in two theses to approximate the difference in the operation of similar roadways with either a four-lane undivided or three-lane cross-section. The variables considered in the analyses were total entering traffic volume (up to 2,300 vehicles per hour), and different levels of left-turn traffic, access point densities, percent heavy vehicles, and bus stop activities (e.g., bus dwell times and headways). An investigation of signalized side-street delays was also completed, and the average arterial travel speed impacts of this type of conversion during non-peak-hours compared. It has been found that in some cases a four-lane undivided to three-lane conversion can improve roadway safety with only a small reduction in operations. Key words: safety, simulation, and operations.

Key words: arterials—CORSIM—lane conversion

INTRODUCTION

The conversion of four-lane undivided roadways to three lanes has occurred throughout the United States (See Figure 1). This is true despite the fact that the safety and operational benefits of this type of cross sectional conversion are not as clearly understood as roadway widening. In April 2001, the "Guidelines for the Conversion of Urban Four-Lane Undivided Roadways to Three-Lane Two-Way Left-Turn Lane Facilities" were produced for the Iowa Department of Transportation (IaDOT) to begin addressing this knowledge gap (*1*). The IaDOT guidelines are available at www.ctre.iastate.edu/pubs/ trafficsafety.htm, and include a series of evaluative questions and chapters on past research, case study results, simulation of comparable four-lane undivided and three-lane operations, and feasibility determination factors (*1*). The operational suggestions in this guideline document were supported and/or extended by results from case study applications and CORridor SIMulation (CORSIM) sensitivity analyses (*2*, *3*).

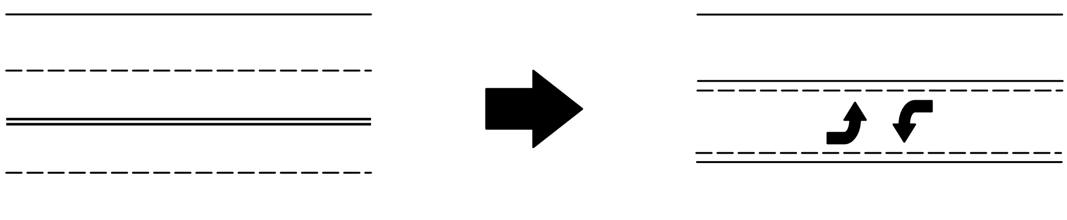

FIGURE 1. Four-lane Undivided to Three-Lane Conversion

CASE STUDY LOCATIONS AND RESULTS

Several references were used to create the list of case study locations in the IaDOT guidelines (*4*, *5*, *6*, *7*, *8*, *9*, *10*). In addition, a number of other conversions have been identified in Georgia, Washington, and Florida since the guideline publication. The list of guideline case study locations, along with their before-and-after operational and safety observations, are shown in Table 1. The data for these case study locations, except Sioux Center, Iowa, were all collected by others. Conversions are also known to have occurred in Alaska, Colorado, Pennsylvania, Michigan, Oregon, Massachusetts, Maryland, and Texas.

The thirteen roadway conversions in Table 1 had average daily traffic (ADT) volumes of 8,400 to 14,000 vehicles per day (vpd) in Iowa ,and 9,200 to 24,000 vpd elsewhere. The reviewed case study conversions appeared to result in a reduction of average or 85th percentile speeds (typically less than 5 miles per hour), and a relatively dramatic reduction in excessive speeding (a 60 to 70 percent reduction in the number of vehicles traveling 5 miles per hour faster than the posted speed limit was measured in two cases). Percent reductions in total crashes ranged from 17 to 62 percent for the case studies listed. However, Huang, et al. will present information at the Transportation Research Board Urban Street Symposium in July 2003 that took a more statistically valid approach to the evaluation of conversion safety and found the percent of total crashes occurring after a conversion was only about 6 percent lower than that of comparison sites (*11*). Additional analysis by Huang, et al. that also controlled for factors like volume and study period showed no impact due to the difference in cross section, and no significant difference in crash severity and crash type "before" and "after" this type of conversion (*11*).

FEASIBILITY DETERMINATION FACTORS

Four-lane undivided to three-lane conversions should only be considered (i.e., compared to other alternatives) at locations where it might be a feasible option. The guidelines identify and discuss more than 20 feasibility determination factors (*1*). These factors are described in this paper, but should not be considered exhaustive. Questions were also suggested in the guidelines to assist in the evaluation of each factor. The existing and expected (i.e., design period) status of the following factors should be evaluated.

ROADWAY FUNCTION AND ENVIRONMENT

The function of a roadway is defined by its amount of vehicular access and mobility activity. The objective of any design change should be to match the roadway environment with the actual roadway function. Turning volumes and/or vehicles patterns, for example, can produce a four-lane undivided cross section that actually operates 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) (See Figure 2). The existing and intended function of the candidate roadway should be thoroughly understood.

OVERALL TRAFFIC VOLUME AND LEVEL OF SERVICE

One argument for widening two-lane undivided roadways to four lanes was that it would serve more through traffic. Many urban four-lane undivided roadways operate both efficiently and safely in this manner, but the existing and/or design period traffic flow capabilities of a four-lane undivided and a three-lane cross section need to be compared for conversion feasibility. One basic measure of comparison is the magnitude of existing and forecast ADT and peak-hour volumes the cross sections appear to be capable of serving. The ADT of the case studies in Table 1 ranged from 8,500 to 24,000 vpd, and according to the American Association of State Highway Transportation Officials (AASHTO) the peak-hour volumes along this type of roadway typically represent 8 to 12 percent of their ADT (*12*). For an ADT of 8,500 to 24,000 vpd these percentages represent a bidirectional peak-hour volume of 680 to 2,880 vehicles. However, there have been "successful" conversions in the United States along roadways with much higher daily volumes than those studied.

TABLE 1. Case Study Analysis Results (*4, 5, 6, 7, 8, 9, 10)**

Location	APPROX. ADT	Safety	OPERATIONS
MONTANA			
Billings – 17th Street West	9,200-10,000	62 percent total crash reduction (20 months of 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 crash reduction (3 years of data)	NA
IOWA			
Storm Lake – Flindt Drive	8,500	Improved**	No Notable Decrease**
Muscatine – Clay Street	8,400	Improved**	NA
Osceola – U.S. 34	11,000	Improved**	No Notable Decrease**
Sioux Center – U.S. 75	14,500	57 percent total crash reduction (1 year of data)	Overall travel speed decreased from 28-29 mph to 21 mph, and free-flow speed from 35 mph to 32 mph. There was a 70 Percent decrease in speeds greater than 5 mph over the posted speed limit.
Blue Grass	9,200-10,600	NA	85th percentile speed reduction up to 4 mph (two locations increased 1 to 2 mph in one direction). The change in percent vehicles speeding depended upon location and direction (see discussion).
Des Moines (Note: This was a conversion from multiple cross sections to a three-lane)	14,000	NA	Average travel speed increased from 21 to 25 mph
CALIFORNIA			
Oakland – High Street	22,000-24,000	17 percent in total crash reduction (1 year of 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 crash reduction (2 years of data)	Maximum of 3 to 4 mph spot speed reduction

WASHINGTON			
Seattle – Nine Locations	9,400-19,400 Before 9,800-20,300 After	34 percent avg. total crash reduction (1 year of data)	NA

*ADT = Average daily traffic. NA = Not Available. Safety data duration is for before/after conversion.
**Summarized results based on anecdotal information.

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

The sensitivity analyses completed as part of the IaDOT guidelines project included most of the volumes in the case studies (See Table 2). A simplified corridor was used in these analyses and is shown in Figure 3. The analysis compared average arterial travel speed, arterial LOS, and intersection LOS of similar four-lane undivided and three-lane roadways with the peak-hour volumes shown in Table 2 (*1*, *2*). The analysis found the smallest difference in average arterial travel speed for the two cross sections occurred at a peak-hour volume of 750 vphpd. However, the simulated difference between the average arterial travel speeds along the two cross section was always less then 4 miles per hour (mph), and differences greater than 1.9 mph were only experienced at 1,000 vphpd (*1*, *2*). The arterial and signalized intersection LOS were generally the same for each cross section except when the 875 and/or 1000 vphpd (depending an the arterial classification assumed) were simulated.

Additional simulations were also done with the same corridor for even larger volumes (*3*). The difference in operations for the four- and three-lane corridors with volumes up to 1,250 vphpd (assuming 20 access points per mile per side and a total access point turning volume equal to 25 percent of the mainline traffic) were considered, but the CORSIM results for volumes above 1,150 vphpd were not reliable and dropped from further consideration (*3*). At volumes of 1,000 vphpd or higher the reduction in arterial speed along the four-lane undivided roadway was larger than the three-lane roadway, but 75 percent of the three-lane arterial speed reduction occurred between 1,000 and 1,050 vphpd (*3*).

TABLE 2. Sensitivity Analysis Factors

Characteristic	Values Evaluated
Total Entering Volume (vehicles per hour per direction)	500, 750, 875, and 1,000
Access Point Left-Turn Volume (percent of through volume)*	10, 20, and 30
Access Point Density (points per mile per side)	0, 10, 20, 30, 40, and 50

*Left-turn volumes are evenly distributed among the access points.

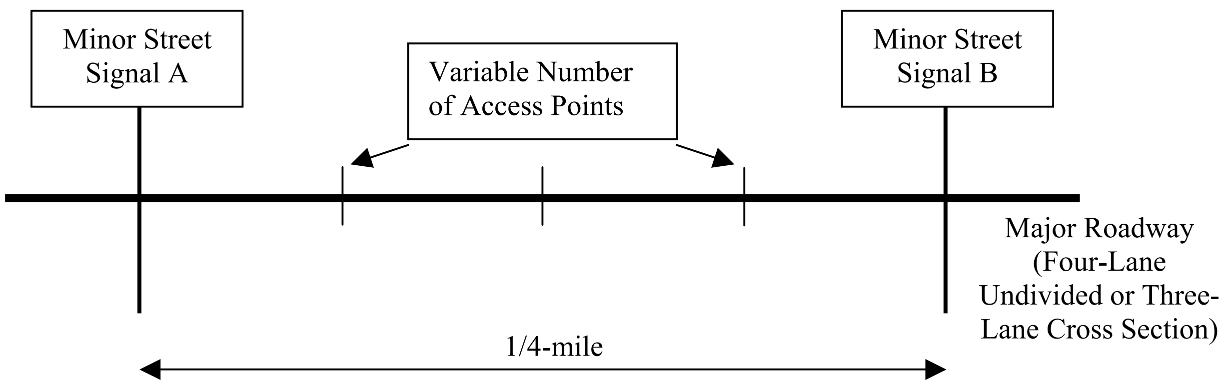

FIGURE 3. Simulated Case Study Corridor

Turn Volumes and Patterns

The sensitivity analyses completed as part of the guidelines project compared the simulated average arterial travel speed and LOS for four-lane undivided and three-lane roadways with a range of access point left-turn volumes and densities (See Table 2 and Figure 3). The analyses results indicated that, given optimized signal timing, the difference between the average arterial travel speeds for the two cross sections decreased as access point left-turn volumes increased, and as access point density increased (*1*, *2*). Arterial LOS for the two cross sections were only different at the highest access point left-turn volume and densities considered. In addition, average arterial travel speeds decreased as access point left-turn volumes increased along the four-lane undivided roadways, but increased along the three-lane roadways. However, the overall range of simulated average arterial travel speed differences for all the access point densities along the corridor considered was only 0.6 mph (*1, 2*).

Frequent-Stop and/or Slow-Moving Vehicles

The amount of frequent-stop and/or slow-moving traffic (e.g., agricultural vehicles, school bus student drop-off/pick-up, mail delivery vehicles, and buggies) that occurs along a roadway also needs to be considered. These types of vehicles have a greater impact on the operation of a three-lane roadway than a four-lane undivided cross section. An extension of the simulations completed for the IaDOT guidelines considered different percentages of heavy vehicles and bus activity were along the corridor shown in Figure 3 (*3*). For a main roadway volume of 750 vphpd (and an access density of 20 access points per mile per side) simulations were completed for heavy vehicles percentages from 0 to 30 percent. Not surprisingly, the results showed a reduction in average arterial travel speed along the three-lane roadway that was three times more than the four-lane undivided roadway reduction (*3*). Approximately 50 percent of the speed reduction, however, occurred at and above 20 percent heavy vehicles (*3*). The impacts of 1 and 2 bus stops (with buses arriving at 5 to 60 minutes headways and 30 to 60 second dwell times) were also simulated. Of course, the impact of the bus activities on average arterial travel speed was greater along the three-lane roadway, but the traffic volumes and corridor characteristics considered in this research did not allow more a more detailed conclusion (*3*).

Weaving, Speed, and Queues

The weaving, speed, and queuing of vehicles on a four-lane undivided roadway are different than those of a three-lane roadway. However, the change in some of these factors can be small if a four-lane undivided roadway is already operating as a "defacto" three-lane roadway (See Figure 2). Clearly, weaving or lane changing (other than vehicles entering the TWLTL) should not occur along a three-lane roadway. If this does occur (i.e., passing in the TWLTL), education and/or enforcement measures may be necessary.

The need to "calm" or reduce vehicle speeds is also often cited as a reason for converting a four-lane undivided roadway to a three-lane cross section. The case study results show that average vehicle speed and speed variability usually do decrease. Overall, the typical reduction in 85th percentile or average speed along the case study roadway segments was 3 to 5 miles per hour (mph). The sensitivity analysis output supported the case study results, and showed that the vehicle speed differences they experienced (i.e., 3 to 5 mph) are possible for a large range of total entering traffic, access point left-turn volumes, and access point densities.

Cumulative off-peak impacts on travel speed are also sometimes a concern, and a simulation of hourly volumes along the corridor in Figure 3 revealed that the largest difference in average arterial travel speed occurs during off-peak travel times (when the two cross sections would have the greatest difference in their general operation) (*3*). If appropriate, the cumulative average off-peak speed impacts during a typical day should be something to consider when determining the feasibility of a four-lane undivided to three- lane conversion.

The conversion of a four-lane undivided roadway to a three-lane cross section includes geometric changes that impact through-vehicle delay and queues. For example, through-vehicle delay related to left-turn traffic can be expected to decrease, but the reduction in through lanes may result in a larger increase of peak-hour segment and/or intersection through vehicle delay. One concern has been the potential increase in delay for minor roadway vehicles. A conversion may have the potential to decrease the number of acceptable gaps within the traffic flow (due to a general reduction in through lanes), and this should be considered in the determination of four-lane undivided to three-lane cross section conversion feasibility. Side street vehicle delay at the signalized intersections was considered in the extension of the IaDOT guidelines project, and the proportion of the total delay experienced by minor street vehicles was found to increase dramatically with main street volume if the number of signal phases was limited to two and the cycle lengths considered were also limited (*3*). Additional analysis is needed to evaluate the impacts of individual roadways.

Crash Type and Patterns

Based on past data and the case study results it is typically expected that a roadway with a three-lane cross section will have a lower crash frequency or rate than a similar four-lane undivided roadway. In fact, data from Minnesota indicate that three-lane roadways have a crash rate 27 percent lower than the rate for four-lane undivided roadways (*13*). The case study results also showed similar or higher decreases in total crashes, and these results were confirmed by Hummer (*14*). A more statistically robust analysis by Huang, et al., however, showed less of an safety improvement impact due to these conversions (*4*). These results were discussed in the case study section of this paper. The expected increase in safety that can apparently occur may be the result of the reduction in speed and speed variability observed along the roadway, a decrease in the number of conflict points between vehicles, and/or improved sight distance for the major-street left-turn vehicles.

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 served well by urban four-lane undivided roadways, and anecdotal 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. Bicycle lanes are also sometimes added when the conversion occurs.

Right-of-Way Availability, Cost, and Acquisition Impacts

Many urban four-lane undivided roadways have a limited amount of right-of-way. If a roadway in this environment is widened (through the addition of a TWLTL or raised median) the cost and acquisition impacts could be significant. Typically the conversion of a four-lane undivided roadway to a three-lane cross section does not require any additional right-of-way or the removal of trees and buildings. The existing curb-to-curb width is simply reallocated with pavement marking from four through lanes to two through lanes and a TWLTL (possibly including bicycle lanes).

General Characteristics

Parallel Roadways. The structure of the surrounding roadway system should be considered when evaluating the feasibility of a four-lane undivided to three-lane cross section conversion. The potential decrease in mobility (i.e., average arterial travel speed) that might occur after a conversion may induce some drivers to choose a different route. Parallel roadways in close proximity to the converted corridor are candidates for this alternative route. Planning level traffic flow analysis may be necessary.

Offset Minor Street Intersections

Minor street offset intersections along an arterial can be a poor design characteristic. The existence of offset minor streets or driveways with high turning and/or through volumes should be considered in the conversion feasibility determination. Overlapping volumes of heavily used offset minor streets or driveways can produce a situation where turning vehicles slow and possibly stop within the through lanes of a three-lane roadway. This is a situation that should be avoided.

Parallel Parking, Corner Radii, and At-Grade Railroad Crossings

Other roadway characteristics that should be considered include the amount and usage of the parallel parking spaces along the corridor, the length of each corner radii, and the impact of any at-grade railroad crossings. Parallel parking occurs along four-lane undivided and three-lane roadways. One parallel parking striping design that can reduce the impact of parking usage on the operations of the through lane traffic includes pairs of parking spaces that are spaced to allow parking movements to occur quickly. This type of design, however, will reduce the number of parking spaces available. Corner radii geometry and/or corner design impact the ability and speed of vehicle entering/exiting the minor cross street or driveway. The movements of these types of turns may be more important along a three-lane roadway, and radii or turn-lane improvements should be done on an as-needed basis. Finally, the impact of at-grade railroad crossings should be considered. In most cases, the queues at a railroad crossing can be expected to approximately double when a roadway is converted to a three-lane cross section. Drivers on a four-lane undivided roadway that approach a railroad crossing occupied by a train will typically choose the lane with the shortest queue (i.e., use both lanes evenly). The three-lane cross section does not provide this option.

RECOMMENDATIONS

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. An investigation of community goals for the roadway and a comparison of the expected before-and-after safety and operational impacts to what is locally acceptable must be completed.

The existing and expected (e.g., design period) characteristics of a number of factors should be investigated further in future research and when considering the design period feasibility of an urban four-lane undivided to three-lane cross section conversion. These factors include:

- Roadway function and environment;
- Overall traffic volume and level of service;
- Turning volumes and patterns;
- Frequent-stop and/or slow-moving vehicles;
- Weaving, speed, and queues;
- Crash types and patterns;
- Pedestrian and bike activity;
- Right-of-way availability, cost, and acquisition impacts; and
- General characteristics: parallel roadways, offset minor street intersections, parallel parking, corner radii, and at-grade railroad crossings.

The results of the work summarized suggest that urban four-lane undivided to three-lane cross section conversions along roadways with peak-hour volumes less than 750 vphpd may experience few operational impacts, but that more caution should be exercised when the roadway has a peak-hour volume between 750 and 875 vphpd. At and above 875 vphpd, the simulations indicated a more severe reduction in average arterial travel speed and greater operational concerns.

The sensitivity of the results appear to indicate that an urban four-lane undivided to three-lane conversion 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 if the current four-lane undivided roadway is already operating as a "defacto" three-lane roadway.

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