SAFETY COMPARISON OF FOUR-LANE MEDIAN DIVIDED AND FIVE-LANE WITH TWLTL SEGMENTS

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ABSTRACT

Highway projects involving access management strategies are among the most hotly debated transportation issues, particularly in regards to the choice of midblock left turn treatment. The two main competitors for midblock left turn treatment on four-lane arterials are raised medians with openings and two-way left turn lanes (TWLTL). This research focused on determining the safety effects of medians on midblock road segments and the adjacent signalized intersections.

For the segment 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, segment length, 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.

To investigate the safety effects on adjacent intersections, the study examined a set of 78 intersection approaches in North Carolina. 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.

INTRODUCTION

Highway projects that include access management strategies tend to be among the most hotly debated transportation issues with the public. In particular, the choice of midblock left turn treatment is often controversial and generates significant discussion at public hearings. The two main competitors for midblock left turn treatment on four-lane arterials are raised medians with openings and two-way left turn lanes (TWLTL).

Both of these cross-sections have their advantages. The raised median reduces conflicts by preventing midblock left turns at locations without a median opening and provides a refuge for pedestrians crossing the street. Additionally, a raised median is generally considered to be more aesthetically pleasing. The TWLTL treatment tends to be preferred by adjacent land owners and may have some economic benefits for businesses by allowing direct left turn access to the arterial. A TWLTL cross-section generally requires a narrower cross-section, which can make it less expensive to implement.

Much of the concern over this issue pertains to the performance of the two basic parts of the roadway – the midblock segments and the intersections. Safety performance of the two cross-sections through midblock segments is a major factor in the design decision. The major effect of raised medians on intersections is expected to be produced from U-turning vehicles. Drivers turning left from a minor driveway without a median opening would have to turn right and then make a U-turn at the nearest median opening. Drivers desiring to turn left from the main highway at a location without a median opening would have to proceed to the next available median opening, then U-turn and turn right at the intended driveway.

Planners, designers, and local officials are often faced with the issue of cross-section design. This project seeks to provide solid research to allow them to make informed decisions on this hotly debated topic.

Project Objectives

1. To calibrate empirical collision models for four-lane roadways in North Carolina with raised medians or TWLTLs.
2. To evaluate the safety impacts of U-turns at signalized intersections on median-divided facilities.

Scope

The project studied midblock segments on four-lane roadways in North Carolina with either a raised median or a TWLTL. Roadway segments with no median or with a traversable or painted median were not included in this study. No signalized intersections were included in the segments we studied in order to remove the complicating factors that these intersections introduce.

Only those segments that had an ADT greater than or equal to 20,000 vehicles per day (vpd) and were at least ¼ of a mile long were included. Additionally, we chose only segments with a posted speed limit of 35 to 45 miles per hour. The quantity and type of median openings in the median-divided segments were not analyzed in this study, as these were likely quite uniform within a single state.

All roadways included in this study were well-engineered and likely conform easily to American Association of State Highway and Transportation Officials (AASHTO) roadway design standards.

The intersection portion of this study was limited to signalized intersections in North Carolina. All sites had raised medians at the intersection, with no restriction placed on median length or width.

LITERATURE REVIEW

Safety on Midblock Segments

Many previous studies have compared various median treatments and levels of access control in terms of their impact on safety. One of the more comprehensive of these studies, conducted by Bonneson and McCoy, involved the development of empirical models that could be used to evaluate midblock left turn treatments in terms of operational, safety, and access impacts. The left turn treatments evaluated were raised-curb median, flush median with TWLTL, and undivided cross-section. For the safety portion of the study, three-year collision histories that were collected for 189 segments (78.6 miles) in Omaha, Nebraska and Phoenix, Arizona were combined with geometric and land use data. Only midblock segments, excluding signalized intersections, were studied. Poisson regression was used to model the effect of volume, geometry, and land use characteristics on collision frequency. The factors that were found to have a significant impact on collisions were average daily traffic (ADT) demand, segment length, driveway density, unsignalized public street approach density, the percentage of property damage only (PDO) collisions in the area, and the type of adjacent land use. The results of this research indicated that the sites with a raised-curb median were associated with fewer collisions that those with a TWLTL. This difference was most pronounced when the ADT of a segment was greater than 20,000 vpd (*1*). Other studies of the relative safety of median treatments on arterial segments include data from California and Michigan (2), Tennessee (3), Indiana (4), Georgia (5), and Charlotte, North Carolina (6). In general, these studies confirm that arterials with medians have lower collision rates than arterials with TWLTLs.

Safety Impacts of U-Turns

The safety impact of U-turning movements has been the subject of extensive research. Current research, however, has been devoted mostly to estimating the safety of U-turns at unsignalized intersections, such as median openings. A search of the literature did not reveal any studies focused on the safety of U-turns at standard signalized intersections.

A study by Xu examined unsignalized intersections on divided highways where a minor street accessed the highway at a median opening (*7*). She measured the collision reduction due to eliminating direct left turns from the minor streets by forcing drivers to turn right and make a U-turn. Her results showed that implementing this measure decreased the total crash rate by 26% and the injury/fatality crash rate by 32% for six-lane arterials. She did not consider U-turns at signalized intersections due to the fact that Florida DOT discouraged this practice. She states that U-turns at signalized intersections on major arterials degrade level of service and may cause serious conflicts with right-turning vehicles.

Dissanayake et el. conducted a similar study that looked at the safety performance of direct left turns as compared to right turns followed by U-turns at unsignalized intersections on major arterials (8). Her study examined conflict rates at each type of site. Her results show that total conflicts were significantly lower at sites with right turns followed by U-turns. While this is indicative of the overall safety performance of a design that incorporates U-turns, her scope did not include a study of conflicts or collisions directly resulting from or involving U-turns. The results of this study cannot be conclusively applied to signalized intersections considering that all sites studied by Dissanayake were unsignalized median openings.

These two studies show that designs that incorporate U-turns as a necessary movement are safer than designs that allow direct left turns. However, these findings are based on research at unsignalized intersections and do not focus specifically on collisions involving U-turns. U-turns at signalized intersections have the potential to create a very different safety situation. This unknown effect provided the impetus for this research.

METHODOLOGY

Midblock Segment Study

Although there have been many safety comparisons of raised median and TWLTL segments, the Bonneson and McCoy study (*1*) had a nationwide scope, used the current state of the art in collision modeling and considered a broad range of independent variables. As a result, the form of that collision model was utilized in this study.

Data that were collected for the Bonneson and McCoy model include the number of through traffic lanes, the segment length, the cross-section width, the median width, the driveway density, the speed limit, the percentage of property damage only (PDO) collisions, and the average daily traffic (ADT). Adjacent land use and the presence of parallel parking were also noted during the data collection process.

Site Selections

Calibrating an empirical collision model requires selecting a large sample of each type of segment. To make the model as encompassing as possible, the sites needed to cover as much of the state as was feasible. Additionally, to remove any bias from the study, the sites needed to be randomly selected.

The North Carolina Department of Transportation (NCDOT) provided a newly-updated inventory of all four- and five-lane roadway segments in North Carolina from which the segments for this project were selected. This database was filtered in order to find all segments that met the desirable characteristics for this study. These characteristics were:

- Either a raised median or a TWLTL dividing the through travel lanes,
- Segment length greater than ¼ mile long in order to lessen signalized intersection influence on collision history,
- 35-45 mile per hour speed limit to maximize the likelihood of selecting suburban highways,
- An ADT of at least 20,000 since few problems with either segment type are encountered at lower volumes, and
- No widening or major changes within the last three years in order to minimize impact of roadway changes on collision history.

The original NCDOT inventory, containing 5,917 segments was filtered for the traits given above and was narrowed down to 429 segments. Of these 429 segments, 214 are 4-lane median divided and 215 are 5-lane with TWLTL. From these remaining segments, 100 of each segment type were randomly selected for drive-through observation.

Data Needs

A great deal of information regarding each roadway segment is needed in order to calibrate the models. These characteristics include volume, geometric, land use, and collision data on each segment.

Volume Data ADT estimates from NCDOT for the year 2000 were used to account for exposure on a given segment.

Geometric Data Geometric data that were needed for calibration included:

- All possible names of the main roadway,
- Names and mileposts of segment endpoints,
- Segment length,
- Posted speed limit,
- Number of driveways and public street approaches,
- Type of intersection control, such as signalization, at endpoints,
- Presence of curb parking,
- Cross-section type (raised median or TWLTL), and
- Median width.

Land Use Data The approximate land use percentage in each segment was estimated during drive-through site visits. Land uses were categorized as business, office, residential, industrial, or undeveloped. For the purposes of the model, the predominant land use in terms of vehicle trips must be specified. In the Bonneson and McCoy study, it was noted that the business and office land uses exhibited similar collision patterns (*1*). Similarly, the residential and industrial land uses had similar collision patterns. Due to these similarities, these land uses were combined.

Collision Data Collision data were collected for each segment for the time period from October 1, 1999 through October 1, 2002 using NCDOT's Traffic Engineering Accident Analysis System (TEAAS). In order to remove collisions that may have been caused by a signalized intersection, all collisions in the first 150 feet from a signalized intersection were discarded and the segment length was reduced by this amount. Additionally, all rear-end collisions in the first 500 feet from a signalized intersection were removed. The total number of collisions as well as severity information was collected for each site.

Site Visits

Each of the randomly-selected segments was visited during the summer of 2003. For each visit, two data collectors were used.

Some segments were discarded during site visits due to a variety of factors. The most frequent cause for discarding a site was a signalized intersection located in the middle of the segment. If the signalized intersection was located in such a way that the distance between the signal and at least one of the original endpoints was still at least ¼ mile long, the portion from that original endpoint to the signal was used.

Other sites were discarded due to incorrect cross-sections, speed limits outside of the desirable limits, or inability to locate the segment due to lack of signage or renaming of roadways. In the event that a nearby segment, not already selected for the study, met all desirable criteria and had similar geometric, land use, and volume characteristics as the discarded site, the nearby segment was substituted into the study. This substitution kept the sample size sufficiently high, which prevented a second round of site selection and site visits. The final sample size is described later.

Model Calibration

The first step in calibrating the empirical collision models was removing a small portion of the data set to be used in validating the model. For each data set, 20% of the sites were randomly extracted and left out of the calibration process.

SAS® was used to calibrate the models. Since the form of the Bonneson and McCoy model proved to be effective, the recalibration process mainly involved determining which parameters were significant and what the coefficients of those parameters should be. The variables we considered for inclusion in the model were:

- ADT, vpd,
- Length of segment, feet,
- Driveway density, drives per mile (two-way total),
- Unsignalized public street approach density, approaches per mile (two-way total),
- Median width, feet,
- Speed limit, mph,
- Countywide percentage of PDO collisions,
- Business/office indicator variable (1.0 if predominantly business or office land use, 0.0 otherwise),
- Residential/industrial indicator variable (1.0 if predominantly residential or industrial land use, 0.0 otherwise), and
- All possible interactions between any two of the above variables.

Including all interaction variables, 45 parameters were examined for each of the models. The “genmod” procedure in SAS®, assuming a Poisson distribution for collisions, was used to perform the model fitting. Collision frequencies are generally assumed to follow the Poisson distribution since a large proportion of the sites will have few collisions and very few sites will experience a large number of collisions.

Model Validation

Once the significant parameters and their coefficient estimates were determined, we tested the model with the previously removed validation sites. To determine the fit of the models, predicted collisions were plotted versus actual collisions. Ideally, the plot of calibration sites would be similar to that of validation sites.

Intersection Study

U-turns are a safety concern because their relatively slow movement can be difficult to anticipate. They could cause conflicts with vehicles turning right from the cross street as well as conflicts with vehicles in the main road left turn queue. Through a study of collision history, this research examined the safety impact of U-turns on a signalized intersection. The process involved the selection of appropriate study sites and the analysis of physical characteristics and traffic volume with collision data.

Site Selection

The set of intersections used for the intersection portion of this study involved the compilation of two groups of sites. The first group contained sites that were randomly chosen. The second group contained U-turn "problem sites" that were recommended based on high volumes of U-turns or a history of U-turn collisions. To be eligible as a study site, an intersection had to meet the following criteria:

1. *Signalized Intersection.* The scope of this portion of the project included only signalized intersections with exclusive left turn lanes. Permitted and protected left turn signal types were both included in the study.
2. *Presence of a Median.* Even though U-turns may occur at intersections that have no median, only sites with medians at the intersections were considered. However, no restriction was placed on the length or width of the median.
3. *Two Lanes Receiving.* Only sites that had two lanes receiving the U-turns were included. This criterion stems from the project goal of comparing four-lane divided highways to five-lane undivided highways. This criterion excluded sites that had three through lanes or a third lane for buses or exclusive right turns, but did not exclude sites with U-turn "bulb-outs" or wide paved shoulders.
4. *U-Turns are Legal*. No sites were chosen that had a signed prohibition of U-turns at the approach. It was desired that the safety analysis examine U-turn collisions under normal conditions. U-turns made illegally cannot be expected by other drivers. The impact of such U-turns would be difficult to predict.

Since the segments for this study were selected randomly, adjacent intersections could also be considered a random sample. All adjacent signalized intersections were analyzed and it was determined that 54 met all criteria and were eligible for the intersection portion of the study.

City and state transportation engineers across North Carolina were asked to provide lists of signalized intersections in their areas that had high percentages of U-turns. Twenty-four of the recommended sites were found to be eligible.

These two sets of intersections were combined to form a list of 78 sites that were intentionally biased to predict higher numbers of U-turn problems than would be predicted with a completely random set of sites. Analysis conducted on this set of sites would produce a very conservative estimate of the safety impact of U-turns at signalized intersections.

Collection of Physical Data
Assembling factors for the intersection study involved collecting data on the physical characteristics of each intersection and surrounding area. This includes the roadway segment leading to the intersection approach of interest. This segment was defined as beginning at the last median break and ending at the intersection. Drivers desiring to make a U-turn would be proceeding along this segment before making a U-turn at the intersection. Data collected during visits to each site included intersection characteristics – such as signal phasing, lane configuration and median width – and segment information, such as segment length and number of access points.

Collection of Collision Data
Collision data in this project were taken from NCDOT records of police-reported collisions. Collision data were collected from October 1, 1999 to October 1, 2002. Every crash report for the time period chosen was visually inspected to determine the number of U-turn collisions at each site. The current North Carolina collision report form does not include a checkbox or code to denote if the collision involved a U-turn movement.

Collection of Traffic Volume Data
For each site in the study, data were obtained from the NCDOT on main road ADT. Turning movement counts were available for 29 sites.

RESULTS

Midblock Segment Study
Of the 200 randomly selected sites, 143 were found to meet all desirable characteristics and were used for calibration and validation of the empirical collision models. Of the 143 total sites, 62 had a raised median and 81 had a TWLTL. Table 1 gives summary information about the data that were collected for each of the cross-section types. Approximately 87 miles of raised median and TWLTL roadways were included in this study. Of the 286 total segment endpoints, 201 were signalized intersections and 85 were unsignalized approaches. The unsignalized approaches either were original endpoints from the NCDOT database or were locations where either the cross-section or the speed limit changed.

Data Analysis
The collision data were analyzed to determine what differences, if any, exist between the two cross-sections in terms of collision severity and type. First, the collision severities were analyzed. The raised median cross-section had a slightly higher proportion of fatalities, class C injuries, and property damage only collisions while the TWLTL cross-sections exhibited a higher proportion of both class A and B injuries. Overall, the collision severities between these two designs were very similar.

Figure 1 is a comparison of collision types between the two left turn treatments. As would be expected, the raised median cross-section experienced a smaller proportion of angle, left turn, and head-on collisions than did the TWLTL cross-section. Rear end collisions were the most predominant collision type for both designs, with the raised median cross-section having a larger proportion of this type than the TWLTL cross-section. Other collision types exhibit very similar proportions for each segment design alternative.

Model Calibration

The final models were:

$$C_{RM} = ADT^{1.327} Len^{0.7233} e^{(-16.6814-0.8463 I_{b/o}-0.6968 I_{r/i}+0.0132(AD) I_{b/o})}$$

$$C_T = ADT^{1.5829} Len^{0.8902} e^{(-21.2535+0.008(AD) I_{b/o})}$$

where,

- C_{RM} = annual mid-signal collision frequency for raised median sites;
- C_T = annual mid-signal collision frequency for TWLTL sites;
- ADT = average daily traffic demand, vpd;
- Len = segment length, feet;
- AD = approach density (two-way total), approaches/mile (driveways and public streets);
- $I_{r/I}$ = indicator variable for residential or industrial land uses (1.0 if res /ind; 0.0 otherwise);
- $I_{b/o}$ = indicator variable for business or office land uses (1.0 if bus/office; 0.0 otherwise)

The general form of the models is the same as that of the Bonneson and McCoy models and the coefficients are very similar. All terms in the model were significant at the 95% confidence level.

Model Validation

The next step was to validate these models. We assessed goodness of fit for both the calibration sites and the validation sites. Ideally, the fit of the two sets of data would be the same. This outcome would indicate that the models can predict collisions for future sites just as well as it can for those sites used to create the model. Table 2 shows the fit of the models to the collected data.

Due to the highly variable nature of collision data, R^2 values in the range of 0.3 to 0.5—as we produced--are generally considered acceptable for collision models. While these R^2 values are not ideal, the models can be helpful in predicting collisions for a variety of applications. Most importantly, the calibration and validation sites yield similar R^2 values for each type of cross section, indicating that, for future sites, the model should predict collisions just as well as it did for those sites used to calibrate the models.

Data Ranges

When using empirical models, it is important to ensure that any analysis is confined to the range of data used to calibrate the models. As a result, it is important to identify the range of collected data.

Most of the sites in this study fall in the range of 20,000 to 40,000 vpd. The models should not be used for sites with ADTs less than 20,000 vpd or greater than 50,000 vpd. Additionally, the models should be applied cautiously for TWLTL segments with ADTs greater than 35,000 vpd due to the small number of TWLTL sites with high traffic volumes.

The models should only be applied to segments with lengths between ¼ mile and approximately one mile due to the small number of sites visited outside of this range. For longer segments, the roadway should be split up at logical, convenient points that are less than or equal to one mile in length and analyzed separately.

The undeveloped land use is the scarcest land use with only four sites from each median treatment that are undeveloped. Results for this land use type are not reliable. As a result, the model should not be used for completely undeveloped land uses. If necessary, future land uses can be assumed in order to utilize the model.

Approach density is the two-way total of all types of approaches including driveways and unsignalized public street approaches. The raised median model is unlikely to accurately predict collisions at approach densities greater than 90 approaches per mile and the TWLTL model is likely unreliable at approach densities greater than 120 approaches per mile.

Sensitivity Analysis

ADT values from 20,000 to 50,000 vpd, segment lengths from 1,320 to 6,000 feet, and approach densities from zero to 90 approaches per mile were compared for both business/office and residential/industrial land uses.

Figure 2 shows the comparison between the model results for a ½-mile segment with predominantly residential/industrial land use over all values of approach density. The raised median segment is associated with fewer collisions over all ADT values. At an ADT of 20,000 vpd, the raised median has almost no safety advantage over a TWLTL. As ADT increases, so does the safety margin between the two cross-sections.

For predominantly business/office land uses with approach densities around 25 approaches per mile, the results are quite similar to that shown in Figure 2. As the approach density increases, the safety margin between the two cross-sections narrows. For example, at approximately 50 approaches per mile, the collision prediction around 35,000 vpd is nearly identical between the two cross sections. At lower ADTs, the TWLTL is associated with fewer collisions and at higher ADTs, the raised median is associated with fewer collisions.

Intersection Study

The intersection study included 78 sites, chosen as described above, consisting of signalized intersections with protected left turns and two lanes receiving the U-turning vehicles. Data collected for these sites include geometry, traffic volumes, and history of collisions involving U-turns.

Analysis of U-turn Collisions

One of the most significant findings of this research is seen in the U-turn collision frequency at the study sites. Figure 3 illustrates that the majority of the study sites (65 out of 78) did not have any U-turn collisions in the three-year study period. It also shows that the maximum number of U-turn collisions seen on any intersection approach was three collisions per year, and that was observed only at one site. The mean number of collisions per year was 0.18 with a 95% confidence interval of 0.11 collisions per year. This finding is especially significant considering that 24 of the sites were selected solely for their reputation as U-turn "problem sites", known to have high U-turning volumes or a history of U-turn collisions.

From the 13 sites with U-turn collisions, a total of 41 U-turn collisions were noted. These collisions fell into one of three categories:

- *Angle* – This collision occurred between a U-turning vehicle and a vehicle making a conflicting right turn from the cross street.
- *Sideswipe* – This collision occurred where there was a double left turn lane and a vehicle attempted to make a U-turn from the outside turn lane.

- *Rear-end* – This collision occurred when a vehicle failed to reduce speed sufficiently to avoid hitting a U-turning vehicle. It was also caused by a right-turning vehicle yielding to a U-turn and being struck from behind – an occurrence that only happened once at the sample intersections during the study period.

The most common U-turn collision observed was the angle collision (22 out of the 41 collisions), followed by rear-ends (11 of 41) and sideswipes (8 of 41).

Significant Factors in U-turn Collisions

Due to the large number of sites with zero U-turn collisions, a collision prediction model, such as that which was calibrated for the segment study, was not deemed to be a logical result of this research. The analysis focused instead on the site characteristics that correlate significantly with U-turn collisions.

The analysis examined factors pertaining to geometry of the intersection, signal type, and traffic volume. Table 3 summarizes the factors and their effects on U-turn collisions. Each statistical test used a 90% confidence level. This level of confidence is appropriate for analyzing collision data, given that these data are quite unstable and the sample sizes were low. Using a stricter level would provide more confident results but would eliminate factors that may have made some contribution to the problem.

The statistical tests compared two groups of sites – those sites with one or more U-turn collisions and those sites without U-turn collisions – to see if a particular factor had significance. If the factor had continuous data, such as median width, a t-test was used to compare the mean values of the two groups. To verify the t-test results, a Wilcoxon Rank Sum test was used. Unlike a t-test, it does not assume any particular distribution of the data. These two tests agreed for all factors.

If the factor could be reduced to a yes/no situation (i.e., right turn overlap vs. no right turn overlap), a Chi-Square test was used to determine if there was a significant difference. In the event that the expected values in the contingency table were below five, the analysis was conducted with a Fisher's Exact test, which is a better test for low sample sizes.

Discussion of Site Characteristics

1. *Median width.* The width of medians at the study sites ranged from 2 to 48 feet, and all medians were raised. The analysis showed no significant difference in the mean width of sites with U-turn collisions and sites without U-turn collisions.
2. *Number of left turn lanes.* Analysis showed that a significantly higher proportion of sites with double left turn lanes had U-turn collisions than sites with single left turn lanes. This could be caused by the fact that the double left turn lanes create the possibility of collisions due to U-turns from the outside lane. All sideswipe collisions in this study were caused by U-turns from the outside lane. Another possible reason for the significance of this characteristic was that sites with double left turn lanes are often accompanied by a protected right turn overlap, which proved to be a significant factor in U-turn collisions.
3. *Right turn overlap.* Most sites with protected right turn overlap had signs posted indicating that U-turns must yield to right-turning vehicles. In spite of this, the presence of right turn overlap proved to be a significant factor in U-turn collisions.

4. *Left turn signal type.* The types of left turn signals included in this study were protected, permitted, and protected/permitted. Upon comparison, these three groups were not found to have significantly different amounts of U-turn collisions.
5. *Number of access points.* This was a count of the number of driveways and public streets on the median-divided segment leading to the intersection approach of interest. These access points are likely the main generators of U-turns at most intersections. No significance was found for this characteristic, however.
6. *Main road ADT.* The main road ADT values ranged from 15,000 to 52,000 vehicles per day, with a median value of 30,000 vpd. Main road ADT was not a significant factor in this analysis.
7. *AM and PM peak turning movements.* Turning movement counts were obtained wherever available to determine the validity of the assumption that more left-turning and conflicting right-turning traffic results in more U-turn collisions. When the two groups were compared (sites with U-turn collisions and sites without U-turn collisions), the groups with collisions were found to have significantly higher turning movement volumes for all movements studied.

CONCLUSIONS

The purpose of the segment portion of this research was to develop empirical models to predict collisions on four-lane median-divided segments and five-lane with two-way left turn lane (TWLTL) segments in North Carolina. Geometric, volume, collision, and land use data were collected on 143 segments totaling approximately 87 miles.

The form of the models was adopted from a previous study conducted by Bonneson and McCoy in Nebraska and Arizona (*1*). Their models were judged as logical and were created using the current state of the art in terms of collision modeling. Poisson regression in SAS® was used to recalibrate the Bonneson and McCoy models. Traffic volume, segment length, predominant land use, and approach density were found to be significantly related to collisions.

For predominantly residential or industrial land uses, the raised median design is always associated with fewer collisions than is the TWLTL. The raised median design also has a safety advantage over the TWLTL for predominantly business or office land uses with low to medium approach densities (0-25 approaches per mile). For business and office land uses with medium to high approach densities (25-90 approaches per mile), the TWLTL appears to be safer at low traffic volumes and the raised median appears to be safer at high traffic volumes. Additional information on the segment portion of this study is available (9).

The intersection study examined U-turn collision history. 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 collision rates at the remaining 13 sites ranged from 0.33 to 3.0 collisions per year. Sites with double left turn lanes, protected right turn overlap, or high left turn and conflicting right turn traffic volumes were found to have a significantly greater proportion of sites with U-turn collisions. Additional information on the intersection portion of this study is available (10).

There are several areas for productive future research. A useful accompaniment to the results from this study would be a U-turn prediction model based on driveway density, land usage, and other such characteristics of the preceding roadway segment. A simple breakdown of land use into residential, business, or office may not be sufficient; it may be necessary to involve trip generation data for the various land parcels that have access points on the highway. The analysis should involve access points on both sides of the main road.

Future research should also study the effect of U-turning heavy vehicles on safety. While not covered in this research, the effect from heavy vehicles could be significant even in locations where there is a low volume of heavy vehicles that would need to U-turn. A new median installation may force delivery trucks and other heavy vehicles to make U-turns in order to complete their routes. A study could determine the effects of this situation and make informed suggestions about ways to minimize capacity loss and safety hazards.

Finally, while not addressed in this research, the frequency and type of median openings is an important aspect of roadway design. Future research should address the impact of median openings on the safety of midblock segments.

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TABLE 1 Summary of Segment Data

	Parameter		Raised Median	TWLTL
Exposure Characteristics	Number of Segments	Total	62	81
		Calibration	50	65
		Validation	12	16
	Segment Length, miles	Minimum	0.25	0.25
		Average	0.59	0.62
		Maximum	1.59	1.3
		Total	36.49	50.5
	Average Daily Traffic (ADT), vpd	Minimum	20,000	20,000
		Average	31,000	27,000
		Maximum	56,000	50,000
Geometric Characteristics	Driveway Density, drives per mile	Minimum	0	0
		Average	22	46
		Maximum	100	123
	Public Street Approach Density, approaches per mile	Minimum	0	0
		Average	4	5
		Maximum	25	23
	Number of Segments with Curb Parking		0	0
	Median Width, feet	Minimum	2	10
		Average	26	12
		Maximum	48	17
Land Use Composition	Average % Residential Land Use		28	24
	Average % Office Land Use		3	2
	Average % Business Land Use		46	61
	Average % Industrial Land Use		0	1
	Average % Undeveloped Land Use		23	12
Safety Indicators	Total Collisions		2174	2562
	Collisions per Segment	Minimum	3	0
		Average	35	32
		Maximum	123	205
	Fatal and Injury Collisions per Segment	Minimum	1	0
		Average	12	12
		Maximum	52	72
	Property Damage Only Collisions per Segment	Minimum	1	0
		Average	23	19
		Maximum	79	133

TABLE 2 Fit of Models to Collected Data

Goodness of Fit Parameters - Raised Median							
	R^2	Slope			Intercept		
		Value	p-value	significantly different from 1.0	Value	p-value	significantly different from 0.0
Calibration	0.4912	0.4929	<0.0001	no	4.5347	<0.0001	no
Validation	0.4165	0.5245	0.036	no	5.6763	0.09	yes

Goodness of Fit Parameters - TWLTL							
	R^2	Slope			Intercept		
		Value	p-value	significantly different from 1.0	Value	p-value	significantly different from 0.0
Calibration	0.3422	0.3508	<0.0001	yes	6.9938	<0.0001	yes
Validation	0.3397	0.23021	<0.0001	yes	8.8829	<0.0001	yes

TABLE 3 Significant Factors in U-Turn Collisions

			Effect on U-Turn Collisions		
No.	**Characteristic**	**Groups to Compare**	**Significant? (90% conf)**	**Description**	**Statistical Test**
1	Median Width	Sites with collisions; sites w/o collisions	NO	-	T-test, Wilcoxon Rank Sum
2	Number of Left Turn Lanes	2 turn lanes; 1 turn lane	**YES**	Double left turn lane sites had more collisions than single left turn lane sites	Fisher's Exact
3	Right Turn Overlap	Overlap; no overlap	**YES**	Sites with protected right turn overlap had more collisions than sites without overlap	Fisher's Exact
4	Left Turn Signal Type	Permitted; protected; protected/permitted	NO	-	Fisher's Exact
5	Number of Access Points	Sites with collisions; sites w/o collisions	NO	-	T-test, Wilcoxon Rank Sum
6	Main Road ADT	Sites with collisions; sites w/o collisions	NO	-	T-test, Wilcoxon Rank Sum
7	AM Left Turn Volume	Sites with collisions; sites w/o collisions	**YES**	Sites with collisions had significantly higher turning volumes	T-test, Wilcoxon Rank Sum
8	AM Conflicting Right Turn Volume	Sites with collisions; sites w/o collisions	**YES**	Sites with collisions had significantly higher turning volumes	T-test, Wilcoxon Rank Sum
9	PM Left Turn Volume	Sites with collisions; sites w/o collisions	**YES**	Sites with collisions had significantly higher turning volumes	T-test, Wilcoxon Rank Sum
10	PM Conflicting Right Turn Volume	Sites with collisions; sites w/o collisions	**YES**	Sites with collisions had significantly higher turning volumes	T-test, Wilcoxon Rank Sum

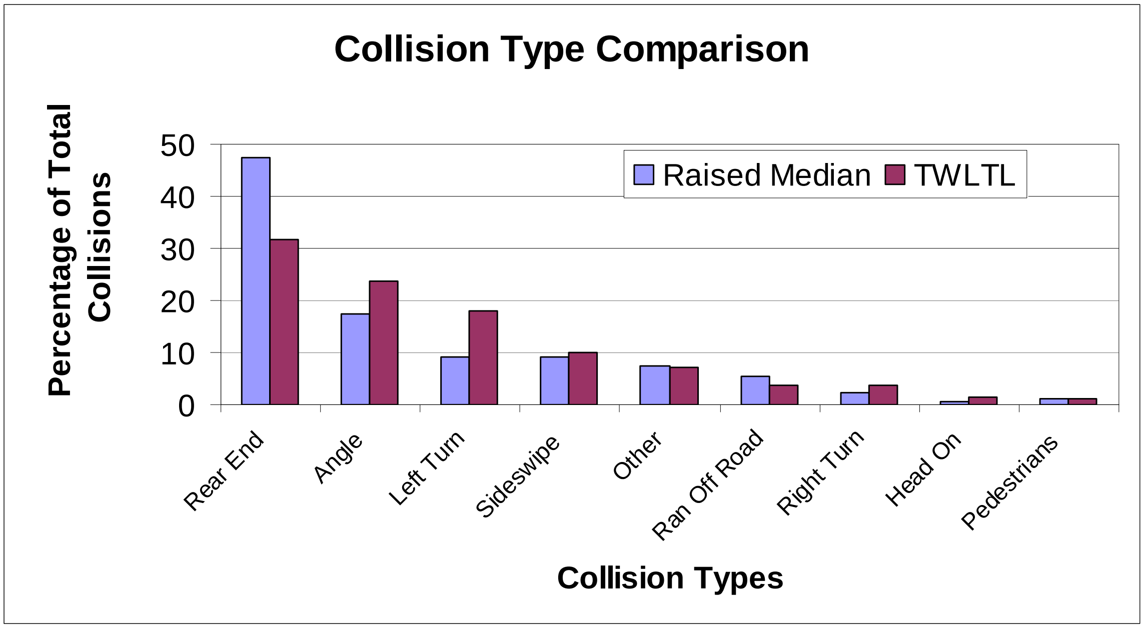

FIGURE 1 Comparison of Collision Types

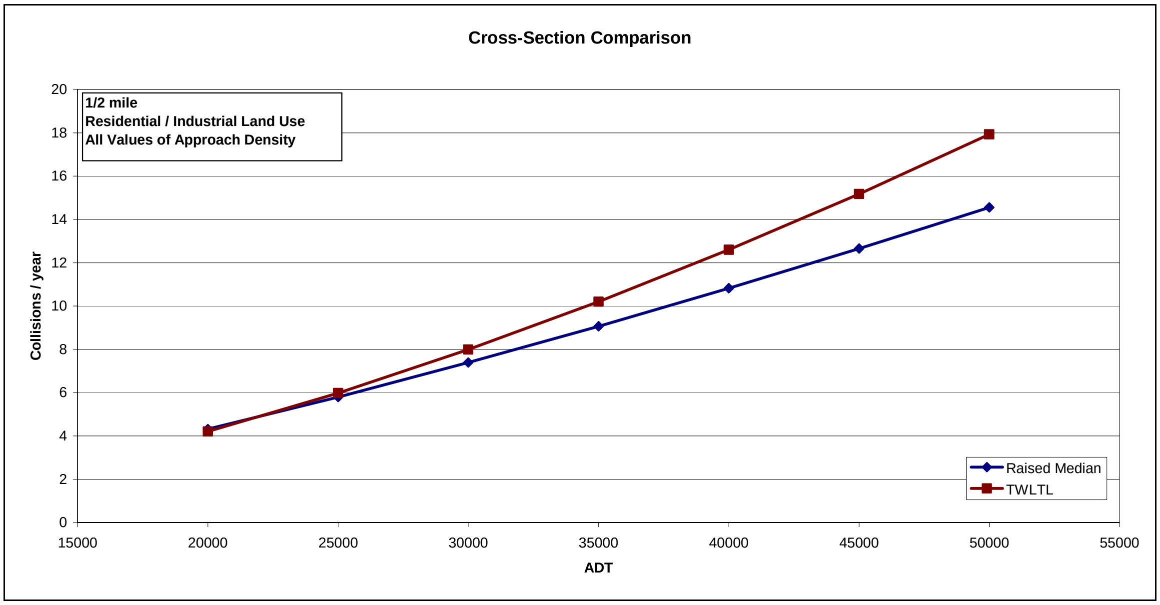

FIGURE 2 Cross-Section Comparison for Residential/Industrial Land Uses

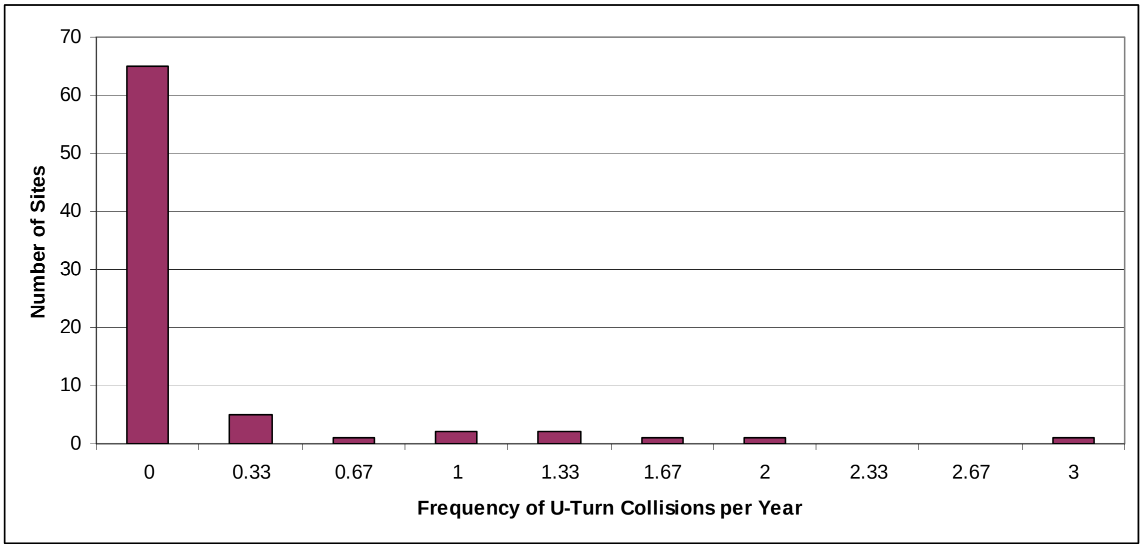

FIGURE 3 Histogram of U-Turn Collision Frequency