Optimum urban clear-zone distance

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Abstract

In urban communities, there are often limited amounts of right-of-way available for establishing a setback distance from the curb for fixed objects. Urban road designers must weigh the cost of purchasing additional right-of-way for clear-zones against the risk of fixed object crashes. From 2004 to 2006, fixed object crashes comprised fifteen percent of all fatal urban crashes and three percent of all crashes in the state of Iowa. Many states use AASHTO recommendations as minimum clear-zone standards, while others states have increased the required minimum clear-zone distance but little research exists to support the specification of these minimums. This paper summarizes a study on the effects of the clear-zone on safety performance of urban curbed streets. The study included synthesizing selected state practices and investigated the benefits of a various clear-zone widths based on thirteen urban corridors in Iowa. The results suggest that a four to five foot clear-zone could be effective in reducing 90 percent of urban fixed object crashes and recommends that additional research be conducted to account for variations in speed, traffic and other corridor characteristics.

Key Words: crashes – safety - fixed object offset –urban clear-zone – curbed streets

Introduction

In urban communities, there are often limited amounts of right-of-way available to establish a clear run-out zone. On roadway projects, the clear-zone recommended by the administering jurisdiction is sometimes not implemented because of the presence of established buildings, trees, or other fixed objects, any of which may be too difficult or too costly to remove. These obstacles present hazards to drivers when the fixed objects are located too close to the roadway to allow drivers to recover if they run off the road.

In Iowa, fixed object collisions on urban curbed roads constitute approximately three percent of crashes, statewide. While only six percent of urban crashes are fixed object crashes, these collisions result in fifteen percent of urban fatalities **Table 1** compares the number of total crashes, urban crashes, and urban fixed object crashes in Iowa from 2004 to 2006.

Table 1. Iowa crashes, average annual crashes from 2004 to 2006

	Fatal	Major Injury	Minor Injury	Possible Injury	Property Damage Only	Total
Total Crashes	380	1,643	5,498	10,263	39,756	57,540
Urban Crashes*	66	584	2,649	6,429	22,797	32,525
Urban Fixed Object Crashes	10	51	186	357	1,240	1,844
% of all Crashes	3%	3%	3%	3%	3%	3%
% of all Urban Crashes	15%	9%	7%	6%	5%	6%

*Urban crashes are those crashes that take place on curbed roads.

Fixed objects near the traveled roadway are clearly hazardous to errant vehicles. However, these same objects may provide a protective barrier for pedestrians when a sidewalk is located behind the fixed objects (such as street trees). Logically, fixed object crashes may be reduced when fixed objects are located further back from the roadway edge. Few previous studies are available which address this reduction (Turner and Barnett, 1989, is a notable exception) and none attempt to quantify it *(19)*. Turner and Barnett made helpful recommendations about how the design engineer can effectively reduce the number of hazardous poles in the clear zone. Although their guidelines can be followed and may result in a reduced number of crashes, they did not attempt to identify the severity or the frequency of crashes that would be avoided, and hence did not identify the safety benefits of following their guidance. Therefore, while design engineers can calculate the cost of removing utility poles from the edge of the roadway, they have no measure of the benefits resulting from the relocation expenditure.

The AASHTO Green Book, *(1)* recommends a minimum 18 inch urban fixed object setback, although many agencies provide design guidance that specifies greater distances. When designing urban roadway reconstruction or improvement projects, the engineer should weigh the costs of clearing aboveground utilities, buildings, walls, and other fixed objects against the benefits of providing additional space for errant vehicles to recover. Unlike many rural areas, the context of an urban corridor is often unique, which complicates the evaluation of the tradeoff between construction and ROW acquisition costs and potential highway safety savings.

In several states, the minimum recommended standard for lateral offset from the curb is ten feet. In Iowa, state maintained urban roads designed or redesigned with less than 10 ft of clearance require a "design exception" report . To support such an exception, economic analysis is preferred. However, while the costs of providing additional clear-zone (removing fixed objects) can be estimated, safety benefits of protecting, relocating, or removing fixed objects to a certain distance are not so easily quantified. In some cases, providing wider clear-zones may be contraindicated by traffic calming treatments and context-sensitive design considerations.

The relationship between urban clear zone and safety costs has not been quantified by previous research. The purpose of this research reported in this paper was to investigate this relationship. Following a brief summary of surveyed state practices, an analysis of the relationship between fixed object offset and safety performance is presented. Several measures of urban clear zone fixed object presence were developed and used in the analysis, including minimum, average, 15th percentile distance of setback and fixed object density. The effects of intersection influence and speed limit are also discussed. An example economic analysis is presented to establish an optimal setback distance based on Iowa crash data. "Cumulative percent" graphs are used to identify the lateral distance within which most urban fixed object crashes and their associated costs occur. To isolate the effect of urban clear zone from other variables, and to identify important causal variables, a mixed linear safety performance function was estimated and is summarized. Finally, conclusions and limitations of the research are presented.

State Synthesis

To evaluate the administration of clear-zones within various states, a survey was sent to 20 state agencies. The survey included six questions regarding federal aid projects and six questions regarding state aid projects. Respondents were also asked to provide additional contacts at the local level who could be interviewed about design exception practices. Results revealed that many standards are currently in use, ranging from minimum clearance of 1 to 35 ft *(2-17)*.

The State of Iowa's clear-zone standards require a generous amount of setback in comparison to many of the states surveyed for this project. Iowa's desirable setback distance is 12 ft, and the minimum setback requirement is 10 ft *(6)*. Eight of the states surveyed had desirable setback requirements similar to Iowa's minimum setback requirement of ten feet. Of those states, three had a minimum requirement of only 1.5 feet from the face of curb. A more complete description of the survey methodology and results is included in the project report *(20)*.

Data Collection

To conduct the evaluation of the significance of the clear-zone, a project database was created. The project database included data from eleven corridors in the Des Moines metropolitan area and two corridors in the Waterloo/Cedar Falls area with speed limits ranging from 30 to 40 mph, volumes from 4,600 to 24,200 ADT, and 2 to 5 lanes (see **Table 2**). At each of the corridor sites, the lateral offset distance to each fixed object in the right-of-way was measured from the face of the curb using a laser distance meter. The location of each object was also collected using a global positioning system (GPS) device.

Table 2. Corridor Characteristics

Corridor	City	Basic No. of Lanes	Speed Limit	Avg. AADT
Williston Ave	Waterloo, IA	2	30	4660
E 4th St	Waterloo, IA	2	30	5900
Hubbell Ave	Des Moines, IA	4	40	10450
Beaver Ave	Des Moines, IA	2-3	30	12350
SW 9th St	Des Moines, IA	3-4	35	12840
Euclid Ave	Des Moines, IA	4	35	14071
2nd Ave	Des Moines, IA	4	30	14760
E University Ave #1	Des Moines, IA	4	35	14900
University Ave	Des Moines, IA	4	35	15033
NE 14th St	Des Moines, IA	4	35	16874
E University #2	Des Moines, IA	4	35	19850
Army Post Rd	Des Moines, IA	4-5	35	21675
Merle Hay Road	Des Moines, IA	4-5	35	24200

Fixed object crashes from the years 2001 to 2006 were extracted from the Iowa DOT's crash database. The Iowa DOT's geographic information management system (GIMS) was used to obtain a data set of centerlines for public roads, to represent the corridors and geographically select the crashes of interest *(18)*. Due to the precision of the crash locations, some crashes occurring on intersecting streets, up to 150 feet away, may have been selected into the data base. The fixed object crashes used in this research were each documented in the crash database with at least one harmful event including a collision with a fixed object. Fixed objects studied in this research include a bridge/bridge rail/overpasses, underpass/structure supports, culverts, ditches/embankments, curbs/islands/raised medians, guardrails, concrete barriers, trees, poles, sign posts, mailboxes, impact attenuators, and other fixed objects (although clearly not all of these are common in urban corridors). A GIS environment was used to analyze the relationship between the presence of fixed objects and safety performance at three levels of spatial aggregation.

Analysis

Descriptive analyses were conducted to better understand the relationship of clear-zone distance to safety performance. Three levels of spatial aggregation (segments, blocks, and 15 m sections) were used to analyze the data for the 13 corridors. Segments were considered as multi-block parts of corridors with similar road and traffic attributes.

Three measures of urban clear zone are proposed in this study. These include: minimum setback, average setback, and 15th percentile setback (the offset distance that 85 percent of fixed objects are behind). The effects of several fixed object descriptors were studied, and include: intersection area of influence, violations to the area of influence, speed limit, and fixed object density. Three additional analyses were conducted to try and identify the most cost effective urban clear zone or setback distances: cumulative percent crashes, cumulative percent cost, and incremental benefit. The three measures of clear zone provided were considered: minimum setback, average setback, and 15th percentile setback. These measurements are used as a proxy for involved fixed objects, as setback distances of objects that have actually been struck in previous crashes are not known.

While all three levels of spatial aggregation were used in each analysis, only the ones demonstrating the clearest relationships are presented in this paper. **Figures 1** through **Figure 3** illustrate the relationship between the fixed object setback and the average number of fixed object crashes per year. The trend lines in each of these figures indicate that the average number of fixed object crashes decreases as the setback distance increases. Minimum setback demonstrates the most consistent trend (in statistical terms, the least heteroskedasticity or unequal variability of the observations across the range of the predictor variable).

Minimum Setback

To determine the effect of the clear-zone the minimum setback was first evaluated. The minimum setback is defined as the setback distance of the object that is closest to the face of the curb over the length of the section. In the segment based analysis, there was a clear relationship between the minimum setback and the average number of fixed object crashes. **Figure 1** illustrates this relationship. This figure shows that as the minimum setback is increased, the average number of fixed object crashes per year decreases.

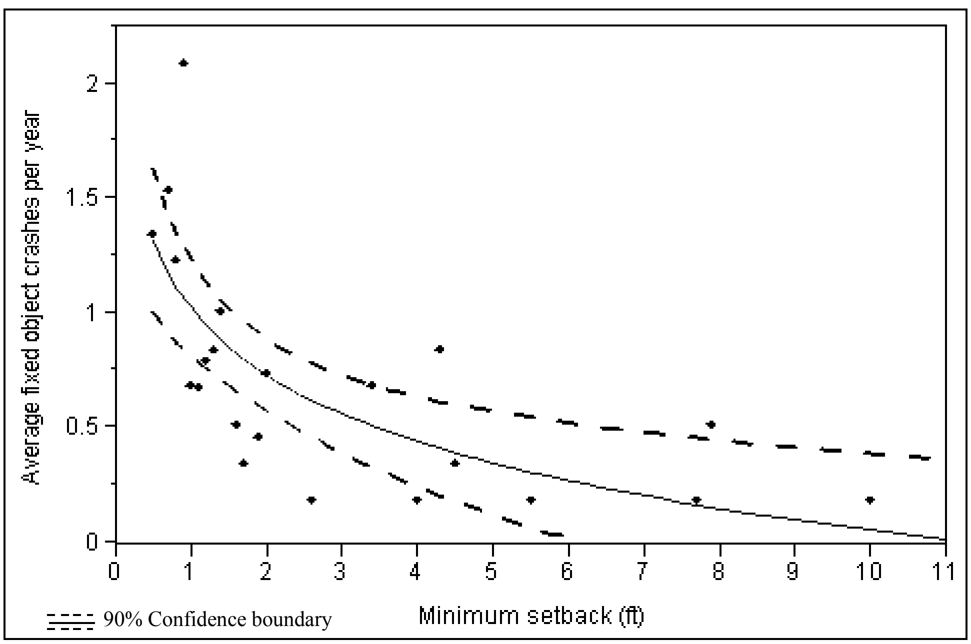

Figure 1. Safety impact resulting from minimum setback

Average Setback

The average setback was next evaluated. The average setback is defined as the average distance between the face of the curb and all the fixed objects in the segment. In the segment based analysis, average number of fixed object crashes demonstrated somewhat of a decreasing relationship to the average setback (see **Figure 2**).

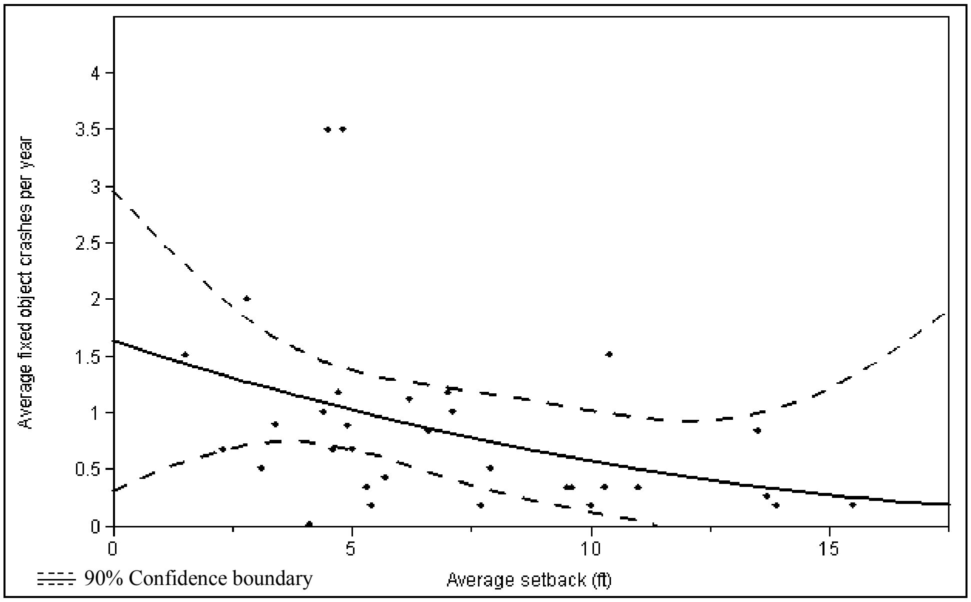

Figure 2. Safety impact resulting from average setback

15^{th} Percentile Setback

The third measurement of the clear-zone, 15^{th} percentile distance, was used to determine if the crash relationship could be better understood when the nearest few objects were ignored. The 15th percentile setback used in this analysis is the offset distance that 85 percent of fixed objects are behind. For example, if the 15th percentile setback is 6 ft for a segment with 100 fixed objects, 85 of those fixed objects would have an offset greater than 6 ft, and 15 of those fixed objects would have an offset less than six feet. **Figure 3** shows a similar decreasing relationship between the average number of fixed object crashes per year and the 15^{th} percentile setback..

Intersection Area of Influence

To determine if there was a change in the number of fixed object crashes near an intersection fixed object crashes occurring near intersections were compared with those occurring on mid blocks. The intersection area of influence in this analysis is defined as the area that is within 150 ft of the center of the intersection. This is the distance used by Iowa DOT safety engineers to spatially identify intersection related crashes, and is the area where most intersection-related maneuvers (speed changes) take place. It is also a distance beyond which some of the older crash data in the database may not be precisely located. Clearly, this distance is affected by traffic volumes, capacities and speeds, but the inclusion of those variables were beyond the resources of the project. The TRB Access Management Manual also provides an alternative approach *(21)*. Using the ten-feet definition, proximity to intersection was found to be a significant factor in the number of fixed object crashes.

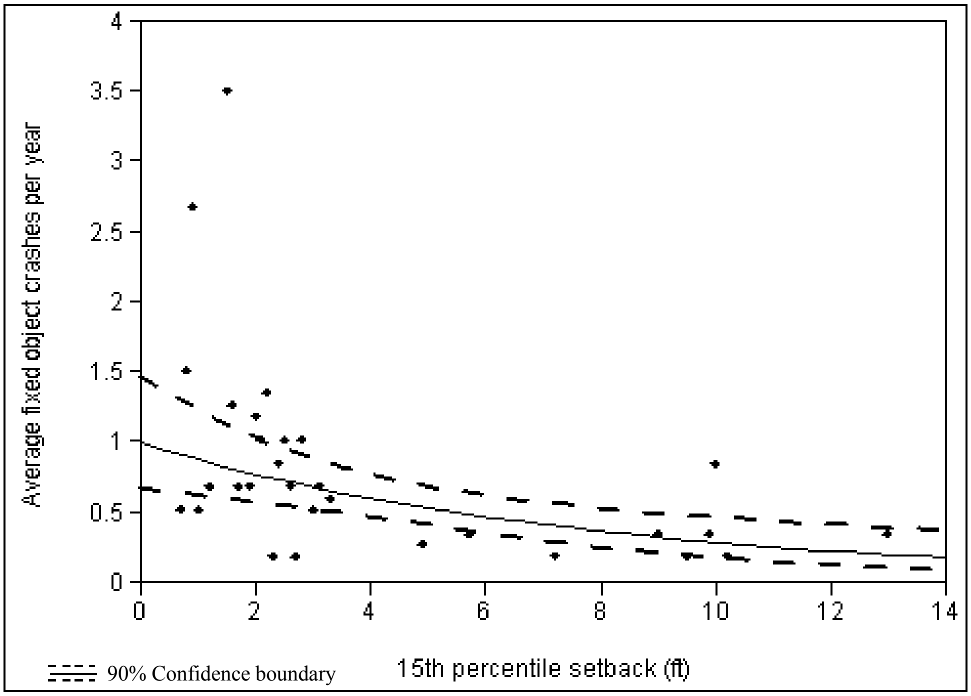

Figure 3. Safety impact resulting from 15th percentile setback

Sections within an intersection's area of influence have a greater average number of fixed object crashes per year (0.0115 fixed object crashes per year) than other sections (0.0053 fixed object crashes per year). This demonstrates that intersections have an impact on the number of fixed object crashes, presumably due to reduced setbacks permitted for signing, signal mast poles and related roadside furniture. In this study the intersection area of influence was found to contain 83 percent more fixed objects than mid block sections. As there are nearly twice as many intersection than mid block fixed object crashes, this finding is as expected.

Violation of Area of Influence

In order to find out if number of violations of clear zone minimums has any impact of the number of fixed object crashes, analyses were conducted for a range of offset distances and spatial aggregations. For this purpose, violations were defined as the number of fixed objects with setback less than a minimum distance. For example, a section may have objects located at three different distances: four objects at two feet, three objects at five feet, and two objects at eight feet. At a minimum area of influence of two feet, this hypothetical section would have no violations. For an area of influence of five feet, it would have four violations. **Figure 4** displays the relationship between average number of fixed object crashes per year and number of violations of a five-foot clear zone area. The increasing and nonlinear relationship shown is similar to most other offset distances.

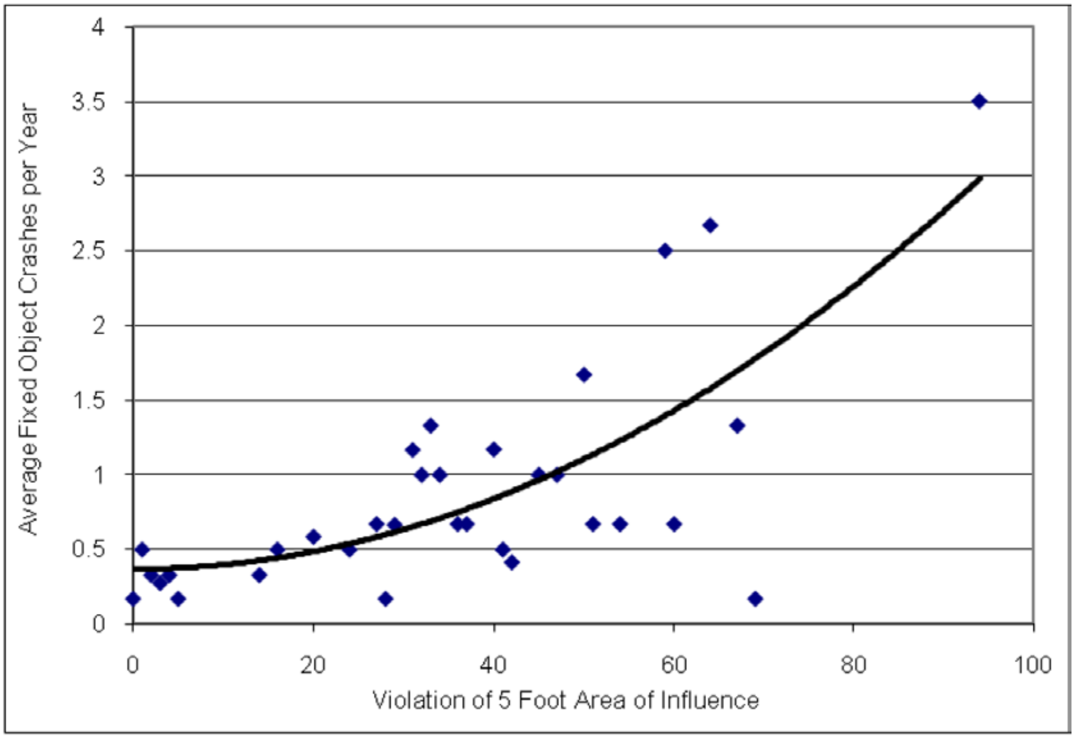

Figure 4. Safety and number of five-foot clear-zone violations

Speed Limit

Each of the three levels of spatial aggregation (segments, blocks, and 15 m sections) were evaluated to determine whether the number of fixed object crashes was correlated to the speed limit. While a weak positive relationship was found to exist between speed limit, and the number of fixed object crashes at block and 15 meter section aggregation, no meaningful relationship was found at the segment level. There were just too few segment-level observations, especially at the 40 mph speed limit. The effect of speed was also considered as a model variable (see below section on Mixed Linear Model Analysis).

Fixed Object Density

The effect of density of fixed objects along the roadside on the number of fixed object crashes was analyzed. Fixed object density was defined as the number of fixed objects per linear mile, as measured along the centerline of the roadway. All fixed object setback distances were used. The maximum distance to a fixed object was 30 feet and objects beyond 30 feet lateral offset (from back of curb) were not measured or included. None of the three spatial aggregation levels of analysis showed any consistent relationship between fixed object density and the number of fixed object crashes (see **Figure 5).**

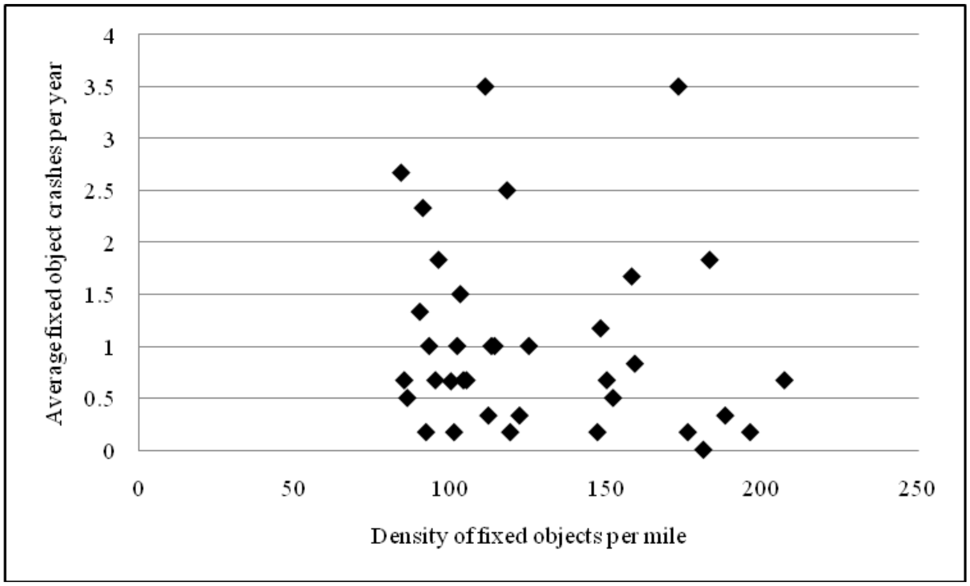

Figure 5. Safety impact resulting from fixed object density

Economic Evaluation of Property Damage

To determine the economic benefit of increasing the fixed object setback, an incremental cost table was developed based on actual reported crash costs in the study area. Cost figures are taken from law enforcement officer estimates of property damage provided on the individual crash reports. The incremental benefits listed in **Table 3** are per-year average savings values estimated for increasing setback in one foot increments. The greatest benefits were found to occur when the setback distance was increased from one to two feet and from four to five feet. However, the results presented are lumpy due to the relatively small sample size of data from 13 corridors. Incremental benefits are probably not directly extensible to generalized locations. Further, due to limited data availability in the observational study, not all conditions could be held constant in comparison sections – they are simply reported as averages for the study area corridors. It should also be noted that economic costs are also highly dependent on officer's ability to estimate property damage at the scene of a collision. Additional work is suggested to smooth out the cost relationship, although the currently observed inflection point between four and five feet reinforces the findings of the other analysis methods presented in the study.

Table 3. Incremental benefit in segment analysis

Setback	Average Incremental Benefit from next lowest setback
2	$40,123
3	$10,134
4	$3,772
5	$35,339
6	$8,350
7	
8	$4,129
9	
10	
11	$1,250

Cumulative Percent of Crashes and their Costs

A "cumulative percent" graph was prepared to determine the minimum setback beyond which safety (as measures by fixed object crashes) improves only marginally. Inspection of the graphs indicated that this distance is somewhere around five feet. That is, 90 percent of fixed object crashes in the study group occurred on segments with 5 feet or less of clear-zone when cumulative fraction of fixed object crashes are plotted against "minimum setback." **Figure 6** demonstrates that widening the clear-zone beyond five feet will likely have only a marginal safety benefit. Further, there is a steep, nearly linear relationship between incidence of fixed object crashes and minimum setback for segments with clear-zones of less than two feet.

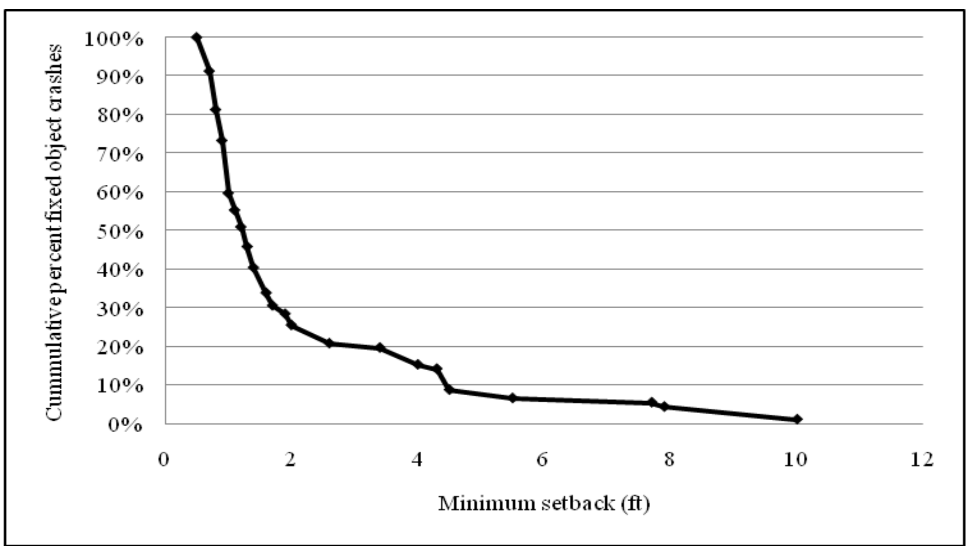

Figure 6. Cumulative percent of fixed object crashes by minimum setback (analysis by segment)

A similar analysis performed for cumulative crash **costs** indicates that 90 percent of fixed object crash costs are incurred by segments with less than four feet of clear-zone.

Crash Model

To isolate the effect of urban clear zone from other variables, a mixed linear safety performance function was estimated for the study segment data. Minimum setback was chosen as the independent measure of urban clear zone distance. In this model, the square root of the average number of crashes in a segment was specified as the response variable and the explanatory variables were specified as the following: minimum setback, Average Annual Daily Traffic (AADT), number of intersections, segment length, speed (as a binary variable: 30 or 35+), density, Area of Influence (AOI) of 2 ft, (AOI) of 5 ft, and corridor (as a random variable). Estimation of model parameters was carried out using the method of maximum likelihood, assuming that the square-root transformed crash frequencies were normally distributed (we verified that the assumption of normality held by inspecting histograms). The two components of variance – within corridor and between corridor – were estimated using the method of restricted maximum likelihood. All calculations were performed using SAS Version 9.1.

Model Results

Upon investigating the results obtained from fitting this model, it was decided that speed should be eliminated because not all speeds are represented in all corridors. Further, we decided to include corridor as a fixed classification effect rather than as a random effect because the intra-class correlation (the correlation between observations in the same corridor) was negligible. The revised model was fitted and we found that:

- As the minimum setback increases, the average number of crashes decreases (p-value 0.075, weakly significant).
- As the number of intersections in a corridor increases, the average number of crashes increases (p-value 0.0045, highly significant).
- As the number of violations at two feet increases, the average number of crashes increases (p-value 0.021, significant).

Other effects in the model were not significant. In particular, results indicated that:

- As segment length increases, the number of crashes decreases, but not significantly so (p-value 0.21).
- As the density of fixed objects increases, the number of crashes decreases, but again not significantly so (p-value 0.42).
- As the number of violations at five feet increases, the number of crashes appears to decrease but the decrease is not statistically significant (p-value 0.46).

Finally, as AADT increases, the number of crashes decreases and the effect is highly significant (p-value 0.006). The direction of this effect is "backwards", or at least not intuitive at first glance. The un-anticipated direction of this association may be due to missing confounders such as perhaps intersection controls or signalization present in high traffic segments and not present elsewhere.

The fit of the model was investigated by looking at how well the model predicts the average number of crashes at each segment and whether the assumptions behind the model (e.g., independent error terms, random residuals distributed symmetrically around zero, no outliers) are met. Figure 7 shows that the predicted number of crashes is reasonable given what we have observed at each segment.

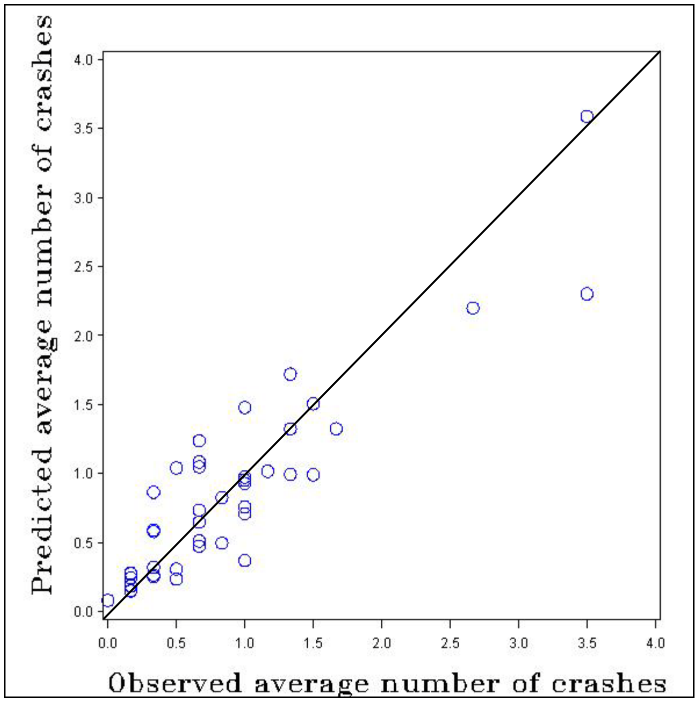

Figure 7. Predicted versus Observed

Figure 8 shows the standardized residuals plotted against the predicted values. The horizontal reference line is at 0. Residuals are all between -3 and 3, they are nicely distributed around zero and they show no obvious tendencies.

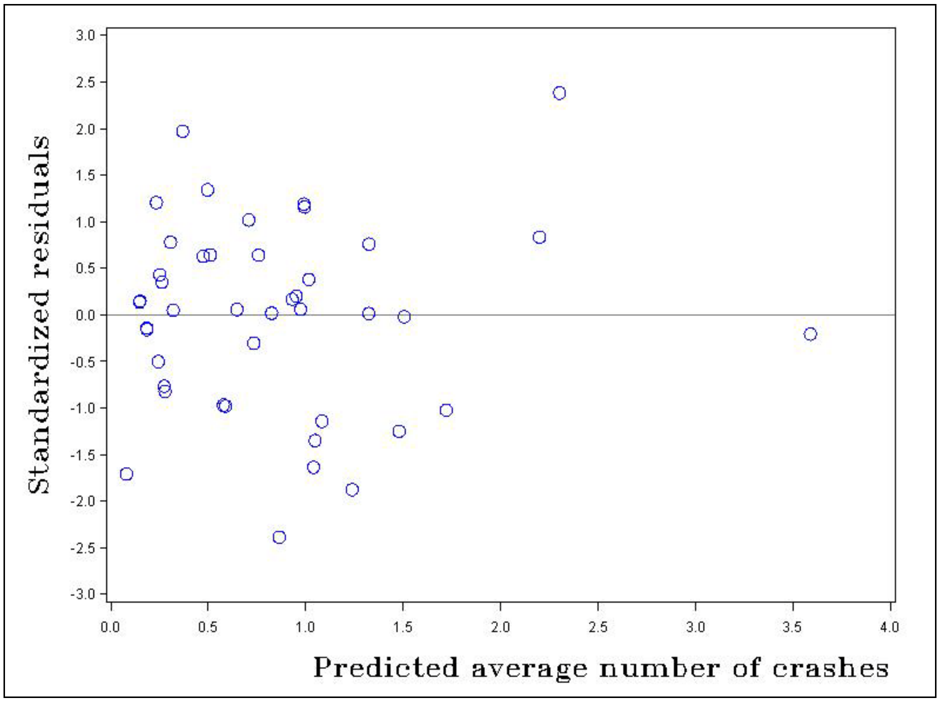

Figure 8. Standardized Residuals versus predicted average number of crashes

Modeling Injury Severity and Crash Costs

The study also attempted to model injury. There was only one fatal crash on any of the segments during the study period. On four segments, only one major injury crash was reported over six years. The maximum frequency of major injury crashes in the dataset was four. Fatal and major injury crashes were therefore combined for analysis. Because there were very few frequencies above one crash, the responses were dichotomized so that the new binary response variable took on the value zero if there were no fatal or major injury crashes observed at a site and one if there was at least one fatal or one major injury crash at the site during the study period.

A logistic regression model was fitted to the binary response variable, with the same set of independent variables that was included in the model for (transformed) average total crashes. It was found that the only factors that appear to be associated with the probability of observing a fatal or a major injury crash are segment length (p-value = 0.08) and number of intersections (p-value = 0.02).

While there were more minor injury crashes in the dataset, there were only five sites at which the frequency of minor injury crashes was three or larger. Frequencies of three and higher were then aggregated into a single category, so that five sites were classified as having at least three minor injury crashes during the study period. A regression model was fitted to the multinomial response variable (with four categories) again including the same set of explanatory variables in the model. No significant associations between the probabilities of the different levels of the multinomial variable and the explanatory variables were found, with one exception. As might have been anticipated, segment length was weakly (p-value = 0.09) associated with the probability of the higher frequencies of minor injury crashes.

Finally, the average (per year) property damage estimated at each site was taken into account. Because property damage was not distributed symmetrically, a square root transformation was used to improve the distributional shape of the variable. A standard linear regression model was fitted to this variable, with the same set of explanatory variables that we used in the models for the other types of crashes. It was found that the number of intersections, the number of violations of a two-foot clear-zone and corridor were strongly associated with the average cost of property damage. Average cost of property damage increased when the number of intersections in a segment increased (p-value = 0.044) and when the number of violations of a two-foot clear-zone increased (p-value = 0.045). Differences between corridors were also observed.

Conclusions

The synthesis of practice developed in the first phase of this research indicates that the 20 state agencies surveyed provide and follow an array of urban clear-zone guidance. Some states followed the minimum operational setback recommended by AASHTO, while other states have created their own guidance, which is currently being followed by design engineers. Some states went as far as to ignore the presence of the curb and to require the use of the AASHTO-recommended setback distances for non-curbed roads.

The descriptive analysis and model resulting from this study add to the earlier work by Turner and Barnett *(19)*, which is believed by to have been the impetus for the 10 ft minimum setback requirement in Iowa and other states. The findings of this research are as follows:

- An increase in the minimum setback distance results in a decrease in the average number or fixed object crashes.
- As the number of intersections in a segment increases the average number of fixed object crashes also increases. This is not a surprising result.
- Within 150 ft of an intersection, roadways were found to have a statistically higher number of fixed object crashes at the 90 percent confidence interval. This is again not surprising if it is plausible to assume that some of these crashes may be the result of a primary collision between two vehicles at the intersection or higher driver workload in the vicinity.
- A weak relationship was found between the number of fixed object crashes and the posted speed limit on the roadway.
- There is no statistically significant or apparent relationship between the density of fixed objects and the number of fixed object crashes.
- If reducing the number of fixed object crashes is a primary goal, a five foot clear-zone may be an efficient clear zone, as 90 percent of study area crashes occurred on segments with less than five feet of setback.
- Similarly, if reducing the cost of fixed object crashes is a primary goal, a four foot clear-zone may be an efficient clear zone, as 90 percent of study area crash costs were incurred on segments with less than four feet of setback.

- Incremental cost analysis indicates that the greatest marginal benefits accrue when setback distance is increased from one to two feet and from four to five feet from the face of curb.

What is the optimal fixed object setback on urban curbed roads? The research reported in this paper suggests a natural break in the fixed object crash frequency and costs at a setback distances around four to five feet. From the study data, there appears to be very little benefit of increasing the fixed object setback above five feet from the face of the curb. For existing corridors with fixed objects less than two feet from the face of curb, and where ROW is not available or it is too expensive to obtain four or five feet of clear-zone, an increase to two feet could have significant economic benefits in terms of reduced crash costs.

Limitations

The scope of this study was limited to the evaluation of thirteen corridors in Iowa. Obviously, more conclusive results may be attained by increasing the number of observations, and it is hoped that additional work in other areas may be added to these results and contribute the professional knowledge of the relationship between urban clear zone distance and safety. In this study there were very few observations on roadways with a speed limit of 40 mph, which contributed to lack of reliable findings in the speed limit analysis. Quantification of additional corridor characteristics (e.g., turning percentages, access point density, vehicle mix and winter weather conditions) may also provide additional insight into the crash behavior on urban curbed roads. Curb type may also be a factor in influencing actual events. Pedestrian safety afforded by fixed objects located between the roadway and sidewalk was not studied, let alone liveability measures (walkability?) of an urban area.

The coding capabilities of the methods used for this project were also limited. Buildings and fences were represented during data analysis by two points at either end of the object's area, not by a line that represents the edge of the object. Because of this limitation, the effects of buildings and fences may have been underrepresented during the analysis.

Finally, statistical manipulation was necessary to evaluate serious crashes, and for these types of crashes, this study did not have enough data to produce a clearly extensible model. The findings of this study are therefore limited to "all" or combined crashes. Additional work is needed to better understand the relationship between urban clear zones and serious crashes, which are increasingly and deservedly gaining the focused attention of the highway safety community.

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