SAFETY ANALYSIS OF ACCESS MANAGEMENT IMPLEMENTATION IN UTAH

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Abstract

Access management, defined in the Transportation Research Board *Access Management Manual* as "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway," has been shown to have a positive impact on roadway safety. Numerous studies have been conducted on the safety relationship of access management techniques as a function of access spacing, corner clearance, and medians. Several of these studies have been conducted in the United States, including studies completed in the state of Utah.

The results of research performed at Brigham Young University for the Utah Department of Transportation are highlighted in this paper. Specific research includes raised median safety impacts from both a traditional analysis methodology and using Bayesian methods, as well as an analysis of access management techniques (e.g., corner clearance, access spacing, median openings, left-turn lanes, etc.) at major-arterial intersections. The purpose of the paper is to present an overview on the safety impacts of access management identified, while providing the necessary references to allow the reader to review details and specific analysis results of these and other safety studies. The results of the analyses indicate that access management techniques play a role in improving and maintaining safety along urban and suburban arterials and at major-arterial intersections in the state of Utah. Access management has, and will continue to, improve safety when implemented appropriately. Agencies across the world should identify how access management can best be implemented in their jurisdictions and apply these principles.

Introduction

Access management is defined by the Transportation Research Board (TRB) as "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway" (*1*). Access management has been shown to have a positive impact on roadway safety. Numerous studies have been conducted on the safety relationship of access management techniques as a function of access spacing, corner clearance, and medians. Several of these studies have been conducted in the United States, including several studies completed in the state of Utah (*2*, *3*, *4*, *5*, *6*, *7*, *8*, *9*, *10*, *11*). These studies have been conducted in urban and suburban settings in Utah. As such, the results are somewhat specific to Utah and U.S. settings; however, the principles, when applied to the individual circumstances, are appropriate in settings throughout the world.

Research performed by researchers at Brigham Young University (BYU) for the Utah Department of Transportation (UDOT) is highlighted in this paper. Specific research includes raised median safety impacts from both a traditional analysis methodology and using Bayesian methods, as well as an analysis of access management techniques (e.g., corner clearance, access spacing, median openings, etc.) at major-arterial intersections. The purpose of this paper is to present an overview on the safety impacts of access management as experienced in Utah, while providing the necessary references to allow the reader to review the details and specific analysis results of these and other safety studies. To accomplish the purpose, this paper first outlines the background of four specific access management techniques followed by a discussion of the methodology and site selection process used in the research. The results of both

the raised median and major-arterial intersection analyses are then addressed, and conclusions to the research provided. Finally acknowledgements followed by references to aid the reader in learning more about the safety analysis of access management implementation in Utah are provided.

Background

The use of effective access management techniques is essential to preserving safety (*12*). Of the access management techniques identified in *National Cooperative Highway Research Program Report 420* (*13*) several are applicable to the research addressed in this paper. The following sections discuss impacts the access management techniques of unsignalized access spacing, corner clearance, medians, and left-turn lanes have on safety.

Unsignalized Access Spacing

Unsignalized access spacing has been shown to have a direct impact on roadway safety. Increased access spacing provides greater separation between conflict points, simplifies turning maneuvers, and generally leads to fewer crashes and lower vehicle delay. From a review of corridor access studies, Gluck et al. found that increasing access density from 10 to 20 accesses per mile increased the crash rate by 30 to 40 percent, while an increase to 40 accesses per mile increased crash rates by about 60 percent (*13*). Others have confirmed the positive relationship between access density and crashes (*1*, *5*, *6*, *10*, *14*, *15*).

Corner Clearance

Corner clearance is defined as the distance between an intersection and the nearest driveway (*13*). The *Access Management Manual* notes that the upstream functional distance of an intersection should make up the minimum corner clearance. Safety concerns that arise from inadequate corner clearances have been reported to include blocked driveway ingress and egress, conflicting and misinterpreted turning movements, inadequate weaving distances, and driveway queue spillover into the intersection (*1*).

Medians

A raised median is a physical barrier, such as a concrete or landscaped island, in the center portion of the roadway that separates opposing lanes of traffic and is designed such that it is not easily traversed. Raised medians are appropriate in some, although not all, locations and have been found to be most useful on high volume, high speed roadways (*16*). Researchers have shown that roadways with raised medians generally experience lower crash rates than roadways of similar use and Annual Average Daily Traffic (AADT) that are undivided or include a two-way left-turn lane (TWLTL) (*1*, *2*, *10*, *13*, *14*, *17*).

Left-Turn Lanes

Left-turn lanes with adequate storage benefit intersections by removing turning vehicles from the through lanes and improving turning-vehicle sight distance. Left-turn lanes have been found to reduce right-angle and rear-end crashes at signalized intersections (*13*).

Methodology and Site Selection

The methodology used for the research included extensive data collection and safety analysis on multiple roadway segments and arterial intersection locations throughout the state of Utah. To address the methodology and site selection components of the data collected and analyzed for this paper this section will include a discussion of the median analysis and the major-arterial intersection analysis.

Median Analysis

Data for the median analysis were collected at six locations across Utah outlined in Table 1. Analyses were completed using traditional before-after studies, as well as Bayesian analysis methods.

Table 1: Raised Median Study Locations

Street	Route	Begin MP	End MP	Length (mi.)	Location	Year Installed
University Pkwy.	265	1.20	1.96	0.76	400 W. to 200 E.	2002
Alpine Highway	74	2.40	4.29	1.89	9840 N. to 11300 N.	2002
400/500 South	186	5.48	7.53	2.05	Main St. to 1300 E.	2001
12300 South	71	4.55	5.45	0.90	265 W. to 300 E.	2004
St. George Blvd.	34	0.00	1.74	1.74	Bluff St. to 1000 E.	2006
SR 36	36	59.29	60.82	1.53	Erda Wy. to Bates Canyon Rd.	2005

Traditional before-after studies generally involve an analysis of crash rates before and after a proposed implementation. Crash rates for road segments are typically reported in crashes per million vehicle miles traveled (MVMT) or per hundred MVMT. Crash rates for intersections are typically reported in crashes per million entering vehicles (MEV) (*18*). Crash rates account for volume and are thus normalized to account for more crashes occurring at busier locations. Rates can also be calculated for different crash severities, while severity indices can also be developed to analyze crash severity reductions (*7*, *9*).

One of the potential concerns with the traditional before-after crash analysis is the natural fluctuation that occurs in crash data. Crashes, by nature, are random events that fluctuate from year to year at any given location. The natural fluctuations in crash frequency make it difficult to determine whether a reduction in the number of crashes is a result of a specific treatment, changes in site conditions over time, or a result of natural fluctuations due to stochastic processes. The fluctuations in crashes that occur naturally are commonly referred to as regression-to-the-mean (RTM), illustrated in Figure 1. The RTM phenomenon expects that a value that is determined to be extreme will tend to regress to the long term average over time. This means that a period of high crash frequencies at a site is statistically probable to be followed by a period of low crash frequencies (*19*). Many traditional analysis methods do not account for the RTM bias, which can lead to an inaccurate reporting of the effectiveness of a specific treatment.

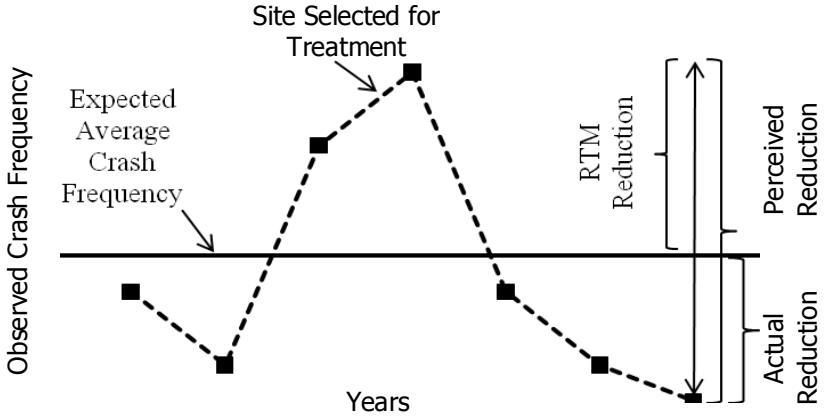


Figure 1. Perceived vs. actual crash reduction (adapted from *20*).

Several methods have been developed to determine the effectiveness of safety measures, while accounting for the RTM bias. The most common of these methods are Bayesian methods, including the empirical Bayes (EB) method, and more recently the full or hierarchical Bayes method. The EB method corrects for the previously mentioned RTM bias by determining the expected crash frequency of an entity

(*21*). The EB method combines an estimation of the crash frequency of the study site with characteristics of similar sites using safety performance functions (SPFs) to estimate the predicted number of crashes. The EB approach has been demonstrated to be better suited to estimate safety than traditional methods (*19*, *22*, *23*).

In recent years, a full or hierarchical Bayesian approach has been suggested as a useful alternative to the EB approach. Though arguably more complex, the hierarchical Bayesian approach has several potential advantages over the EB approach in that it is believed to require less data for untreated reference sites, it better accounts for uncertainty in data used, and it provides more detailed causal inferences and more flexibility in selecting crash count distributions (*24*). In a hierarchical Bayesian analysis, prior (before) information and all available data are integrated into posterior (after) distributions from which inferences can be made on the trends of safety data (crash frequency) before and after safety implementations. In this manner all uncertainties are accounted for in the analyses. These trends are then compared with actual posterior data results and inferences are made on both the safety improvement and the probability of that improvement (statistical significance). A hierarchical Bayesian model was utilized for this research. The specific details of the model can be found in the literature (*2*, *3*, *4*, *25*) and will not be included in this paper.

Major-Arterial Intersection Analysis

For the major-arterial intersection analysis, data (including safety and access characteristics) for 144 signalized study intersections were evaluated. Study intersections were defined as intersections that were located along corridors that permit unsignalized access, according to the UDOT Access Classification system (*26*). Study intersections were thoroughly examined in order to gather a large set of explanatory, or independent, variables for statistical analysis. The attributes, geometric parameters, and accesses within the functional area of each intersection were evaluated. Collected data included: access classification, functional classification, major-street AADT, type of left-turn protection, speed limit, proximity to freeway interchange, median type, lane configuration, upstream corner clearance, total accesses within the functional area, total conflict points, access density, conflict density, and access land use. The functional area was calculated for each intersection utilizing the current state-of-the-practice procedure for determining the upstream functional area at an intersection as documented within the *Access Management Manual* (*1*). The procedure is based on guidelines from the American Association of State Highway and Transportation Officials (AASHTO) Green Book (*27*) and Stover and Koepke's *Transportation and Land Development*, 2nd Edition (*28*). The data were then organized into sets of access-related and non-access-related variables. All intersection data that were collected in a qualitative form were converted to a quantitative form to allow for statistical analysis. Correlation between all independent variables was examined to remove any redundancy that may occur within the data. Details on the data collection and conversion to quantitative data are provided in the literature (*5*, *6*).

A set of statistical analysis tools, including stepwise variable selection and multiple linear regression models, expressed mathematically in Equation 1, were utilized to identify those factors (independent variables) that contribute to the safety (dependent variables) at intersections. The dependent variables included: crash totals, crash rate, crash severity, right-angle collisions, and rear-end collisions. Non-access related independent variables were evaluated first, while access related independent variables were then added in the analysis, while maintaining the non-access related independent variables in the model, to determine if access-related variables had a significant role in further describing the intersection crash frequency or rate even after the non-access-related independent variables were accounted for. The impacts of access-related variables on intersection safety were therefore evaluated through the process (*5*, *6*).

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \quad (1)$$

where:
- Y = mean of the distribution of the dependent variable,
- β_0 = constant,
- β_i = regression coefficient of independent variable,
- X_i = independent variable, and
- n = number of independent variables.

Results

Analysis results are provided for both the median analysis and the major-arterial intersection analysis in the following subsections. It should be noted that only the results of the Bayesian analysis are provided in the median analysis section. More traditional analysis results can be found in the literature (*10*, *11*).

Median Analysis

A hierarchical Bayesian analysis was performed at the six study sites, summarized previously in Table 1, where raised medians had been installed. The analysis follows the procedure outlined in previous sections where analyses were performed for both overall crash frequency as well as severe crash frequency for each segment. The hierarchical Bayesian model allows the user to calculate a percent change in crash frequency before and after the raised median installation, as well as the probability that the crash frequency (overall or severe crashes) decreased. The probability of reduction acts as a surrogate in determining the statistical significance of the change (*4*).

The results of the analysis of the individual locations where raised medians were installed are summarized in Table 2. The results of the overall crash analysis indicate that three of the six study sites experienced a statistically significant (greater than 95 percent probability of decrease) reduction (26 to 43 percent) in overall crash frequency. One site, 12300 South (SR 71), experienced what can be reported as a statistically significant increase (31 percent) in the overall crash frequency. As an increase was reported in this location, researchers reviewed the site to identify why this increase may have occurred. Based on the site review, it is anticipated that this increase is a direct result of a roadway widening project that occurred in response to land use changes and subsequent growth in the surrounding area at the same time as the raised median installation. As such, the researchers considered removing this site from the analysis as it was somewhat of an outlier, but determined that they would maintain the sites for the purpose of this paper. The probability of difference for the remaining two sites, University Parkway (SR 265) and Alpine Highway (SR 74), was too low to confidently determine if a reduction or increase occurred (although the results for SR 74 were practically significant at a 93 percent probability of decrease). In these situations the mean is increasing, but not at a statistically significant rate (*4*).

Similar to the overall crash analysis, several of the sites also showed a reduction in the frequency of severe crashes. A summary of the impact of raised medians on severe crashes is provided in Table 3. The results of the severe crash analysis indicate that three of the six study sites experienced a significant (greater than 95 percent probability) reduction (60 to 67 percent) in the frequency of severe crashes after raised medians were installed on the segments. The analysis indicated an increase (12 to 55 percent) may have occurred at two of the remaining sites, Alpine Highway (SR 74) and 12300 South (SR 71); however, the probability of a difference at both of these sites was too low to confidently determine if a reduction or increase occurred. The final site (SR 36) showed a practically significant (90 percent) probability that a decrease of 43 percent occurred. More detailed analysis results for both overall and severe crash frequencies are provided in the literature (*4*).

Table 2: Summary of Overall Crashes at Raised Median Study Sites

Location	State Route	Year Installed	Probability of Decrease	Percent Change Expected
University Parkway	265	2002	38%	3%
Alpine Highway	74	2002	93%	-19%
400/500 South	186	2001	100%	-29%
12300 South	71	2004	0%	31%
St. George Blvd.	34	2006	100%	-26%
SR 36	36	2005	99%	-43%

Table 3: Summary of Severe Crashes at Raised Median Study Sites

Location	State Route	Year Installed	Probability of Decrease	Percent Change Expected
University Parkway	265	2002	100%	-60%
Alpine Highway	74	2002	41%	55%
400/500 South	186	2001	100%	-67%
12300 South	71	2004	37%	12%
St. George Blvd.	34	2006	99%	-61%
SR 36	36	2005	90%	-49%

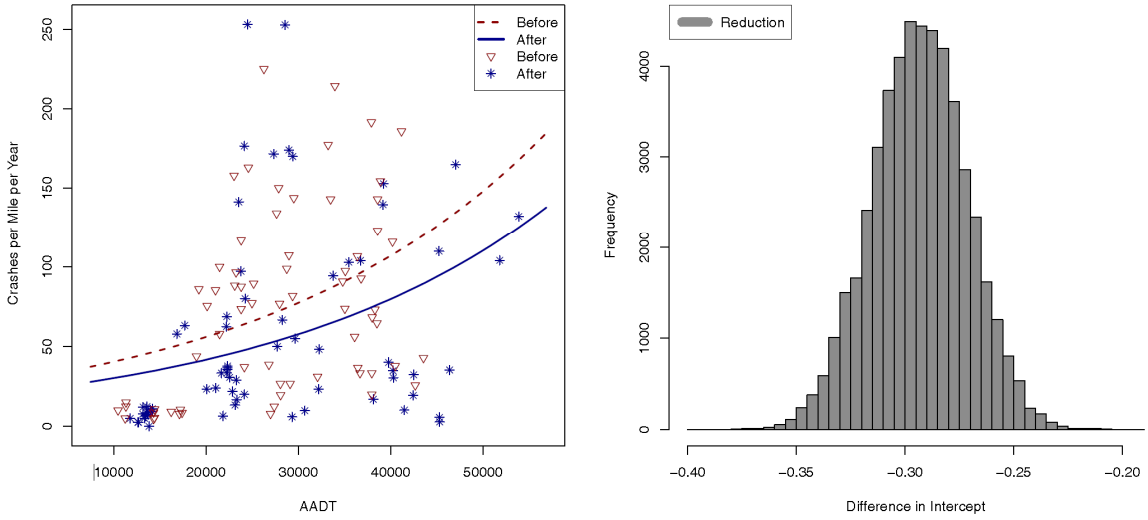
In addition to evaluating safety at each site independently, an analysis of all sites combined was conducted to provide a more detailed statistical analysis. The results of this analysis are provided with the use of two distinct data analysis plots. The first plot displays the actual data points before and after installation of the raised medians, along with the means of the posterior predictive distributions for the before and after analysis results. The mean of the posterior predictive distribution is a representation of the mean regression line through the points from a Bayesian perspective. The reduction (before and after) is calculated by taking the mean of the posterior distribution of differences between the two intercepts. The mathematical details are discussed in the literature (*3*, *25*), where it is noted that this is conceptually equivalent to taking the after curve and dividing it by the before curve to obtain the percent reduction (note that if an increase is encountered, this is calculated as well).

The second plot produced for the overall analysis results is the plot of the distribution of the differences (statistical significance) between the before and after periods. The differences plots display the posterior distributions of differences between the before and after intercepts of the model. Negative values indicate that the after time period saw a reduction in crashes. As the exact form of the posterior distributions is unknown, the model uses simulated draws from the posterior distribution using the Markov Chain Monte Carlo (MCMC) sampling, the details of which can be found in the literature (*3*, *25*, *29*, *30*). Because the draws represent the actual posterior distribution, the proportion of the draws less than zero represents the probability that there was a reduction in crashes from the before time period to the after time period.

Figure 2(a) displays the overall crash frequency for the before and after periods as a function of AADT. The overall analysis results indicate a 25 percent reduction in overall crash frequency after the raised medians were installed. Figure 2(b) shows the corresponding probability distribution of the differences between the before and after periods for overall crashes. The entire distribution of differences in Figure 2(b) is less than zero, indicating a 100 percent probability that a reduction in overall crash frequency occurred after raised medians were installed (*2*, *4*).

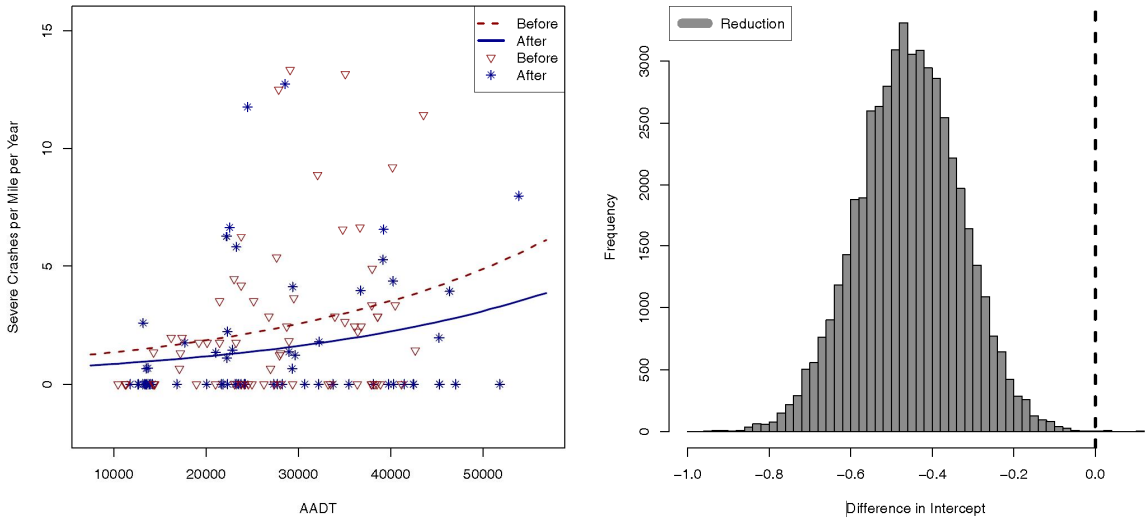
The severe analysis results are provided in Figure 3 and display an even greater reduction than the overall crash frequency results. Figure 3(a) displays the results of the severe crash analysis for all locations where raised medians were installed in Utah. The severe crash analysis results indicate a 36

percent reduction in severe crash frequency after raised median installation. The results in Figure 3(b) indicate that there is a 100 percent probability that a reduction in severe crash frequency occurred after raised medians were installed (*2*, *4*).



(a) (b)

Figure 2. (a) Overall frequency and (b) distribution of differences for overall crashes at all raised median study sites (*4*).



(a) (b)

Figure 3. (a) Overall frequency and (b) distribution of differences for severe crashes at all raised median study sites (*4*).

Major-Arterial Intersection Analysis

For the major-arterial intersections, statistical analyses were conducted for five dependent variables: crash total (frequency), crash rate, crash severity, right-angle collision, and rear-end collision. In each case, at least one access-related variable was found to be significantly related to the crash variable. Table 4 summarizes the access-related factors that were related to dependent crash variables at a 95 percent significance level. The signs of the resulting regression coefficients are also presented. Note that a "+" symbol indicates a positive regression coefficient while a blank cell indicates that an access-related variable was not selected for the multiple linear regression model. As the results in Table 4 indicate, the crash total and crash rate variables were positively related to the commercial access density access-related variable, the crash severity and right-angle variables were positively related to the corner clearance score access-related variable, and the rear-end variable was positively related to the commercial access density and the median score access-related variables (*5*).

Table 4: Summary of Significant Access-Related Variables

	Dependent Crash Variable (Natural Log Transformed)				
Access-Related Variable	Crash Totals	Crash Rate	Crash Severity	Right-Angle	Rear-End
Commercial Access Density	+	+			+
Corner Clearance Score			+	+	
Median Score					+

"+" denotes positive relationship.

The association between corner clearance score and intersection functional area crash patterns supports the importance of adherence to access management corner clearance standards. Study intersections that exhibit what most jurisdictions would consider to be substandard corner clearance standards were found to have more severe crashes and more right-angle crashes (*5*). The actual corner clearance standards for the state of Utah are published as part of the Administrative Rule R930-6 (*26*). Other recommendations can be found in the literature (*1*, *28*).

The median score access-related variable was shown to have a positive association with functional area rear-end crashes. This finding is consistent with previous research which indicates that the presence of raised medians have been found in some instances to be associated with a slight increase of rear-end crashes on roadway corridors (*10*). However, as noted in the previous research, rear-end crashes are less severe than most other crash types. Consequently, raised medians reduce overall severity of crashes. Since raised medians prohibit ingressing and egressing left-turns at accesses, intersection approaches with raised medians are expected to exhibit increased rear-end crashes with fewer right-angle crashes and; therefore, decreased crash severity and overall safety benefit (*5*).

Conclusions

The overall results of both the median and major-arterial intersection analysis showed that access management practices play a significant role in reducing crash frequency and improving overall safety along urban and suburban arterial corridors (median analysis) and at major-arterial intersections in the state of Utah. The median analysis results showed that the overall crash frequency on corridors where raised medians have been installed was reduced by 25 percent and the frequency of severe crashes was reduced by 36 percent after the installation of raised medians along the corridor. The major-arterial intersection analysis showed that at least one access-related independent variable was found to be significantly related to the crash variable after all non-access related independent variables were evaluated. The existence of accesses within the functional areas of study intersections showed a relationship with increased crashes and crash severity. In particular, increases in commercial access density were associated with increases in crash totals, crash rates, and rear-end crashes in intersection

functional areas. As such, adherence to access standards was shown in these instances to improve safety and increase efficiency of the transportation network in Utah.

Access management techniques have been shown to improve safety along urban and suburban arterial corridors and at major-arterial intersections in the state of Utah. Access management has, and is expected to continue to, improve safety when implemented appropriately. The proper installation of access management principles may vary across the world; however, as it is implemented it is expected to improve safety. Agencies across the world should identify how access management can best be implemented in their jurisdictions and apply these principles accordingly.

Acknowledgements

The research presented in this paper was made possible with funding from UDOT and BYU. Special thanks to Robert Hull and W. Scott Jones in the UDOT Traffic & Safety Division who were involved throughout the majority of the work. Thanks also go to those at UDOT and BYU who played key roles as members of the technical advisory committee for each of the projects that provided input to the research. Finally, thanks to the graduate research assistants who have worked on projects related to access management and the overall safety benefits of such. These include: Jeff S. Lewis, Kordel T. Braley, Charles G. Allen, Daniel J. Thurgood, Andrew N. Olsen, and Steven C. Dudley. The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the information presented herein, and are not necessarily representative of the sponsoring agency.

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