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SAFETY EFFECTS OF TRAFFIC SIGN UPGRADES IN ALBUQUERQUE, NEW MEXICO

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ABSTRACT

The City of Albuquerque, New Mexico has upgraded its traffic signs in several sections of the city. The upgrade process replaces *all* traffic signs with signs made from the newest materials. Because sign improvements are traditionally made on a case-by-case basis, as funding challenges can limit an agency's ability to implement widespread changes, this sign upgrade process in Albuquerque provided an opportunity to evaluate the safety effects of a systemic upgrade. The systemic improvements are still ongoing throughout the city as not every section has been addressed. The analyses of this study were therefore arranged to compare the crash frequencies experienced on segments that had the upgraded signs with crash frequencies from years before treatment on those same segments or on segments in other parts of the city that have not yet been treated. Findings indicate that, when viewed collectively as a systemic treatment, the upgraded signs may have contributed to reducing as many as 13 nighttime crashes across the entire collection of the treated segments. Crash reductions of other groups (such as total crashes or fatal and injury crashes) were less certain, though possible. When viewed at the level of individual segment, where effects of specific road features are also considered, the benefits of the upgraded signs were more elusive with no statistically significant findings directly related to the upgraded signs.

INTRODUCTION

Sign visibility is often classified as a nighttime concern. The Manual on Uniform Traffic Control Devices (MUTCD) addresses nighttime sign visibility with minimum retroreflectivity requirements for regulatory, warning, and guide signs (1). In most cases, these minimum levels are met for several years after installing new signs. Over time, the sign faces deteriorate. Long-term weathering first produces a loss in retroreflectivity, then color fading, and eventually cracking and peeling of the sheeting. The sign's deterioration results in a loss of conspicuity and legibility, decreasing the ability to command attention and properly convey its message. What starts as exclusively a nighttime problem thus extends into daytime.

When old signs are replaced, the degraded sign performance is abruptly improved by the new, bright sheeting. This change stands in contrast to the long and continual degradation that occurs in the years before replacement. Such a sudden change presents a unique opportunity to measure safety impacts of the replacement, and several municipalities have observed crash reductions after upgrading their signs (2).

Safety research shows that improving a TCD's conspicuity can lead to reductions in crashes (3–5), though the effect is not always clear, as observed by Persaud et al. (6). Davis et al. (5) raise the issue that even though some treatments in the literature have produced very high crash reductions, confidence intervals have also been notably high, underscoring a well-known difficulty with investigating safety impacts. Crash occurrences can be so sporadic and random, especially in low-volume areas, that it is difficult to attribute changes in crash frequencies or rates to a feature like TCD age or brightness. After increasing the retroreflectivity of Stop signs, Persaud et al. (6) found small reductions in several crash types, though not always significant. Understanding some of the difficulties that arise from small sample sizes and dealing with crash frequencies, they concluded that, even if the effects on crashes are insignificant statistically, enhancing Stop signs with upgraded sheeting is a small cost that requires only modest crash reductions to be cost-effective.

In an effort to enhance the transportation infrastructure within Albuquerque, New Mexico, city officials initiated a program of upgrading the traffic signs throughout the city. The upgrade program started in 2013 and (as of 2016) has not been completed. It is being executed in phases with different sections of the city receiving sign upgrades at different times. All traffic signs within each targeted section are replaced unless the city is not responsible for the road maintenance (such as on Interstates). The traffic signs in the city are old enough that there are no records of when they were most recently replaced. There are no measurements of retroreflectivity for these signs. In the city's upgrade program, all traffic signs are replaced with high performance Diamond Grade™ DG^3 sheeting produced by 3M™ (ASTM D4956 Type XI).

Crashes have a high amount of variability in their frequency, not only from one location to another, but from one time period to another. Multiple years of crash data and a large sample of different locations are generally required for the trends and relationships in crash frequencies to overcome high levels of variability. The most recent available crash data in Albuquerque are from 2014. With the sign upgrades started in 2013, there is only one complete calendar year of "after" data. Since the treatment has not been implemented throughout the entire city, untreated control areas can be compared with treatment areas in a cross-sectional analysis. Crash data starting in 2010 are used. The treatment effect would come from observing changes in crash frequencies in one group in 2014 but not in the other.

Safety performance functions (SPFs) are crash models that can identify the roadway geometric and traffic conditions that affect crash frequencies. SPFs are powerful tools because the effect of an individual factor can be identified while accounting for the effects of other features. Recent studies have used SPFs to investigate such characteristics as medians, shoulders, land use, intersection density, on-street parking, bike lanes, and school zones (8, 9). These and other features are included in the SPFs created in this study as one method of analyzing the effects of the sign upgrades.

The following crash types are evaluated in this study: total, nighttime, fatal and injury, and nighttime fatal and injury crashes. Different findings with respect to these subsets may highlight the signs' specific contributions to providing a safe road network.

DATA

The city funded the sign upgrades in multiple installments, starting one section of the city only after another is completed. Upgrades started in January 2013 and have continued with the most recent sector beginning in July 2015, as shown in Figure 1. The city traffic engineers supplied dates for when each section's upgrades started. Each upgrade cycle was completed within approximately 6 months. Unless necessary on an individual basis, signs have not been replaced in any areas not highlighted in Figure 1.

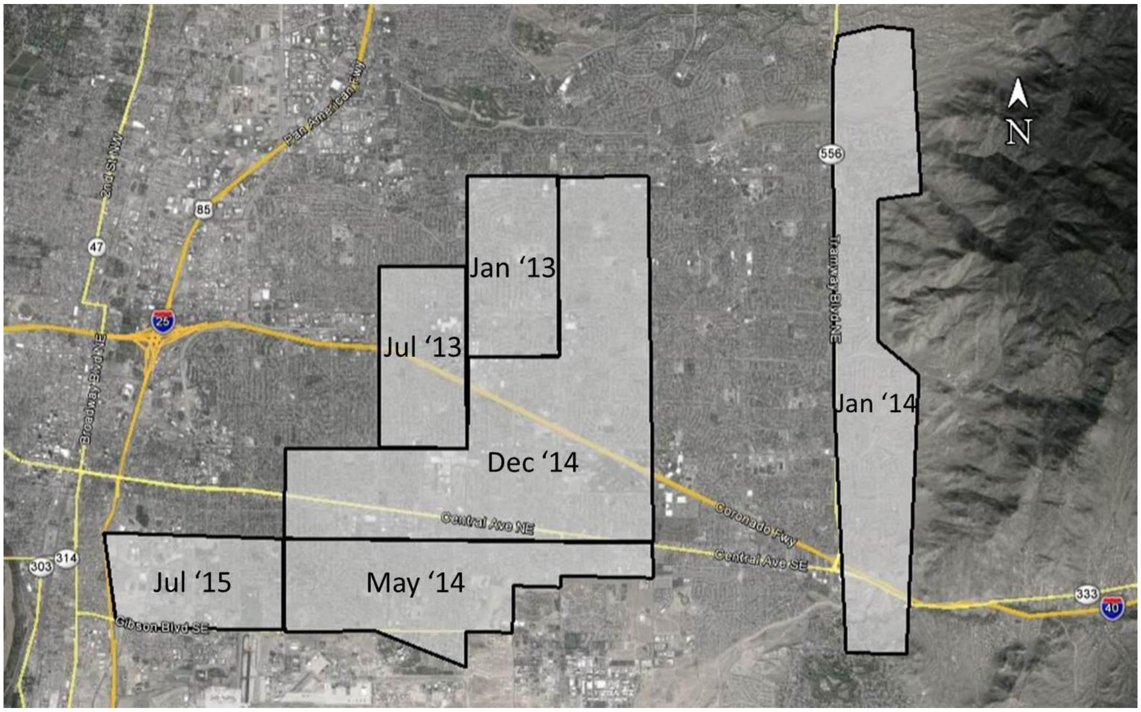


Figure 1. Sections of sign upgrades with noted starting dates.

Study Areas

Because crash data were available only through 2014, the two sections of the city that received upgrades in 2013 were selected to form a treatment group for the study. These two neighboring sections (treated in 2013) cover a combined area of 4 square miles. Control sites were selected from sections near the treatment area that have not yet received sign upgrades. The collector and arterial roads in these control areas are similar in functional class, traffic volumes, and neighboring land use to those in the treatment group. It is intended that the primary difference between the two groups is the age of the signs. New signs have replaced the aged signs in the treatment area, which still remain in the control area. Figure 2 identifies the locations of the control and treatment areas and highlights the recorded 2014 traffic volumes on the collectors and arterials. Combined, the sections in the control group cover 4.25 square miles.

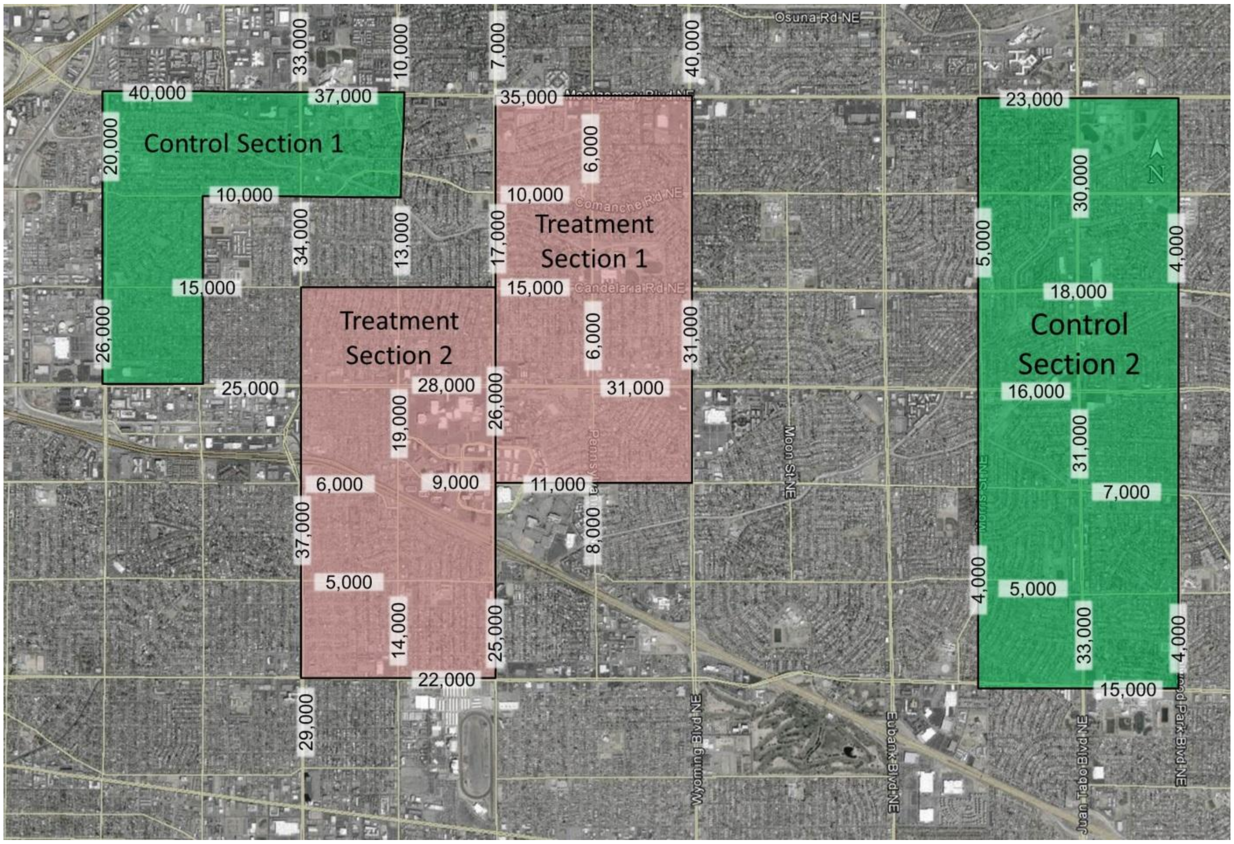


Figure 2. Treatment and control areas (treatments started in January and July 2013) with average daily traffic volumes (veh/day) recorded in 2014.

Road Inventory Data

The areas of Albuquerque used in this study contain an orthogonal grid of arterials, collectors and local streets in suburban areas. Treatment Section 2 contains a segment of I-40, which is excluded from the analysis. Segments extending from interchanges to the nearest intersection are also excluded.

An extensive data collection effort produced an inventory of the roadway geometry and infrastructure. Aerial and street-level imagery obtained by Google was used to observe these features and identify the starting and stopping points of homogenous street segments that excluded the influence areas of signalized intersections. These influence areas extended to the beginning of any exclusive turn lanes. Segments were excluded from the final inventory if they had any known roadway geometric modification from 2010 through 2014. In addition to the roadway geometry and infrastructure features, researchers acquired from the Mid-Region Council of Governments yearly traffic volumes and land use codes for the study areas. The land use zoning was divided into seven classifications: commercial, industrial, multi-family residential, single-family residential, recreational, public institution, and vacant.

Recent research on guide and street name signs indicates that drivers are less able to read signs at night in areas of high visual clutter and ambient light (10). That research produced a method to evaluate the nighttime visual complexity on a 1–5 value scale. As a unique component of this study, researchers obtained nighttime roadway imagery from the study areas and evaluated each segment's nighttime visual complexity. The objective was to compare how the effectiveness of the new signs varies with nighttime visual complexity.

Descriptive statistics for the segments in the roadway inventory are shown in Table 1. Several indicator variables are directionally dependent, where they are present for one direction and not the other. A value of 0.5 was used in these instances. A value of 0 indicated the feature is not present for either direction; 1 indicated it is present for both directions. Not listed in Table 1 are the classifications for medians and street lighting. There were four classifications of median use: undivided (21.5 percent), two-way left-turn lane (TWLTL) (10.2 percent), raised median with openings (65.0 percent), and fully closed (3.4 percent). There were three classifications of lighting: no lighting (13.6 percent), intersection lighting (30.5 percent), and continuous lighting (55.9 percent).

Table 1. Descriptive Statistics

Variable	Min.	Mean	Max.	St. Dev.
Total number of through lanes	2	4.40	8	1.69
Presence of left turn lane[1]	0	0.63	1	0.42
Presence of right turn lane[1]	0	0.02	1	0.11
Presence of bus stop[1]	0	0.51	1	0.43
Presence of bike lane[2]	0	0.31	1	0.46
Presence of school zone[1]	0	0.07	1	0.26
Presence of advertising signs[1]	0	0.46	1	0.44
Presence of crosswalk[2]	0	0.07	1	0.26
U-turns Permitted[1]	0	0.69	1	0.42
Nighttime Visual Complexity[3]	1	2.14	3	0.82
Speed (mph)	15	34.4	40	6.1
Segment length (mi)	0.04	0.17	0.45	0.13
Driveway density (per mile)	0	46.7	187.65	34.76
Density of uncontrolled intersections (per mile)	0	12.5	39.41	9.99
AADT (veh/day)	3,331	18,639	43,465	11,314
Ratio of commercial land use per segment	0	0.44	1	0.41
Ratio of multi-family land use per segment	0	0.1	1	0.21
Ratio of single family land use per segment	0	0.34	1	0.39
Ratio of recreational land use per segment	0	0.03	0.5	0.09
Ratio of institutional land use per segment	0	0.07	0.6	0.14
Ratio of industrial land use per segment	0	0.01	0.5	0.04
Ratio of vacant land use per segment	0	0.03	0.5	0.09

[1] (0= No direction; 0.5= One direction; 1= Two Directions)
[2] (0= No; 1= Yes)
[3] (139 out of 179 segments)

Despite efforts to have similarities between the segments in the control and treatment groups (from proximity to each other and rough comparisons of AADT in Figure 2), closer inspection of the roadway data revealed that the segments in the two groups, as selected, were not sufficiently comparable. One metric for comparison was the zoning of the adjacent land. The segments in the treatment area had dramatically more commercial activity than the segments in the control area, which had a higher proportion of residential zoning. There was also notably more vacant land in the control area (4% compared to 1%). When factoring in the length of each segment, the treatment segments also have notably higher traffic volumes.

The disparity between the two groups was addressed by removing segments that appeared to cause the imbalance. These segments had a high proportion of residential land use in the control group, a high proportion of commercial land use in the treatment group, or low traffic volumes (less than 5,000 veh/day) in the control group. A final target for removal in the control data was segments with school zones. There were a disproportionate number of school zones in the control area compared to the treatment area, many of which are attached to areas with residential land use. Several of these segments were eliminated. The original and final land use proportions are shown in Table 2. The original and final AADT averages are shown in Table 3.

Table 2. Land Use Representation, Weighted by Segment Length

		Commercial	Multifamily	Single-Family	Industrial	Public Institution	Rec	Vacant
Original Dataset	Treatment	47%	4%	36%	0.0%	8%	3%	1%
	Control	31%	14%	44%	0.4%	5%	2%	4%
	Difference	16%	-10%	-12%	-0.4%	3%	1%	-3%
Final Dataset	Treatment	44%	5%	37%	0%	8%	3%	2%
	Control	46%	7%	36%	0.6%	6%	2%	2%
	Difference	-2%	-2%	1%	-0.6%	2%	1%	0%

Table 3. Average AADT (veh/day), Weighted by Segment Length

		2010	2011	2012	2013	2014
Original Dataset	Treatment	20,650	18,242	20,489	21,111	20,272
	Control	15,055	16,894	15,895	16,097	15,569
	Difference	27%	7%	22%	24%	23%
Final Dataset	Treatment	20,368	18,215	19,996	20,738	20,641
	Control	18,651	18,181	19,545	19,907	19,935
	Difference	8.4%	0.2%	2.3%	4.0%	3.4%

Of the 113 segments in the original control group, 87 remained in the final dataset. Of the 66 segments in the original treatment group, 59 remained in the final dataset. The final dataset contains 146 total segments.

Land use is a complicated variable to include in crash models because segments can have multiple adjacent land uses. In the study dataset, over 60 percent of all segments have two or more distinct land uses on the adjacent land; over 15 percent of all segments have three or more land uses. Without a common denominator, it would be difficult to compare two segments with different compositions of land use. The researchers created a variable called Land Use Value to allow for such comparisons. The Land Use Value ranges from 0 to 100 and is calculated from the proportion of the land uses along each segment and the weight factors for each category. These weights reflect differences in traffic generated by the adjacent land and the resulting ingress and egress movements. Commercial land, given a weight of 100, has a higher traffic impact than residential land, which has a weight of 20 for single family zones or 60 for multi-family zones. The other weights are as follows: 60 for industrial use, 40 for public institutions, 30 for recreational use, and 0 for vacant land. The average Land Use Value of the treatment segments is 62.1. The average for the segments in the control group is 64.5.

With road segments separated into treatment and control groups, the investigation can be carried out with a cross-sectional study. Additionally, the inventory of road features on the segments allows for the effects of the upgraded traffic signs to be tested in SPFs. An indicator for the new signs in the models, if statistically significant, identifies whether the effect is associated with an increase or decrease in crashes.

Crash Data

Crash data from all crashes reported in Albuquerque were acquired from the New Mexico Department of Transportation for the years 2010–2014. The crashes were categorized as follows: total, fatal and injury, nighttime, and nighttime fatal or injury. Crashes occurring before morning nautical twilight and after evening nautical twilight were classified as nighttime crashes.

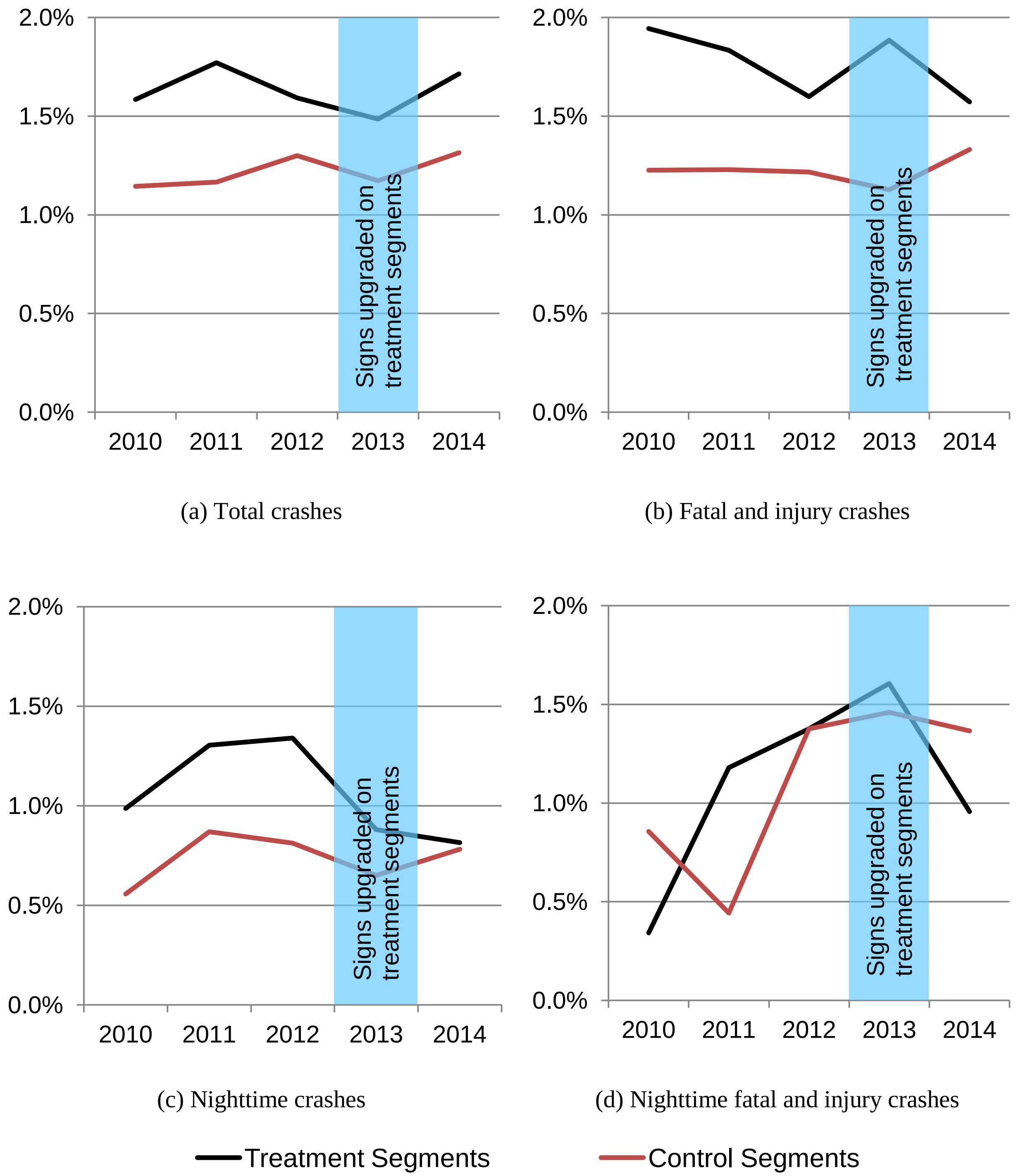
Table 4 lists crash frequencies for each year during the study period throughout the city of Albuquerque and on the treatment and control segments of the final dataset. Less than 20 percent of the total crashes occurred at night. The data in Table 4 show a decrease in most crash types for 2012 and 2013, followed by a notable increase in 2014. This increase is consistent with the 6.6% increase in reported crashes observed nationally that year (7).

The investigation of the effects of new signs installed during 2013 puts the focus on the changes in crash frequencies for 2013 and 2014. The charts shown in Figure 3 were created from data in Table 4. They compare the crash frequencies on the treatment and control segments as a percentage of the crashes in the entire city. The number of segments in the treatment group is different than the number of segments in the control group, and their lengths differ. The number of crashes should naturally be different, as is seen in Table 4. Dividing the number of crashes in the study groups by the number of crashes in the city controls for some of the yearly trends in the region (such as the overall increase in crashes in 2014). The graphed percentages for the two groups should have a similar pattern. Opposing trends in 2013 and 2014 may be indicative of the treatment's effect.

Table 4. Crashes Recorded in 2010–2014

	2010	**2011**	**2012**	**2013***	**2014**
City of Albuquerque					
Total Crashes	15,022	16,546	16,070	16,292	17,728
Fatal and Injury Crashes	4,320	4,798	4,190	4,614	4,959
Nighttime Crashes	2,331	2,529	2,462	2,612	2,943
Nighttime Fatal and Injury Crashes	584	678	581	685	732
Treatment Segments					
Total Crashes	238	293	256	242	304
Fatal and Injury Crashes	84	88	67	87	78
Nighttime Crashes	23	33	33	23	24
Nighttime Fatal and Injury Crashes	2	8	8	11	7
Control Segments					
Total Crashes	172	193	209	191	233
Fatal and Injury Crashes	53	59	51	52	66
Nighttime Crashes	13	22	20	17	23
Nighttime Fatal and Injury Crashes	5	3	8	10	10

*Treatment occurred in 2013



(a) Total crashes

(b) Fatal and injury crashes

(c) Nighttime crashes

(d) Nighttime fatal and injury crashes

Figure 3. Crashes in the two study areas as a percentage of crashes occurring in Albuquerque.

Figure 3a shows a small increase in total crashes in 2014 on both control and treatment segments in comparison to the total crashes occurring in the city. Figure 3b shows that the treatment segments had the lowest proportion of fatal and injury crashes of any year in 2014, but the control segments experienced the highest proportion that year. At night, there was also a proportional decrease in crashes occurring on the treatment segments in 2014, while the control segments experienced an increase (shown in Figure 3c). The fatal and injury crashes at night in 2014 (Figure 3d) experienced a substantial decrease on the treatment segments when adjusting for the nighttime fatal and injury crashes in the entire city. There was only a minor decrease on the control segments. The graphs in Figures 3b, 3c, and 3d suggest the upgraded signs may be reducing fatal and injury, nighttime, and nighttime fatal and injury crashes.

ANALYSIS

The following sections present different analyses of the data. The first set of analyses investigates the cumulative crash frequencies from the study groups in Table 4. A significant effect in the aggregate crash data can show the large-scale impacts of systemic upgrades. The second set of analyses incorporates the roadway inventory data to develop crash models for individual segments.

Aggregate Crash Frequencies in Study Groups

The analyses of the aggregate crash data (Table 4) tested whether the upgraded signs affected the aggregate number of crashes on the treatment segments. An analysis of variance (ANOVA) was used, testing the effects of Study Area (either Treatment or Control), the use of new signs, and a continuous variable for the number of crashes occurring within the city of Albuquerque. A variable for the total vehicle-miles traveled for the year, calculated from factoring the lengths of each segment by the observed AADT, was tested and never significant. The ANOVAs are recorded in Table 5 with least square mean values and t Tests shown in Table 6. The ANOVA for Nighttime Fatal and Injury Crashes was not significant.

Treatment area data from 2013 are not used in the analyses, meaning that the treatment effect is based only on data from 2014. This is a significant limitation in that only one year (and one observation) of data for the treatment segments had upgraded signs. Multiple years of data are usually needed to account for effects such as regression to the mean. The sections below contain information on the ANOVAs for total crashes, fatal and injury crashes, nighttime crashes, and nighttime fatal and injury crashes.

Table 5. ANOVAs for Aggregate Crashes in Study Areas

Effect	DF	F Ratio	p-Value
ANOVA for Total Crashes			
Study Area (Treatment or Control)	1	58.5	0.001
Total Crashes in Albuquerque	1	17.7	0.008
Signs (Old or New)	1	0.019	0.896
ANOVA for Fatal and Injury Crashes			
Study Area (Treatment or Control)	1	41.72	0.001
Fatal and Injury Crashes in Albuquerque	1	8.84	0.031
Signs (Old or New)	1	2.94	0.147
ANOVA for Nighttime Crashes			
Study Area (Treatment or Control)	1	268.9	0.008
Nighttime Crashes in Albuquerque	1	4.05	0.100
Signs (Old or New)	1	5.29	0.070

Table 6. Least Squares Means and t Tests from the ANOVAs for Aggregate Crashes in Study Areas

Effect	Least Squares Mean	Standard Error	Student's t Test
ANOVA for Total Crashes			
Study Area			
Control	197.2	18.9	A
Treatment	270.8	14.9	B
Signs			
Old	199.7	5.68	A
New	197.2	18.88	A
ANOVA for Fatal and Injury Crashes			
Study Area			
Control	43.7	7.64	A
Treatment	70.1	6.05	B
Signs			
Old	56.1	2.43	A
New	43.7	7.64	A
ANOVA for Nighttime Crashes			
Study Area			
Control	5.22	6.22	A
Treatment	18.0	4.84	B
Signs			
Old	18.9	1.71	A
New	5.22	6.22	A

Total Crashes

The ANOVA for Total Crashes indicates that the use of new signs has no significant effect on total crashes. For illustrative purposes, the effect of new signs is shown in the following predictive equation based on least-squares regression:

$$N_{Total\ (Group)} = -190.51 + 0.0239 \times Abq_{Total} + 73.5 \times Treatment - 2.49 \times NewSigns$$

where:

$N_{Total\ (Group)}$ = total number of crashes on a group of segments,
Abq_{Total} = total number of crashes in Albuquerque for a given year,
Treatment = 1 if calculating for segments in Treatment area, 0 if otherwise, and
NewSigns = 1 if signs have been upgraded, 0 if otherwise.

Fatal and Injury Crashes

The ANOVA for Fatal and Injury Crashes indicates that the use of new signs has no significant effect, though it is noteworthy that the F Ratio has increased, bringing the effect of signs closer to a reasonable level of significance. The least square mean values and corresponding predictive equation show that the new signs *may* have contributed to a reduction in approximately 12 fatal and injury crashes (the p-value is 0.147, not within a level of confidence that is typically accepted). The predictive equation is:

$$N_{F\&I\ (Group)} = -37.8 + 0.0205 \times Abq_{F\&I} + 26.3 \times Treatment - 12.4 \times NewSigns$$

where:

$N_{F\&I\ (Group)}$ = number of fatal and injury crashes on a group of segments,
$Abq_{F\&I}$ = number of fatal and injury crashes in Albuquerque for a given year, and
all other variables as previously defined.

Nighttime Crashes

The ANOVA for Nighttime Crashes indicates that the use of new signs is significant with 90 percent confidence. The least square mean values and corresponding predictive equation show that the new signs may have contributed to a reduction in 13 crashes at night (p-value is 0.07). Significant with more than 90 percent confidence, this finding suggests the new signs benefit nighttime crashes the most. The predictive equation is:

$$N_{Night\ (Group)} = -22.3 + 0.016 \times Abq_{Night} + 12.8 \times Treatment - 13.7 \times NewSigns$$

where:

$N_{Night\ (Group)}$ = number of nighttime crashes on a group of segments,
Abq_{Night} = number of nighttime crashes in Albuquerque for a given year, and
all other variables as previously defined.

Summary of Findings from Aggregate Crash Frequency Analysis

The ANOVAs show that, when examined in aggregate across all segments that were treated, there may be an effect of the new signs on fatal and injury crashes and nighttime crashes. This was calculated to be approximately 12 fatal and injury crashes and 13 nighttime crashes. The value of these reductions is limited by the short time period of the study and the possibility for other variables to confound the true effect of the new signs. It is worth noting that fatal and injury crashes tend to be reported reliably and that nighttime crashes are the subset that seems likeliest to be affected by new signs.

Crash Models

The crash frequencies for each segment were analyzed with generalized linear models applying a negative binomial distribution with a log link function. The negative binomial distribution was an appropriate assumption since the crash data are overdispersed (the standard deviation of the crashes on the study segments is nearly twice the value of the mean). The segment length was incorporated in the models as an offset variable in order for that element of exposure to linearly relate to the predicted crash frequency.

Crash models investigating the effect of the new signs are presented for the following crash types: total, fatal and injury, and nighttime. The nighttime fatal and injury crashes could not be modeled.

The two sections of the treatment area were treated during separate 6-month intervals in 2013, making it unfeasible to use the entire calendar year of crash data from 2013. The ANOVA presented previously used full-year crash frequencies and excluded 2013 data from the treatment group. For modeling total crashes, the crash frequencies were separated into 6-month periods, allowing crashes that occurred in the latter half of 2013 on the segments treated in the first half of the year to be included in the analysis. The models for fatal and injury or nighttime crashes only used crash frequencies for full calendar years. These models did not include any data for treatment segments in 2013.

Each model contains Median as a variable. The base case for Median Type in the models is an undivided median, with the parameter's estimate automatically set to 0. The model parameters, their estimates, and significance values are shown in Table 7. The parameter New Signs is not significant in any model. Several iterations of the models with different variables were tested, and New Signs was never significant. Table 8 identifies the models with the inclusion of the insignificant New Signs parameter. The models are discussed in the sections below.

Table 7. Parameters for Crash Models

Parameter	Estimate	Wald Chi-Square	p-Value
Total Crashes (6-Month Frequency)			
Intercept	-4.615	37.372	0.000
Median		25.422	0.000
Undivided	0		
TWLTL	0.105	0.333	0.564
Raised, With Openings	-0.564	10.042	0.002
Closed	-1.602	12.683	0.000
Number of Through Lanes	0.317	40.476	0.000
Unsignalized Intersection Density	0.026	38.178	0.000
Land Use Value	0.008	26.754	0.000
Ln(AADT)	0.495	27.629	0.000
Fatal and Injury Crashes			
Intercept	-1.200	12.130	0.000
Median		7.875	0.049
Undivided	0		
TWLTL	0.270	0.740	0.390
Raised, With Openings	-0.492	2.533	0.111
Closed	-1.085	2.385	0.122
Number of Through Lanes	0.347	15.654	0.000
Unsignalized Intersection Density	0.031	15.825	0.000
Land Use Value	0.006	4.754	0.029
School Zone	0.831	9.462	0.002
AADT	3.159×10^{-5}	12.307	0.000
Nighttime Crashes			
Intercept	-1.042	8.604	0.003
Median		12.747	0.005
Undivided	0		
TWLTL	-0.323	0.610	0.435
Raised, With Openings	-1.251	9.824	0.002
Closed	-2.169	4.058	0.044
Number of Through Lanes	0.560	33.798	0.000

Table 8. Parameters for Crash Models with Insignificant New Signs Parameter

Parameter	Estimate	Wald Chi-Square	p-Value
Total Crashes (6-Month Frequency)			
Intercept	-4.758	33.030	0.000
Median		24.549	0.000
Undivided	0		
TWLTL	0.101	0.312	0.577
Raised, With Openings	-0.555	9.671	0.002
Closed	-1.584	12.391	0.000
Number of Through Lanes	0.316	40.138	0.000
Unsignalized Intersection Density	0.026	37.907	0.000
Land Use Value	0.008	27.471	0.000
Ln(AADT)	0.487	26.666	0.000
New Signs	0.181	2.392	0.122
Fatal and Injury Crashes			
Intercept	-1.263	9.181	0.002
Median		7.737	0.052
Undivided	0		
TWLTL	0.269	0.732	0.392
Raised, With Openings	-0.489	2.490	0.115
Closed	-1.078	2.352	0.125
Number of Through Lanes	0.346	15.556	0.000
Unsignalized Intersection Density	0.031	15.738	0.000
Land Use Value	0.006	4.802	0.028
School Zone	0.830	9.441	0.002
AADT	3.153×10^{-5}	12.244	0.000
New Signs	0.057	0.073	0.787
Nighttime Crashes			
Intercept	-0.898	3.565	0.059
Median		12.888	0.005
Undivided	0		
TWLTL	-0.317	0.588	0.443
Raised, With Openings	-2.356	9.895	0.002
Closed	-2.182	4.101	0.043
Number of Through Lanes	0.561	33.869	0.000
New Signs	-0.130	0.205	0.650

Total Crashes

The total crash frequency model includes all reported crashes occurring on the treatment and control segments. The crashes were divided into 6-month intervals, rather than annual periods, meaning that each control segment is represented 10 times during the 5-year period. The treatment segments each appear 9 times since one 6-month period covers the time the treatments were installed during 2013 (some segments were treated in the first half, the others in the second half). The predictive equation for the model is:

$$N_{Total} = L \times AADT^{0.495} \times e^{\{-4.615+Median+0.317\times Lanes+0.026\times Unsig.+0.008\times L.U.\}}$$

where:

N_{Total} = number of total crashes on a segment,
L = segment length (mi),
AADT = average annual daily traffic (veh/day),
Median = type of median (undivided, TWLTL, raised with openings, or closed) with values as shown in **Error! Reference source not found.**,
Lanes = number of through lanes,
Unsig. = unsignalized intersection density (intersections/mi), and
L.U. = land use value.

The equation shown gives the number of expected crashes over a 6-month period. Nighttime complexity was tested as a variable and significant in some iterations of the model; however, nighttime complexity was removed upon discovering that its significance was dependent upon having other variables present. The final model presented contains all parameters that were statistically significant, had a practical coefficient, and were not dependent upon other variables.

Fatal and Injury Crashes

Analyses using fatal and injury crashes are valuable not only because they focus on the elements that cause the most damage, but because they are considered to be more reliable. It is unlikely for their frequencies to be influenced by differences in crash reporting thresholds or the possibility of having unreported crashes. The predictive equation is:

$$N_{F\&I} = L \times e^{\left\{-1.20 + Median + 0.35 \times Lanes + 0.031 \times Unsig. + 0.006 \times L.U. + 0.831 \times School + \frac{31.6 \times AADT}{10^6}\right\}}$$

where:

$N_{F\&I}$ = number of fatal and injury crashes on a segment,
School = 1 for the presence of a school zone, 0 for no school zone, and
all other variables as previously defined.

AADT was included in the model without a transformation, resulting in its position in the exponential term. The variable for school zone indicates that school zones tend to have more fatal and injury crashes than locations without school zones, when accounting for the other model effects. After including the insignificant variable New Signs, Table 8 shows that the categorical variables for median type are now insignificant.

Nighttime Crashes

Nighttime crashes are of particular interest for upgraded traffic signs. Unfortunately, the small crash frequency makes it difficult to identify significant effects in a model. This can be seen by the few parameters for the model listed in Table 7. The predictive equation is:

$$N_{Night} = L \times e^{\{-1.042 + Median + 0.56 \times Lanes\}}$$

where:

N_{Night} = number of nighttime crashes on a segment, and
all other variables as previously defined.

Compared to the other models, the model for nighttime crashes is missing some parameters. AADT, unsignalized intersection density, and land use value are not present. These observations suggest that: 1) AADT is not a good representation of nighttime traffic volumes, 2) unsignalized intersections result in a trivial amount of conflicts at night because there is less traffic, and 3) land use has little meaning at night when many establishments are not open. Again, the use of the upgraded signs is not significant. As with the model for total crashes, the variable for nighttime complexity was only significant when other variables were present in the model.

Summary of Findings from Crash Models

The process of generating the models in Tables 7 and 8 is quite iterative. All data variables from the inventory were tested in different combinations and with different forms. For example, the number of through lanes was tested as a categorical variable rather than a continuous variable. Speed limit was tested as categorical and continuous variables (neither type was significant). Transformations of continuous variables were tested to explore alternative model forms. The researchers tested variables for specific land uses, interactions of different variables, and random effects of the individual segments, all in an attempt to improve the predicting power and find an effect of the new signs. The variable for new signs was not significant in any reasonable iteration.

CONCLUSION

This study evaluated the effects of systematically replacing traffic signs on crash frequencies in Albuquerque, New Mexico. The analyses were performed with two different approaches: The first was macroscopic, evaluating the cumulative crash frequencies in the study areas. The analysis incorporated the crash frequencies in the entire city as a variable to account for regional trends. The second approach tested the crash frequencies at the level of individual segments, developing models that account for specific road features and traffic characteristics.

The macroscopic evaluation identified a decrease in approximately 13 nighttime crashes in 2014 that may have been a result of the new signs ($p=0.07$, significant at 90 percent confidence). This decrease was found while accounting for the differences in nighttime crashes expected in the two areas (the treatment segments tend to experience more crashes than the control segments) and while accounting for the number of crashes that occurred at night throughout the entire city (2014 experienced the most crashes of any year). The analyses indicate that there may be similar reductions observed in fatal and injury crashes, though the effect is not quite significant ($p=0.15$). Analyses of total crashes or nighttime fatal and injury crashes did not reveal an effect of the new signs.

When the crash frequencies were allocated to their individual segments and analyzed with traditional crash models, the results did not show an effect on crash frequencies from the sign upgrades. In fact, the nighttime crash model could not attribute effects on crashes to any variable other than median type or number of lanes. For the crash models, it seems that the sample sizes and crash frequencies were simply too small to reveal significant findings with this type of analysis.

There are two notable limitations impacting the analyses. One is the use of only one complete calendar year of crash data after the treatment. While the crash model for Total Crashes attempted to address this by analyzing 6-month periods of data to include crashes on the segments treated in the first half of the year, it was not enough to identify an effect of the signs. The second limitation is the sample size. While having more years of crash data can partially make up for this limitation, it would be preferable to perform the tests with more treated segments.

While it appears that crashes across the treatment group may have been impacted by the sign upgrades as a systemic upgrade, evaluating the effect on aggregate crash frequencies, it seems the effect is too elusive at the level of individual segments to be identified with the limited sample size used. As concluded by Persaud et al. (6), it can be suggested that a relatively inexpensive treatment, such as upgraded sign sheeting, may in fact be economically beneficial despite insignificant crash reductions, since only a small number of crashes must be reduced to make the treatment effective.

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