SAFETY EFFECTIVENESS OF HIGH-SPEED EXPRESSWAY SIGNALS

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Final Report • August 2005

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16. Abstract The safety benefit of signalizing intersections of high-speed divided expressways is considered. Analyses were conducted on 50 and 55 mph and on 55 mph only intersections, comparing unsignalized and signalized intersections. Results of the 55 mph analysis are included in this report. Matched-pair analysis indicates that generally, signalized intersections have higher crash rate but lower costs per crash. On the other hand, before-and-after analysis (intersections signalized between 1994 and 2001) indicates lower crash rates (~30 percent) *and* total costs (~10 percent) after signalization. Empirical Bayes (EB) adjusted before-and-after analysis reduces estimates of safety benefit (crash rate) to about 20 percent. The study shows how commonly used analyses can differ in their results, and that there is great variability in the safety performance of individual signalized locations. This variability and the effect of EB adjustment are demonstrated through the use of innovative graphics.			
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INTRODUCTION

High-speed expressways are becoming increasingly common as two-lane roads are upgraded to handle suburban and rural traffic growth. As traffic levels increase, stop-controlled intersections are often signalized with the intent to improve operational or safety performance. Unfortunately, rather than improving safety, signalization may simply replace right-angle crashes with rear-end collisions, often with similar severities. This project studied 50 and 55 mph, at-grade, median-separated intersections with at least two lanes of traffic in each direction. This paper reports on the findings of the 55 mph analysis only.

Three types of analysis were performed: a matched-pairs analysis, a conventional before-and-after analysis, and a state-of-the-art Empirical Bayes before-and-after analysis. The ultimate finding of this project indicated improvements in safety on the order of 10 percent (crash costs), 41 percent (modified[1] crash costs), and 20 percent (crash rate)[2].

DATA PREPARATION

While an attributed road segment database is maintained by the Iowa Department of Transportation (Iowa DOT), it does not contain intersection data (e.g., date of signal installation or other point data). However, the database segments *do* indicate type of control on adjacent intersections. In a previous study, Hallmark (*1*) created a point database (nodes) for Iowa intersections. Further, Iowa DOT crash data indicate the type of control present at the time of the crash. These three databases were used to compile the database used in this study. Intersection data were collected for 4-lane, median-separated highways with less than full access control with speed limits of 55 mph (there are no signals along Iowa highways with speed limits greater than 55 mph). For each intersection location, aerial imagery was examined to verify the presence of a traffic signal.

Traffic volume and date of expressway construction were also taken from the Iowa DOT database. Date of signal installation was *approximated* from *consistent*[3] reporting of presence of signal in the crash database (see Figure 1 for an example[4]). To confirm, the final list of installation dates was shared with DOT district personnel and, in two cases, with local officials. This process resulted in the identification of 45 high-speed signalized locations, statewide. About ten of these locations had significant reconstruction within three years of signal installation, and over half of the 45 were converted too early (before 1994) or too late (after 2001) to have a full three years of before-and-after data available for analysis. Therefore, 12 of the 45 were used for before-and-after analysis.

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[1] Modified: first fatal crash at an intersection is counted as a major injury crash to reduce the effect of single random fatal crashes.

[2] A similar analysis, not reported herein, for 50 mph signals indicates **decrease** in safety on the order of 336 percent (crash costs), 156 percent (modified crash costs), and 74 percent (crash rate).

[3] The database is not completely consistent with regard to identifying presence of signal and does not include signal installation or modification date; therefore, it cannot be used to identify *all* of the intersections of interest in the State.

[4] In the example, prior to 1996, most crash reports indicated no signalization. Similarly after 1996, stop control was reported infrequently.

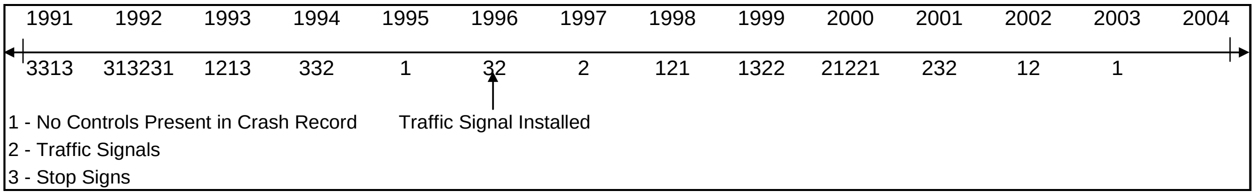

Figure 1. Example of estimating the date of traffic signal installation

To create a control group of unsignalized locations, 158 candidate sites were selected. From these, 45 sites similar to the signalized locations were identified. Aerial images at each of these intersections were examined to verify the intersections were unsignalized. Presence of turn lanes, median type, and skew angle (from the aerial photo), and major/minor traffic volume and speed limit (from the Iowa DOT database) were used to match the intersections.

Next, crash data were assembled. For this study, if a crash was designated by a reporting officer as “at or near intersection” or was coded as the type of crashes that typically occur at intersections (i.e., right-angle, rear-end), the crash was selected for analysis.

Using Iowa DOT values for injury severity, each crash was assigned a value, enabling the computation of total crash cost for each intersection. Frequency by collision type was also compiled for each intersection. Crash data were compiled for 45 matched intersection pairs (using data from 2001-2003) and for 12 before-and-after study intersections (signalized between 1994 and 2001).

MATCHED (YOKED) PAIR ANALYSIS

To control for exogenous factors that may influence intersection safety performance, a yoked or matched-pairs analysis of 45 intersections was conducted for the period 2002 through 2004. Unsignalized intersections experienced an average of 5.8 crashes in three years, while the signalized intersections experienced an average of 16.9 crashes in three years. Table 1 presents summary statistics for the matched-pair analysis.

Table 1. Crash statistics for matched intersections

	Unsignalized	Signalized	% Change
Fatal Crashes	6	6	0.0%
Major Injury Crashes	7	25	257.1%
Minor Injury Crashes	42	74	76.2%
Possible Injury Crashes	54	145	168.5%
Property Damage Only Crashes	153	510	233.3%
Total Crashes	262	760	190.1%
Average Crash Rate (Crashes per MEV)	0.42	0.97	133.0%
Average DEV	11,600	17,000	46.6%
Average Total Cost per Crash	$41,800	$21,900	-47.6%
Total Crash Cost	$7,990,000	$12,130,000	51.8%
Average Modified Cost per Crash	$25,500	$16,300	-36.1%
Total Modified Crash Cost	$3,740,000	$7,880,000	110.7%
Average Fatal Crash Rate (Crashes per MEV)	0.0099	0.0061	-38.4%
Average Fatal & Major Injury Crash Rate (Crashes per MEV)	0.0245	0.0362	47.8%
Average Broadside Crash Rate (Crashes per MEV)	0.226	0.351	55.3%
Average Rear-end Crash Rate (Crashes per MEV)	0.119	0.361	203.4%

The average crash rate of signalized intersections is 133 percent *higher* than the rate of their unsignalized counterparts. Fatal crashes are the same, and all other types of crashes are higher for signalized intersections. Broadside crash rates are 55 percent higher and rear-end crash rates are 203 percent higher. As signalized intersections experience many more property damage only crashes, their average crash cost is 48 percent *lower* than the cost of the unsignalized sites. However, total crash cost at all study area signalized intersections is 52 percent *higher*.

If costs are modified to count the first fatal crash at an intersection a serious injury crash, average crash cost is observed to be 36 percent *lower*, and overall cost is observed to be 111 percent *higher*.

Figure 2 illustrates the crash performance of signalized and unsignalized matched-pair intersections as a function of DEV. Signalized intersections generally have higher crash frequency for a given traffic level. Figure 3 illustrates a comparison of total crash costs for the matched-pair analysis using Iowa severity values.

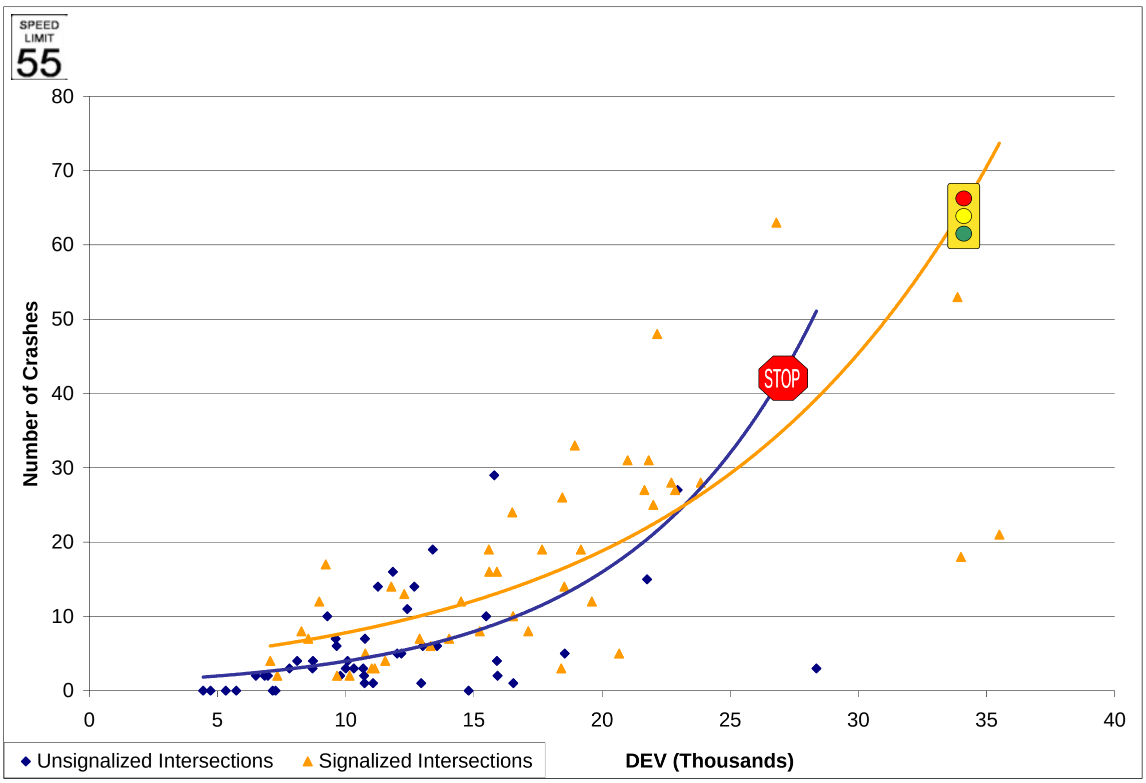

Figure 2. Comparison of signalized and unsignalized crash performance, matched-pair analysis, 2002-2004

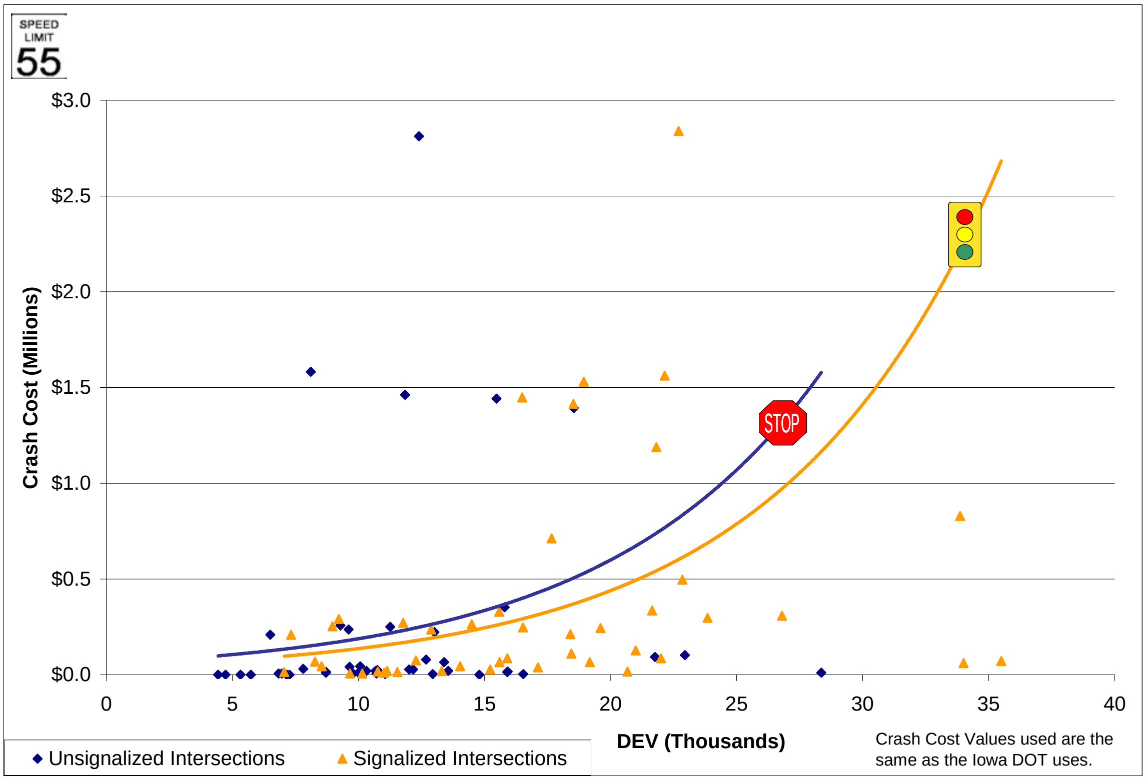

Figure 3. Comparison of signalized and unsignalized total crash cost, matched-pair analysis, 2002-2004

BEFORE-AND-AFTER ANALYSIS

A conventional before-and-after analysis was conducted for 12 intersections that were signalized between 1994 and 2002. During the three-year before period, intersections experienced on average 17.1 crashes. Following installation, these intersections experienced an average of 12.7 crashes. Table 2 presents summary statistics for the before-and-after analysis. A conventional before-and-after analysis has limitations. This analysis relies on data acquired only at these 12 intersections. These intersections may represent the few intersections with either extremely high or low number of crashes, thereby skewing the data.

Table 2. Crash statistics, before and after

	Before	After	% Change
Fatal Crashes	2	2	0.0%
Major Injury Crashes	8	7	-12.5%
Minor Injury Crashes	39	21	-46.2%
Possible Injury Crashes	54	38	-29.6%
Property Damage Only Crashes	102	84	-17.6%
Total Crashes	205	152	-25.9%
Average Crash Rate (Crashes per MEV)	1.11	0.76	-31.5%
Average DEV	13,600	14,800	8.8%
Average Total Cost per Crash	$26,600	$32,100	20.7%
Total Crash Cost	$3,980,000	$3,570,000	-10.3%
Average Modified Cost per Crash	$22,450	$20,900	-6.9%
Total Modified Crash Cost	$3,130,000	$1,870,000	-40.3%
Average Fatal Crash Rate (Crashes per MEV)	0.0125	0.0087	-30.4%
Average Fatal & Major Injury Crash Rate (Crashes per MEV)	0.0601	0.0436	-27.5%
Average Broadside Crash Rate (Crashes per MEV)	0.55	0.27	-51.1%
Average Rear-end Crash Rate (Crashes per MEV)	0.30	0.21	-30.0%

While the average crash rate of treated intersections *decreased* by 31.5 percent with signalization, most of the reduction was in minor crashes. Fatal crashes remained constant, and major injury crashes were reduced by 12.5 percent. Broadside crash rates were reduced by 50 percent and rear-ends were reduced by 30 percent. As many property damage only crashes were eliminated after signalization, the average crash cost *increased* by 20 percent. However, total crash cost at all study area intersections was *reduced* by 10.6 percent.

If costs are modified to count the first fatal crash at an intersection a serious injury crash, average crash cost is observed to *decrease* by 6.9 percent, and overall cost is reduced by 40.6 percent.

While the matched-pair analysis indicates that signalized intersections are more dangerous than their unsignalized comparison sites, before-and-after analysis indicates a marginal improvement in safety. Before-and-after analysis is generally accepted to be more reliable for this type of study. However, as both methods are subject to statistical limitations, a more modern analysis was performed (Empirical Bayes).

Figure 4 illustrates the change in crash frequency before and after signalization. The arrows indicate the direction and magnitude of change (green hatching indicates reduction, red indicates increase, and purple indicates no change). For the 12 intersections studied, some experienced a decline in number of crashes, whereas others experienced an increase. Figure 5 illustrates the change in total cost of crashes after signalization. (Tables showing crash statistics for the individual intersections in the before-and-after analysis are provided in the appendix.)

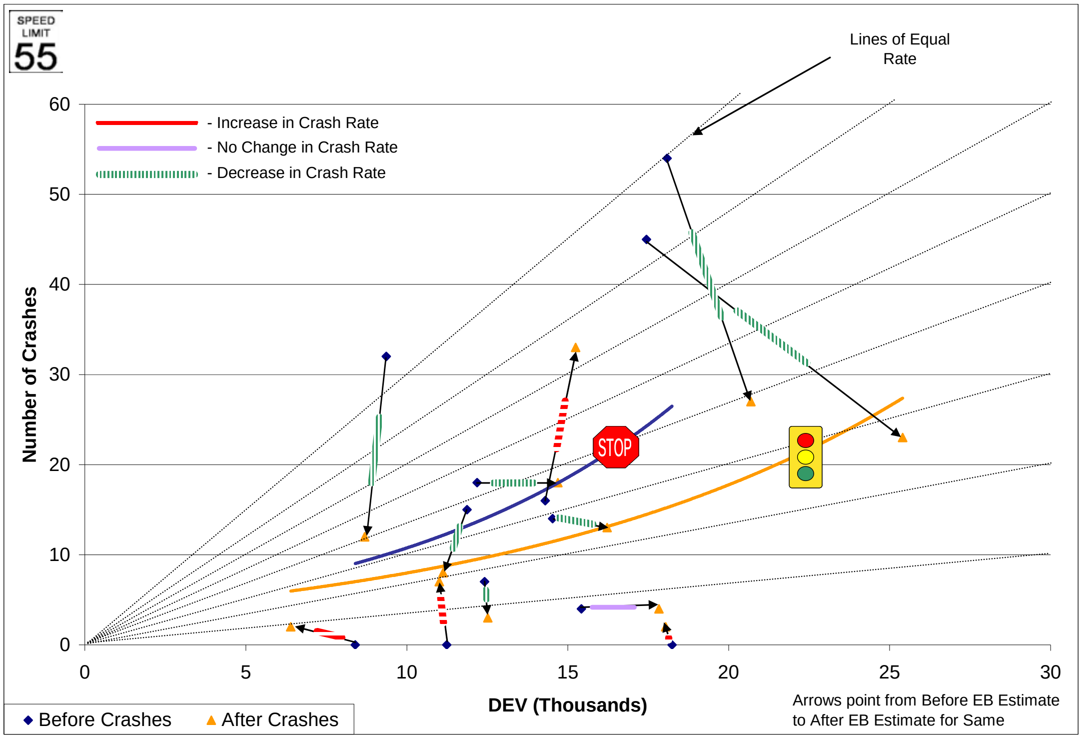

Figure 4. Crash frequency, before-and-after analysis

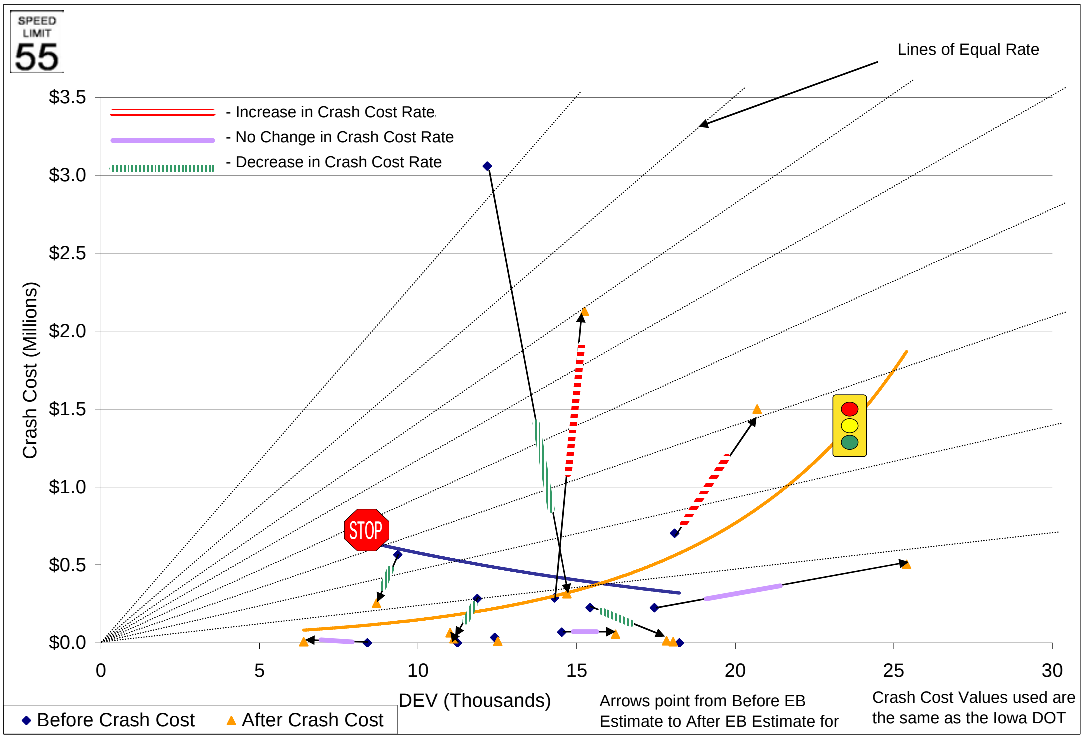

Figure 5. Crash cost, before-and-after analysis

EMPIRICAL BAYES ANALYSIS

Empirical Bayes (EB) is considered by many to be the state-of-the-art statistical method for conducting before-and-after analysis. It is the FHWA recommended analysis method for safety countermeasure studies. The method accounts for natural variations (cycles and randomness) in crash data. To perform an EB study, models were developed for the entire set of 158 unsignalized and 45 signalized intersections using SAS. Parameters[5] were used to compute weighting factors for EB adjustment[6] as suggested by Hauer et al. (2).

Figure 6 shows raw and EB adjusted crash frequencies for the before and after periods. The resulting average crash rate, EB adjusted, for the before period was 0.97 crashes per MEV. The EB adjusted average crash rate for the after period was 0.77 crashes per MEV. To graphically illustrate the magnitude of EB adjustment, Figure 7 is provided. The trapezoidal areas on the chart represent the effect of EB adjustment. The vertical faces represent the EB adjustment (toward the model), and the arrows point in the direction from before to after. As can be seen, after adjustment, crashes at five intersections decreased, crashes at four intersections increased, and three intersections showed no change in crash rate. When compared to the conventional before-and-after analysis, two intersections changed from a decrease in crash rate to no-change.

[5] Negative Binomial allows the variance of the dataset to exceed the mean (vs. Poisson); the overdispersion parameter is an output of SAS NB regression, estimated with maximum likelihood.

[6] EB takes into account the past safety performance of a site in question, as well as the performance of similar sites to treat the effect of small sample sizes and temporal trends causing regression to the mean. For a fuller explanation, see Hauer et al (2). Typically, EB adjustment is applied only to the before period site crash average. In this study, the after period was also adjusted.

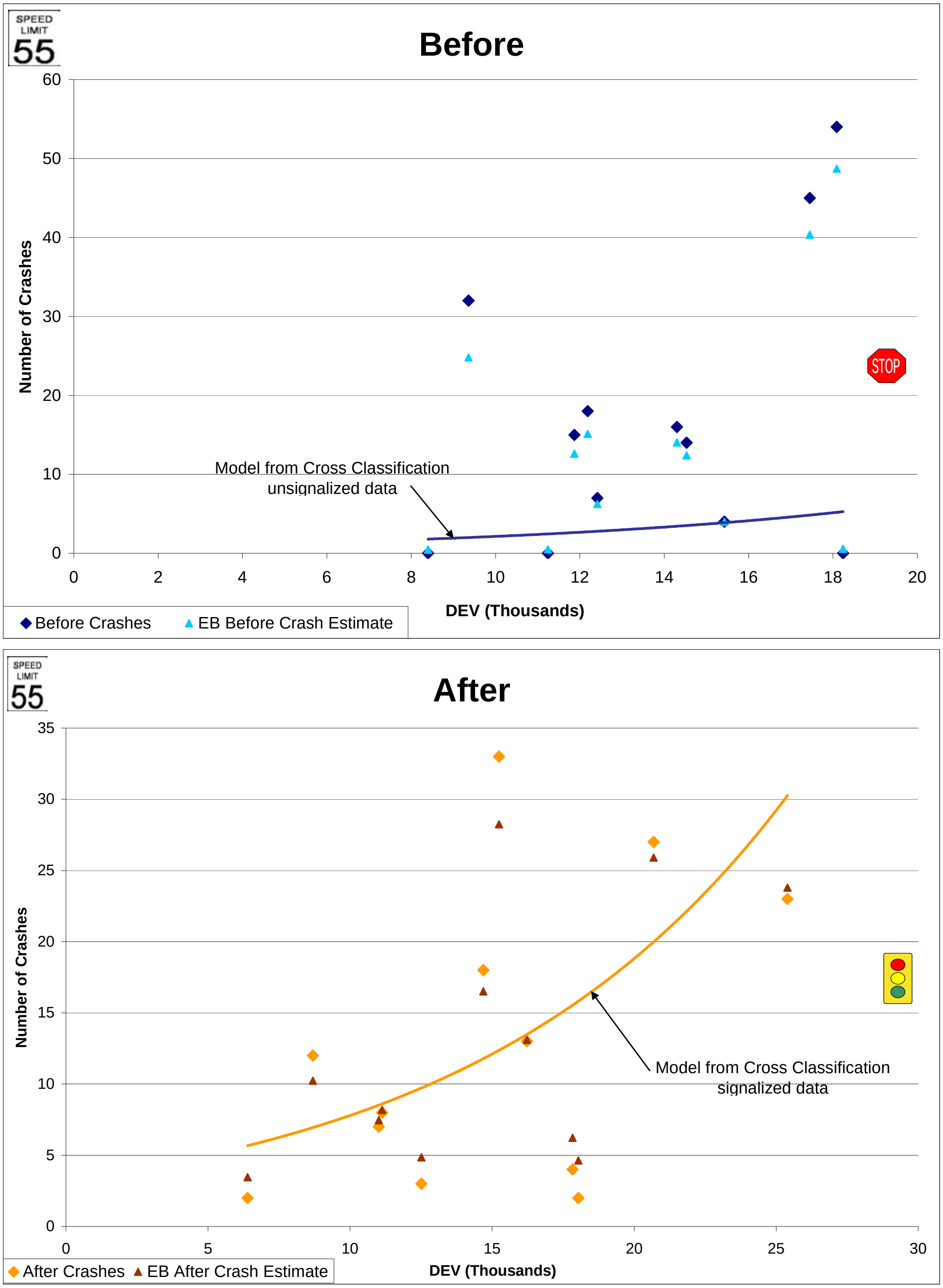

Figure 6. Crash frequency, Empirical Bayes analysis

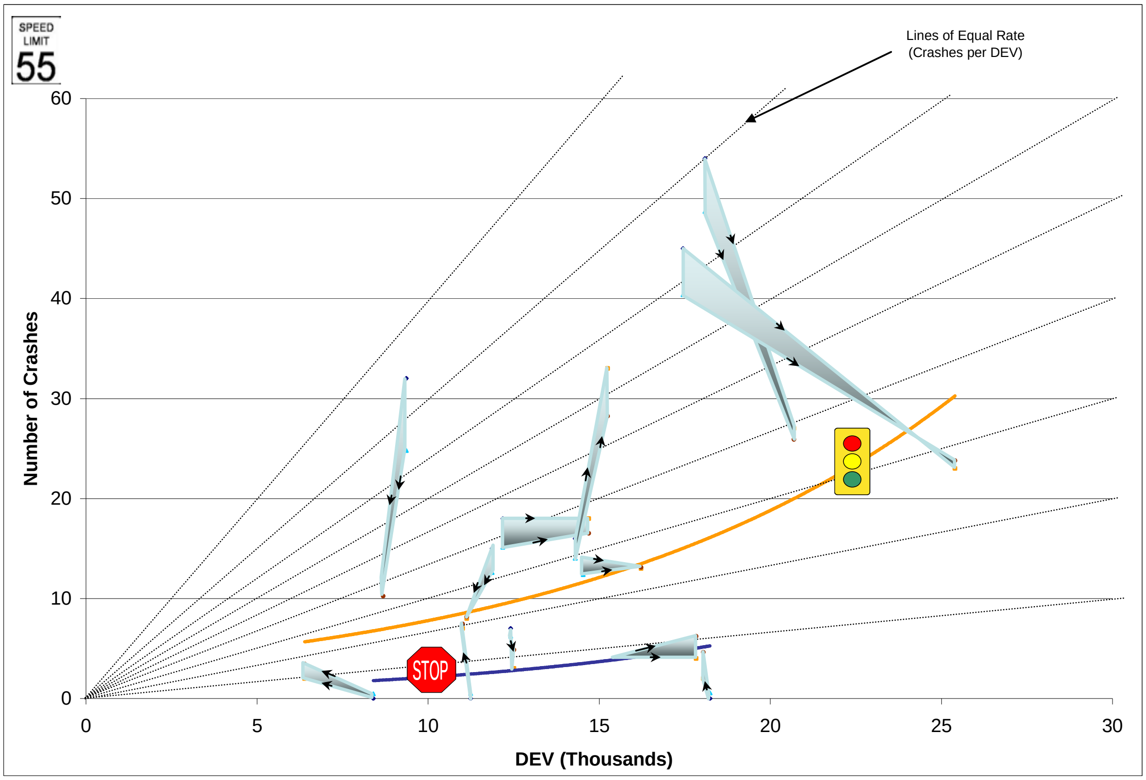

Figure 7. Comparison of signalized and unsignalized crash frequencies, Empirical Bayes analysis

CONCLUSIONS

To summarize some of the key findings of the study, Table 3 compares the matched-pair, before-and-after, and Empirical Bayes results. The EB analysis uses the actual performance of the intersections and weights it with the average of intersections with similar characteristics.

Adjusted by the EB procedure, a crash rate of 0.97 crashes per MEV is computed before signalization and 0.77 crashes per MEV after. For these data and analyses, the EB adjustment was marginal, overall. However, for specific sites, the adjustment resulted in meaningful differences. This has implications for policy in general and for site ranking, specifically. In short, signalizing high-speed expressways seems to have only marginal safety benefit—about 20 percent based on rate and 10 percent based on cost. However, at individual sites, safety benefits can be observed[7].

Future work should include a careful examination of the sites to determine if local conditions permit some signals to improve safety while others may not. While the study relied upon a rather large set of intersection data, additional data could improve the models (e.g., presence of turn lanes). In order to conduct a more thorough study, data from additional states are needed. The development of accident modification functions (AMFs) to address varying site characteristics is

[7] The characteristics of these intersections will be examined to determine if there are any common features that influence the safety performance.

also a potential topic for future study. To do this, it is likely that data from additional states will be required.

Table 3. Summary of results

Measure of Effectiveness	Match Pairs Unsignalized	Signalized	% Difference
Number of Intersections	45	45	
Average DEV	11,600	17,000	46.6%
Average Crash Rate	41.5 (40.5)*	96.7 (49.3)*	133.0%
Average Fatality Rate	1.10	0.61	− 44.5%
Average Fatal Crash Rate	0.99	0.61	− 38.4%
Average Fatal & Major Injury Crash Rate	2.45	3.62	47.8%
Average Crash Cost	$41,800	$21,900	− 47.6%
Average Modified Crash Cost	$25,500	$16,300	− 36.1%
Rear-End Crash Rate	11.9	36.1	203.4%
Broadside Crash Rate	22.6	35.1	55.1%

Measure of Effectiveness	Before and After Before	After	% Difference
Number of Intersections	12	12	
Average DEV	13,600	14,800	8.8%
Average Crash Rate	111.3 (109.3)*	76.3 (55.2)*	− 31.4%
Average Fatality Rate	1.87	0.87	− 53.5%
Average Fatal Crash Rate	1.25	0.87	− 30.4%
Average Fatal & Major Injury Crash Rate	6.01	4.36	− 27.5%
Average Crash Cost	$26,600	$32,100	20.7%
Average Modified Crash Cost	$22,450	$20,900	− 6.9%
Rear-End Crash Rate	30.4	21.0	− 30.9%
Broadside Crash Rate	52.2	26.8	− 48.6%

Measure of Effectiveness	EB Before	% Adjustment	After	% Adjustment	% Difference
Number of Intersections	12		12		
Average Crash Rate	96.5	-15.3%	76.8	0.7%	− 20.4%

Rates are units per HMEV
Hundred Million Entering Vehicles

* Standard Deviation
** Rho-Squared of the model

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1. Hallmark, Shauna and Kim Mueller. *Impact of Left-Turn Phasing on Older and Younger Drivers at High-Speed Signalized Intersections*. CTRE Project 03-149. Prepared for Iowa Department of Transportation. Ames, IA: Center for Transportation Research and Education. August 2004.
2. Hauer, Ezra, Douglas W. Harwood, Forrest M. Council, and Michael S. Griffith. “The Empirical Bayes method for estimating safety: A tutorial.” *Transportation Research Record 1784*, 126–131. Washington, DC: National Academies Press, 2002.

APPENDIX: INDIVIDUAL BEFORE AND AFTER INTERSECTION DATA

Table 4. Crashes, volumes, and rates

								Before Installation				
POINTID	CITY	COUNTY	MAJOR ST	MINOR ST	Major DEV	Minor DEV	TOT DEV	Crashes	Crash Rate	EB Estimate	EB Crash Rate	% Difference(Rate)
32101	Raymond	Black Hawk	Dubuque Rd	Plaza Dr	6,400	2,000	8,400	0	0.000	0.5	0.051	
38421	Waterloo	Black Hawk	W San Marnan Dr	Ansborough Ave	7,070	4,800	11,870	15	1.154	12.6	0.970	-16.0%
41967	Waterloo	Black Hawk	E San Marnan Dr	Shopper Blvd	17,100	1,140	18,240	0	0.000	0.6	0.028	
139759	Granger	Dallas	IA 141	190th St	9,900	1,340	11,240	0	0.000	0.5	0.041	
293365	Iowa City	Johnson	IA 1	Mormon Trek Blvd	14,000	3,450	17,450	45	2.355	40.4	2.113	-10.3%
437945	Altoona	Polk	US 6	US 65 Ramp	7,500	1,860	9,360	32	3.122	24.8	2.419	-22.5%
439944	Grimes	Polk	IA 141	NW 54th Ave	17,400	690	18,090	54	2.726	48.7	2.459	-9.8%
440241	Pleasant Hill	Polk	IA 163	NE 64th St	14,000	1,425	15,425	4	0.237	4.0	0.236	-0.5%
440263	Pleasant Hill	Polk	IA 163	NE 80th St	12,250	2,050	14,300	16	1.022	14.0	0.897	-12.2%
619371	Waterloo	Black Hawk	Broadway St	Wagner Rd	10,900	1,515	12,415	7	0.515	6.2	0.458	-11.1%
667226	Muscatine	Muscatine	US 61	Mulberry Ave	9,800	2,385	12,185	18	1.349	15.1	1.133	-16.0%
667227	Muscatine	Muscatine	US 61	Isett Ave	12,300	2,230	14,530	14	0.880	12.4	0.780	-11.4%
				Average	11,552	2,074	13,625	17.1	1.113	15.0	0.965	-12.2%

								After Installation				
POINTID	CITY	COUNTY	MAJOR ST	MINOR ST	Major DEV	Minor DEV	TOT DEV	Crashes	Crash Rate	EB Estimate	EB Crash Rate	% Difference(Rate)
32101	Raymond	Black Hawk	Dubuque Rd	Plaza Dr	4,090	2,305	6,395	2	0.286	3.5	0.493	72.7%
38421	Waterloo	Black Hawk	W San Marnan Dr	Ansborough Ave	6,780	4,350	11,130	8	0.656	8.2	0.671	2.3%
41967	Waterloo	Black Hawk	E San Marnan Dr	Shopper Blvd	16,900	1,140	18,040	2	0.101	4.6	0.234	131.5%
139759	Granger	Dallas	IA 141	190th St	9,750	1,260	11,010	7	0.581	7.5	0.619	6.6%
293365	Iowa City	Johnson	IA 1	Mormon Trek Blvd	17,500	7,900	25,400	23	0.827	23.8	0.856	3.5%
437945	Altoona	Polk	US 6	US 65 Ramp	6,700	1,990	8,690	12	1.261	10.2	1.076	-14.7%
439944	Grimes	Polk	IA 141	NW 54th Ave	18,850	1,840	20,690	27	1.192	25.9	1.143	-4.1%
440241	Pleasant Hill	Polk	IA 163	NE 64th St	15,700	2,135	17,835	4	0.205	6.2	0.319	55.7%
440263	Pleasant Hill	Polk	IA 163	NE 80th St	12,700	2,545	15,245	33	1.977	28.2	1.691	-14.4%
619371	Waterloo	Black Hawk	Broadway St	Wagner Rd	11,000	1,515	12,515	3	0.219	4.9	0.355	62.0%
667226	Muscatine	Muscatine	US 61	Mulberry Ave	11,800	2,895	14,695	18	1.119	16.5	1.026	-8.3%
667227	Muscatine	Muscatine	US 61	Isett Ave	13,950	2,275	16,225	13	0.732	13.1	0.738	0.8%
				Average	12,143	2,679	14,823	12.7	0.763	12.7	0.768	24.5%

Table 5. Side-by-side rate comparisons

POINTID	CITY	COUNTY	MAJOR ST	MINOR ST	Before Crash Rate	After Crash Rate	% Difference	Before EB Crash Rate	After EB Crash Rate	% Difference
32101	Raymond	Black Hawk	Dubuque Rd	Plaza Dr	0.000	0.286		0.051	0.493	873.2%
38421	Waterloo	Black Hawk	W San Marnan Dr	Ansborough Ave	1.154	0.656	-43.1%	0.970	0.671	-30.7%
41967	Waterloo	Black Hawk	E San Marnan Dr	Shopper Blvd	0.000	0.101		0.028	0.234	732.0%
139759	Granger	Dallas	IA 141	190th St	0.000	0.581		0.041	0.619	1420.6%
293365	Iowa City	Johnson	IA 1	Mormon Trek Blvd	2.355	0.827	-64.9%	2.113	0.856	-59.5%
437945	Altoona	Polk	US 6	US 65 Ramp	3.122	1.261	-59.6%	2.419	1.076	-55.5%
439944	Grimes	Polk	IA 141	NW 54th Ave	2.726	1.192	-56.3%	2.459	1.143	-53.5%
440241	Pleasant Hill	Polk	IA 163	NE 64th St	0.237	0.205	-13.5%	0.236	0.319	35.3%
440263	Pleasant Hill	Polk	IA 163	NE 80th St	1.022	1.977	93.5%	0.897	1.691	88.6%
619371	Waterloo	Black Hawk	Broadway St	Wagner Rd	0.515	0.219	-57.5%	0.458	0.355	-22.5%
667226	Muscatine	Muscatine	US 61	Mulberry Ave	1.349	1.119	-17.1%	1.133	1.026	-9.5%
667227	Muscatine	Muscatine	US 61	Isett Ave	0.880	0.732	-16.8%	0.780	0.738	-5.4%
				Average	1.113	0.763	-26.2%	0.965	0.768	242.7%