

Impact of Some Site-Specific Characteristics on the Success of the Signalization of High-Speed Intersections

Final Report
June 2008

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IMPACT OF SOME SITE-SPECIFIC CHARACTERISTICS ON THE SUCCESS OF THE SIGNALIZATION OF HIGH-SPEED INTERSECTIONS

**Final Report
June 2008**

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PROBLEM STATEMENT

The conversion of two-lane roadways to four-lane, divided expressways has become a common solution to the need for high-speed, higher capacity travel between rural and suburban communities. As traffic volumes increase on these facilities there are seemingly inevitable increases in intersection crashes. A frequently proposed solution to intersection crashes is the installation of traffic signals, with results that can at best be described as mixed. In some cases there have been reductions in crash risk following signalization while in others there has been no change or even an increase. The public perception seems to be that signals are the universal fix, while transportation safety specialists at present cannot state with assurance that installing signals at a particular intersection will be successful at reducing the frequency of problem crashes. In an effort to provide some indicators for the safe signalization of high-speed intersections, this study focuses on an analysis of a variety of intersection characteristics and how they relate to crash risk at these intersections.

This project expands upon work by Souleyrette and Knox (2005) that evaluated the safety of signalized intersections on high-speed expressways.

LITERATURE REVIEW

The literature provides a diversity of studies, with results that either support or reject the assertion that the safety of an intersection will improve with signalization. For example, Voss (1997) performed a before-and-after crash reduction and benefit/cost analysis to measure safety improvements in the state of Kansas. New traffic signals were found to reduce crashes by 45%. However, type and severity of crash and selection bias were not accounted for in that study. Thomas and Smith (2001) reported that installing 16 new traffic signals reduced overall crashes by 29%, with a 71% reduction in right-angle crashes but with increases of 44% in rear-end crashes and 41% in left-turn crashes. This study was a simple before/after study of 16 intersection projects using 3 years of before and 3 years of after data. Contrast this to Persaud (1988), who reported on studies whose results ranged from a 24% reduction to a 51% increase in total crashes after signal installation. Persaud concluded that a failure to account for regression to the mean and incorrectly interpreting the results of cross-sectional studies calls into question "...much of the knowledge about the safety impact of signal installation. In particular, the foundation of the belief that, where unwarranted, signal installation is likely to increase accidents appears to be shaky."

In a 1993 report for the Nebraska Department of Roads concerning economic justification of interchanges, Bonneson and McCoy developed regression models for the safety of signalized and unsignalized (2-way stop control) expressway intersections as well as interchanges using generalized linear modeling. They concluded that only the main and side road ADT values were significant in intersection crash prediction models and that expressway ADT was the only significant variable affecting crashes at interchanges. They also found that interchanges were economically justified (considering all costs) at a side road ADT of about 4,000. They compared crash frequencies predicted by their models for main line ADT values between 7,000 and 15,000 and side road ADT between 100 and 4,000. Their analysis indicated that signalized intersections

are expected to have more crashes than stop controlled intersection where side road ADT is greater than about one fourth of the main line ADT.

Several others have developed models to predict the crash frequency at expressway intersections. As far back as 1953, McDonald, in a study of 150 intersections in California, developed a series of curves relating the major and minor road daily volumes to average number of crashes per year. Abdel-Aty et al (2006) examined some 1,335 signalized intersections in Florida to develop a simplified procedure to use the number of approach lanes to predict crash frequency. Such a model may function well in locations where most of the mainline highways are at similar volumes such that they are approaching capacity. On rural highways the number of lanes is frequently not well correlated with volume but rather reflect minimum design standards.

Keller et al (2006) analyzed 22,748 crashes over 2 years at 832 intersections in Florida. They used regression tree analysis to determine the relationship between various site characteristics and different types of crashes. The most significant independent variable predicting angle crashes was the number of lanes on the minor road, while the presence of exclusive left-turn lanes on the minor road was the most significant independent variable predicting left-turn crashes. Daily minor road volume was most significant for side-swipe crashes, and minor road speed limit was not a significant predictor for any type of crash.

Sarchet (2005) examined the safety effect of signalizing intersections in Colorado. He examined 112 intersections that were signalized between January, 1993 and January, 2000, including 65 crash characteristics (including crash/injury severity, crash type, light conditions, weather, and driver factors). Each characteristic was compared before and after signalization at each intersection and across all intersections. The research concluded that the total number of crashes increased at 75% of the intersections and the total number of crashes also increased by 75%. Twenty-six crash types and attributes increased at a greater rate than traffic volume (including property damage only, injury, multi-vehicle, rear-end, approaching turn (left turning) crashes and persons injured).

Expressways (Divided Highways)

Harwood, et. al., in NCHRP 375 (1995) reported crash rates for signalized and unsignalized divided highway intersections. Rural 4-leg unsignalized intersections had an average crash rate of 0.17 crashes per million entering vehicles (0.10 fatal and injury crashes per MEV). Their urban counterparts had an average crash rate of 0.14 (0.07 fatal and injury crashes per MEV). While signalized rural intersections were not reported, signalized urban 4 leg intersections had an average crash rate of 0.16 (0.08 fatal and injury crashes per MEV). Little overall difference in crash rate was observed between signalized and unsignalized intersections in this study.

Souleyrette and Knox (2005) compared the results of a traditional (classical or naïve) before and after study of high-speed signalized expressway intersections to a study of the same intersections utilizing the Empirical Bayes method. Where the classical study method showed a reduction of 11.7 percent in crash rates, the Empirical Bayes method found a 4.8 percent reduction in crash

rate. They concluded that overall, while crash rates are slightly lower, crash costs at signalized intersections are much higher.

Regardless of statistical procedure used, the safety performance of signalizing particular high speed expressway intersections is mixed.

METHODOLOGY

Seventeen intersections were used in the current study, selected from the data studied by Souleyrette and Knox (2005). Two intersections studied by Souleyrette and Knox were removed to provide for a more homogenous comparison group. Table 1 lists the intersections.

Table 1. Study intersections

Int#	City	Description	Expressway Speed Limit
01	Raymond	Dubuque Road and Plaza Drive	55
02	Waterloo	West San Marnan Dr & Ansborough Ave	55
03	Mason City	Iowa Hwy 122 & N. Roosevelt Ave.	50
04	Granger	IA 141/190th	55
05	Dubuque	US 20 & Old Highway Rd	50
06	Iowa City	Iowa Hwy 1 & Mormon Trek Blvd	50
07	Grimes	Iowa Hwy 141 & NW 54th Ave	50
08	Pleasant Hill	Iowa Hwy 163 & Copper Creek Dr	50
09	Pleasant Hill	Iowa Hwy 163 & NE 64th Street	55
10	Pleasant Hill	Iowa Hwy 163 & NE 80th Street	55
11	Waterloo	Broadway Street & Wagner Road	55
12	Osceola	US 34 & Warren Ave	50
13	Muscatine	US 61 & Mulberry Avenue	55
14	Muscatine	US 61& Isett	55
15	Des Moines	Iowa Hwy 28 & SW McKinley Ave	50
16	Pleasant Hill	Iowa Hwy 163 & NE 56th St	50
17	Ft. Dodge	2nd Ave S & Country Club Dr	50

For most of the intersections, Iowa DOT video logs were reviewed to determine attributes such as shoulder type, presence and type of left-turn lanes, presence and type of right-turn lanes, presence of curbs, type of left-turn signal phasing, presence of advance warning signs and flashers, and speed limit. The number of approach lanes was taken from the Iowa DOT's state roads database, then checked by reviewing the aerial photography and the video logs. Where video logs were not available, local officials were contacted or site visits were conducted. Using ArcGIS, the distance to the nearest access points, the orientation of the primary route, and the skew angle of the intersection were measured. Traffic volumes were taken from the Iowa DOT's

roadway inventory data, or GIMS database. Crash data and costs were taken from Souleyrette and Knox (2005).

Categorical variables were created to represent several of the intersection characteristics, as follows:

- Type of turn lane (either right or left) – none, parallel, or offset
- Left-turn signal type – protected, permitted, or protected plus permitted
- Type of advance flasher – none, simple, and coordinated (prepare to stop when flashing)
- Median type –raised or depressed
- Shoulder type –granular, paved, or curb and gutter

Scatter plots were prepared to determine if there were any perceivable relationships or patterns in the data. Total change in crashes (before and after signalization) and changes in injury crashes were investigated. Change in injury crashes, while a smaller data set than total crashes, would seem to be a better indicator of the effectiveness of the signal, as these are the most expensive types of crashes, and the ones the safety community is most interested in reducing. Three years of data were used in both the before and after periods in this analysis. Data from the year of change (signalization) was omitted.

Figure 1 presents an example of these plots. In this case, change in crash frequency (positive means an increase in crashes) is plotted against side road ADT, showing no discernable pattern.

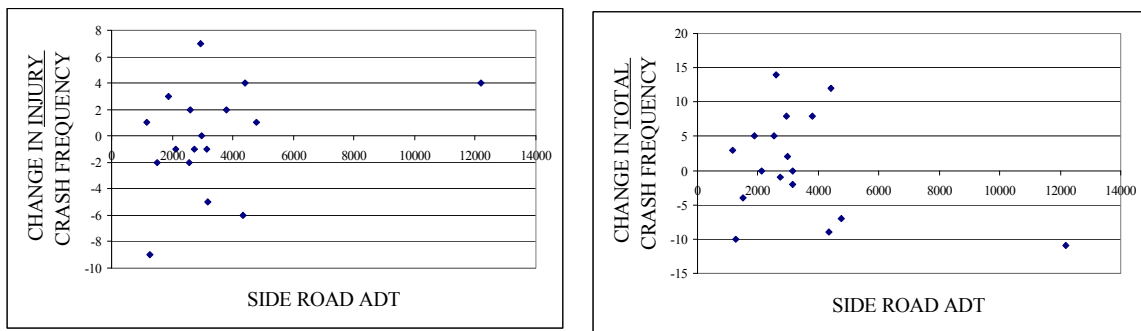


Figure 1. Changes in injury and total crash frequency vs. side road ADT

Figure 2 shows how changes in total crash frequency are related to the number of side road lanes. Sample size is indicated on the charts, in circled numbers. Note that there were only one T intersection (one side road lane) and one multilane side road (four side road lanes) included in the study. For the bulk of the intersections (two or three entering side-road lanes), overall there is little safety effect of signalization.

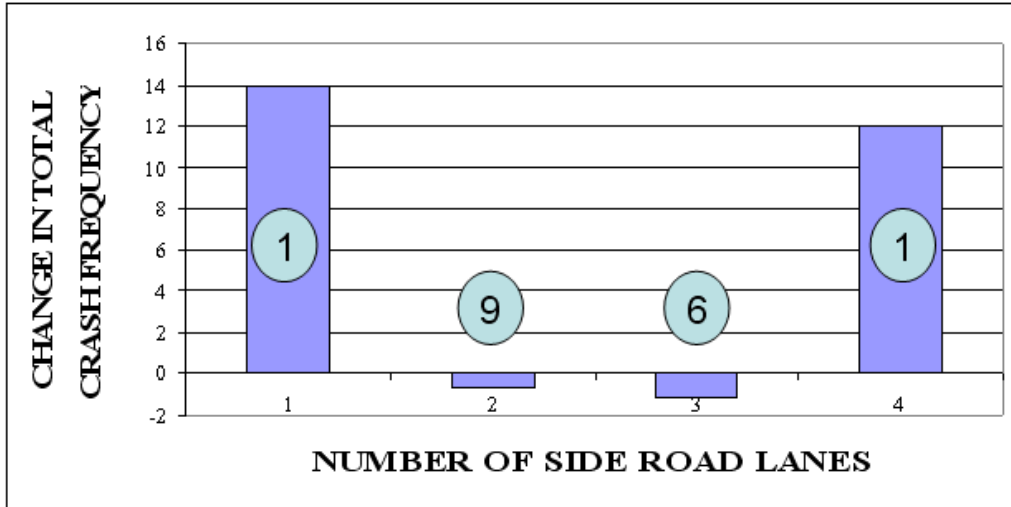


Figure 2. Change in crash frequency vs. number of side road lanes

ANALYSIS

An initial assessment of these intersections confirmed the variability in the impact of traffic signal installation on crashes, reflecting the findings of other studies as discussed above. Table 2 presents a basic summary of the study intersections and their total crash history. On average, the frequency of total crashes increased by about a quarter of a crash per year per intersection. However, intersections 1, 3, and 17 had either zero or very few crashes in the before period. This suggests that there may have been some changes (e.g., side road added at same time as signal) that are not reflected in the data we had available. If these intersections are removed, the effect of signalization is a reduction of crashes by about one per year per intersection.

On the whole, injury crashes are slightly reduced by signalization (0.06 crashes per year). If intersections 1, 3 and 17 are removed, this reduction increases to about 0.25 crashes per year.

All of these changes are small compared to the average total number of crashes (~13) and injury crashes (~7) expected in the before and after time periods.

Table 2. Changes in total and injury crashes

Node	Change in Total Crashes		Change in Injury Crashes	
	Total	Annual Average	Total	Annual Average
01	2	0.67	0	0.00
02	-9	-3.00	-6	-2.00
03	12	4.00	4	1.33
04	-10	-3.33	-9	-3.00
05	14	4.67	2	0.67
06	-11	-3.67	4	1.33
07	-7	-2.33	1	0.33
08	8	2.67	7	2.33
09	0	0.00	-1	-0.33
10	5	1.67	-2	-0.67
11	-4	-1.33	-2	-0.67
12	-2	-0.67	-1	-0.33
13	0	0.00	-5	-1.67
14	-1	-0.33	-1	-0.33
15	3	1.00	1	0.33
16	8	2.67	2	0.67
17	5	1.67	3	1.00
AVG.	0.76	0.25	-0.18	-0.06

Figure 3 presents the change in total crash frequency compared to the mainline ADT. The apparent trend is emphasized if the two data points having high ADT values are removed.

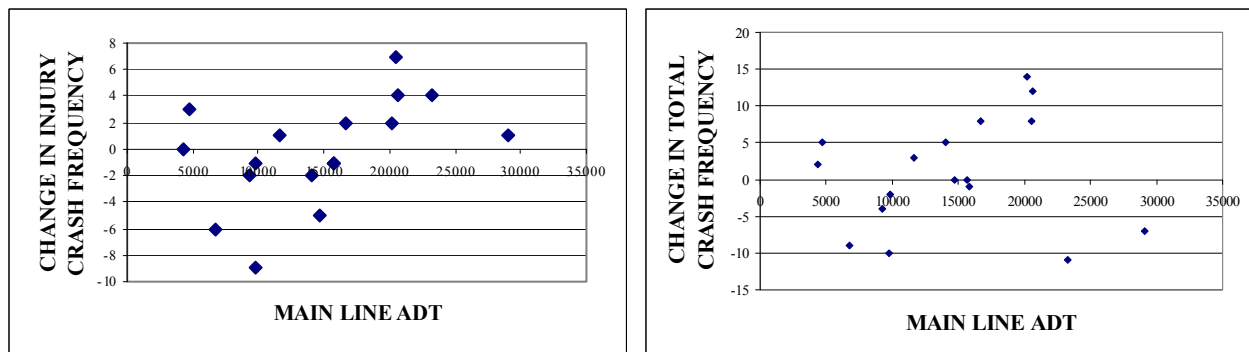


Figure 3. Injury and total crash frequencies vs. mainline ADT

Changes in crashes by type were plotted against the number of side road lanes approaching the intersections. For most of the intersection groups, as expected, the reduction in broadside crashes is slightly greater than the increase in rear-end crashes. However, for intersections with one or

four side-road entering lanes, both types of crashes are noted to increase after signalization (because of the small sample size one should be careful in extending these results). See Figure 4.

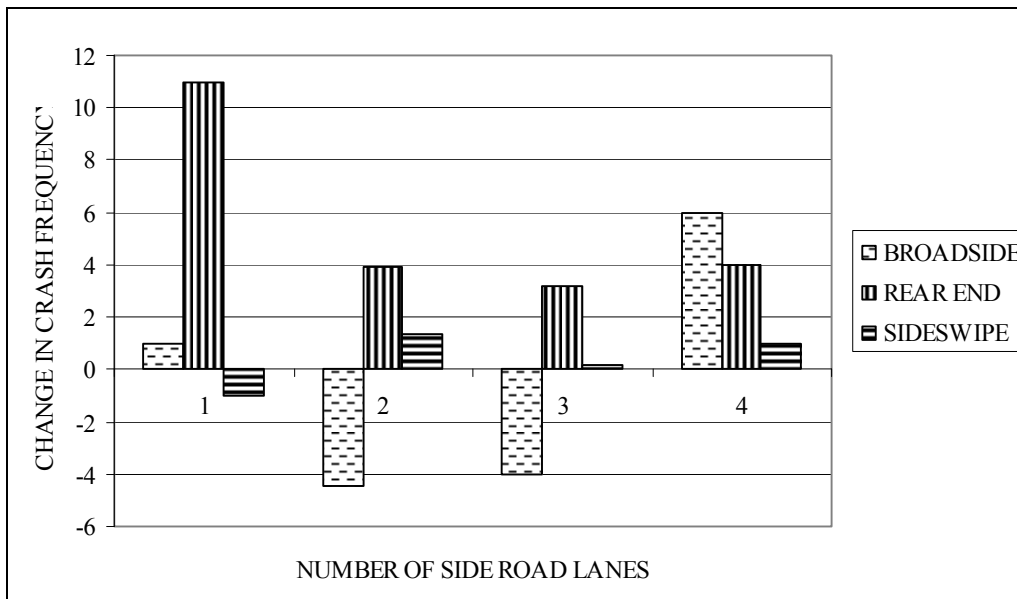


Figure 4. Change in crash frequency by number of side-road lanes

Figure 5 compares change in crashes by type for the two major road speed limits represented in the data set. Signalization appears to provide a greater safety benefit on the facilities with the 55-mph speed limit than on those with the 50-mph limit. Note the expected pattern for 55 mph intersections (increase in rear-ends, decrease in broadsides) while at 50 mph, both types increase.

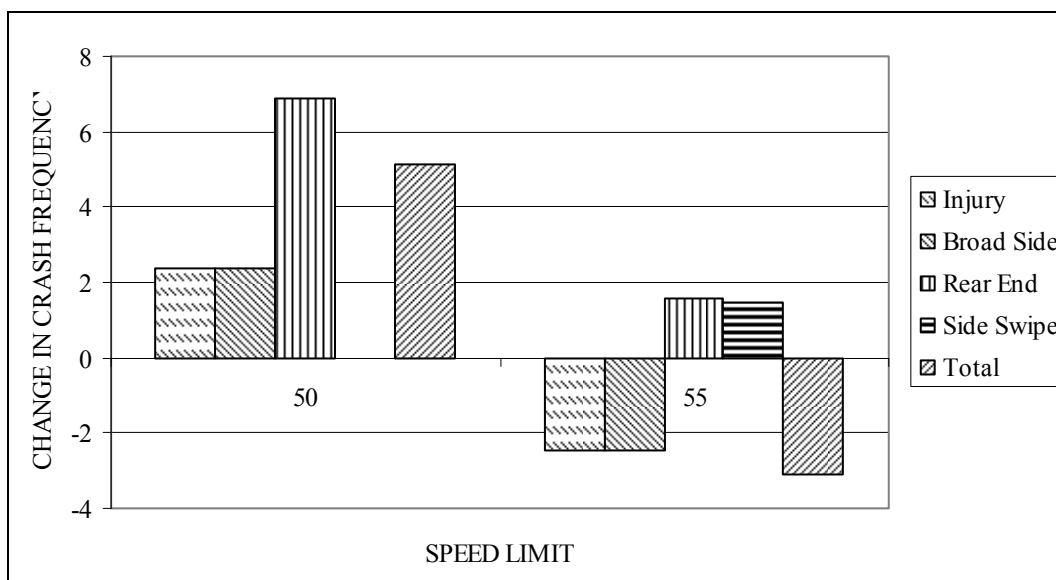


Figure 5. Changes in various crash types vs. mainline speed limit

Figure 6 compares safety performance by type of left-turn protection (protected only, permitted only, and protected plus permitted). Seven of the intersections have protected-only phasing, five have permitted-only phasing, and five have the combined type of phasing. The protected and protected-plus-permitted signal types are associated with the lowest rate of broadside crashes and the highest rate of rear-end crashes, both by substantial margins. This finding is consistent with practitioner expectations (for example, see Persaud (1988)); it is generally viewed that broadside crashes are more severe than rear-end crashes, although in the higher speed regimes this may not always be the case. Note that only the intersections with the protected-only phasing showed a reduction in the frequency of injury crashes, again consistent with practitioner expectations. Note also that the total crash frequency went down for the intersections whose phasing includes protected left-turns while it went up for the intersections with permitted phasing.

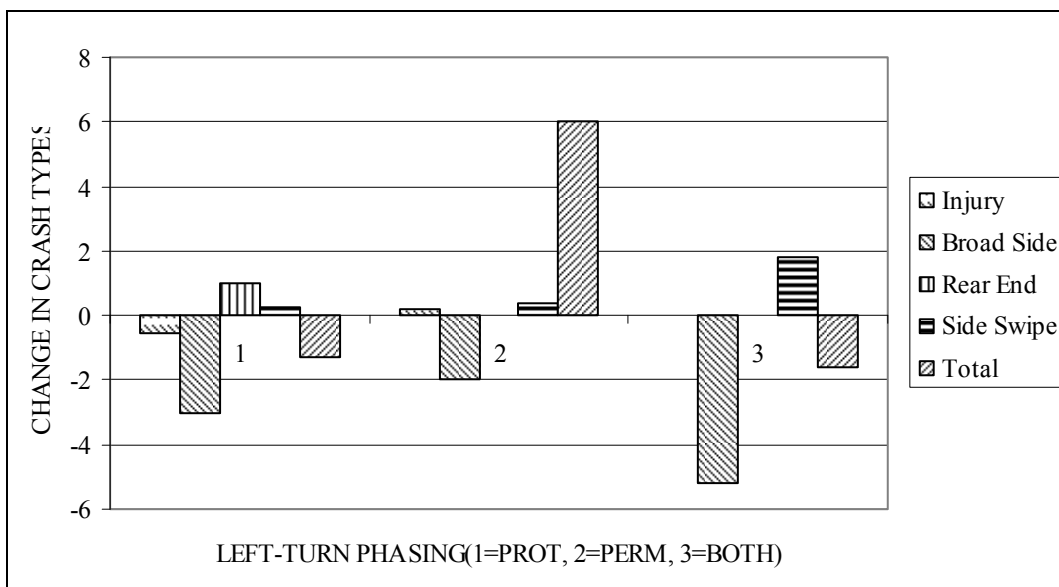


Figure 6. Change in crash frequency by type of left-turn signal phasing

Table 3 presents a comparison of the change in injury crash frequency ($Inj \Delta$) to various site characteristics. As one would expect, the inclusion of a protected left-turn phase, either alone or with a permitted phase, is associated with lower crash frequencies. Somewhat surprisingly, the higher speed limits on the main line are associated with more improvement in crash frequencies. Less clear are the relations between ADT and the number of side road lanes on the one hand and the reduction in injury crash frequency.

Table 3. Comparison of change in injury crash frequency and various site characteristics

Node	Inj Δ	Speed Limit	Main ADT	Sideroad ADT	# Sideroad Lanes	LT Type
04	-9	55	9,750	1,260	2	3
02	-6	55	6,780	4,350	3	1
13	-5	55	14,700	3,160	2	3
10	-2	55	14,050	2,545	3	2
11	-2	55	9,250	1,515	2	1
09	-1	55	15,700	2,125	2	2
12	-1	50	9,800	3,140	3	3
14	-1	55	15,800	2,725	2	3
01	0	55	4,345	2,985	3	1
07	1	50	29,100	4,765	2	1
15	1	50	11,650	1,175	2	2
05	2	50	20,200	2,610	1	2
16	2	50	16,700	3,800	3	1
17	3	50	4,730	1,878	2	3
03	4	50	20,600	4,420	4	1
06	4	50	23,300	12,200	3	1
08	7	50	20,500	2,948	2	2

CONCLUSIONS

In general, the crash frequency following signal installation seems to be directly related to the main line traffic volume. Signals also seem to have lower crash frequencies in the areas with main line speed limits of 55-mph than in the 50-mph areas. Side road volumes seem to be slightly lower in those areas with lower crash frequencies. With this small data set, there does not seem to be any well-defined relationship between the number of side road lanes and the crash frequency. As expected, protected left turn phasing lowers injury crash frequency.

LIMITATIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

Because some of these intersections were signalized as many as 12 years ago, it has been difficult to determine some of the site characteristics present in the three years before and after signalization. This especially pertains to the type of left-turn phasing, such that it is unclear as to the type of phasing at the time of interest. At some of the intersections there are indications that modifications have been made to the geometry, such that it cannot be assumed with complete certainty that the intersections were unchanged over the study period.

It should be especially noted that it appears reasonable to infer that the speed limit, signal phasing, and traffic volume could be correlated. Areas with higher volumes tend to be in more developed areas, where there is frequent pressure to lower speed limits. Signal phasing is

frequently adjusted to provide for additional “green time” in higher volume areas by omitting protected phases.

A further limitation on this current research is in the size of the sample, comprising only seventeen intersections. Persaud (1988), in discussing a methodology for estimating the safety impacts of installing traffic signals notes “At least of 2 years of detailed traffic and accident data before and after (for) as many installations as possible (a minimum of 100) is required.” He also notes that this minimum of 100 is for “each category of traffic volumes (individual turning movements) and accidents...” To meet this requirement for just three crash categories (such as the current study’s broadside, rear-end, and sideswipe categories) and three left-turn signal types (protected, permitted, and protected/permitted) would necessitate a minimum of 900 intersections in the study. This number of intersections would require the involvement of multiple states or a national effort.

It was not the objective of this study to develop a reliable statistical prediction model but to dig into the details of each intersection and see if some explanation of the difference in safety performance could be observed to be related to site specific character. To that end, this research is a work in progress and additional details about the traffic, control, and geometry of each intersection are being pursued.

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APPENDIX A. SUMMARY DESCRIPTION OF CHARACTER

Intersection 01: Waterloo

East west roadway is the expressway. It is 4-lanes divided at the intersection and to the east, with the 4-lanes dropping to 2 about 1100 feet west. The west approach has an AADT of 3,560 and the speed limit is 55 mph. The east approach has an AADT of 10,000, also with a speed limit of 55 mph. Ansborough is 4 lanes to the north and 2 lanes to the south. On the north approach the AADT is 8,100 and the speed limit is 35 mph; on the south approach the AADT is 600 and the speed limit is 45 mph. There is a golf course in the NW quadrant, with the access via Olympic Drive approximately 1000 feet to the north on Ansborough. The NE quadrant is developed, with an office-type building adjacent to the intersection. Access is from Home Plaza approximately 500 feet north of the expressway intersection. To the west of the intersection, in the SW quadrant, is an office or medical (?) facility with access to W. San Marnan via Galactic Drive, about 800 feet west of study intersection. Also in the SW quadrant is what appears to be a farmstead, located about 600 feet south of the study intersection. The first driveway to the farmstead is about 400 feet south. There is another farmstead in the SE quadrant, located about 900 feet south of the intersection. The land in the SE quadrant adjacent to San Marnan appears to be farm ground. There is what may be a frontage road along the south side of San Marnan, running east from just south of the intersection.

Intersection 02: Iowa City

Iowa Highway 1 is oriented NE/SW. According to the aerial imagery (Google maps) Mormon Trek Blvd connects SE to Dana Rd. SE, while the 2002 CIR orthophotos show a small business or office building at the intersection with its driveway being the SE approach to the intersection. The NW approach on Mormon Trek Blvd shows an AADT of 12,200 with a speed limit of 35 mph. Iowa Hwy 1 has an AADT of 25,300 and a speed limit of 55 mph on both approaches. The left-turn lanes on Hwy 1 are parallel to the mainline (not offset) and the median is grass. There is a right-turn lane for west-bound traffic on Hwy 1. Hwy 1 appears to be on a downgrade from west to east and is on a slight horizontal curve through the intersection. To the SW the nominally east ramp terminals of US 218 are about 700 feet away from the intersection. There is an entrance about 800 feet NE of the intersection. No other accesses along IA 1. The first driveway on Mormon Trek Blvd. is about 450 feet NW of the intersection. Traffic signals are on mast arms, with secondary signals on the poles and on separate poles (for cross-traffic) in the median. The left-turn signal for east-bound traffic is located on the secondary pole in the median, while the left-turn signal for west-bound traffic is on the mast arm. The left-turn phasing appears to be protected only. There are signal advance warning signs with red flags on both sides of the eastbound lanes, just on the west side of the bridge over US 218. There is an advance guide sign for Mormon Trek Blvd on the right side for east-bound traffic, however, it is approximately opposite the beginning of the left-turn lane and perhaps should be located farther west. The intersection is lighted. Shoulders on Hwy 1 are granular. There is commercial or office development on both sides of Mormon Trek Blvd on the NW side of IA 1. The business at the west corner of the intersection is an automobile dealership, while the business on the north corner is a fast food restaurant.

Intersection 03: Cedar Rapids

The west ramp terminal of I-380 is about 750 feet east of the intersection. At the intersection Wright Brothers Blvd. is four lanes, with a painted median on the east approach and a depressed median to the west. The west approach has an AADT of 8,600 and a speed limit of 45 mph, while the east approach has an AADT of 1,000 and a speed limit of 55 mph. Between the intersection and the interchange the expressway transitions from 4 lanes to 2 lanes. On the north side of the expressway, about 400 feet west, is a side street with no median break. Atlantic Drive, about 900 feet west, has a full median break with turn lanes. The north approach has an AADT of 4,560 and a speed limit of 55 mph, while the south approach has an AADT of 4,910 and the same speed limit. At the intersection, 6th Street S.W. has left turn lanes and a single through lane for N/S traffic. The intersection is about 1.7 miles east of the Eastern Iowa Airport. America Blvd. is located about 550 feet north of the intersection. There is a business to the southeast of the intersection, with its access to 6th Street S.W. about 550 feet south of the intersection, which appears to be a truck service or fueling operation. The CIR orthophotos show no development adjacent to the intersection.

Intersection 04: Altoona

US 6 is the expressway in this intersection. It is oriented NE/SW, with the US 65 east ramp terminus forming the cross-street. The speed limit through the intersection is 45 mph, although it changes to 55 mph just to the NE of the intersection. Shoulders are granular. The AADT to the northeast is 6,400 and to the southwest it is 7,000. The northbound on-ramp is the NW leg; it has an AADT of 2,540 and a speed limit of 55 mph. The SE leg is a one-lane connector between US 6 (Hubble) and 8th Street SW; it has an AADT of 1,990 and a speed limit of 55 mph. It serves as an extension to the northbound exit ramp from US 65 to 8th Street SW. 36th Ave SW is about 1100 feet to the NE of the intersection and provides access to a Menard's that is immediately adjacent to the intersection. Other businesses in the area include Lowe's, Target, and Wal-Mart. The NB ramp terminus forms the cross-street at this intersection. The only service provided by the ramps is access to US 65, and they are one-way. To the SW the expressway becomes Hubble Avenue and is not divided. The SB ramp terminus is about 660 feet to the SW of the signalized intersection. The study intersection is lighted. Traffic signals are mounted on mast arms, with the signals for the ramp traffic mounted in the grassed median. There are signal ahead signs for west-bound traffic. The east-bound left turns onto US 65 are protected plus permitted.

Intersection 05: Grimes

Iowa Hwy 141 is oriented N/S at this intersection with NW 54th Street. There is a frontage road going south about 200 feet east of the intersection. There are gas stations/convenience stores on the northeast and southeast quadrants; the one on the southeast is on the east side of the frontage road. The driveway to the convenience store on the NE is about 400 feet east of the expressway intersection. At the time of the aerial photography there was no development adjacent to the highway on the west side. To the north the next access is to a commercial/office development on the west side, located about ¼ mile from the intersection. There is a T-intersection about 1200 feet to the south of NW 54th that connects to the frontage road. The speed limit at the intersection is 50 mph, although just to the south it is 45 and about ¼ mile to the north it changes to 55 mph.

The south leg has an AADT of 30,900 and the north leg has an AADT of 27,300. The AADT on NW 54th Street is 5,200 to the east and 4,330 to the west. The speed limit is 45 mph on NW 54th Street. This intersection has heavy truck and commuter traffic. During the summer of 2005 this intersection was reconfigured to extend the left-turn lanes and to add a right-turn lane for northbound traffic and a third lane for southbound traffic wanting to enter I-35/80 about 1,800 feet to the south. Traffic signals in the video log (from 2001) show signals on mast arms with no secondary indications on the masts. Left-turn indications were for protected-only phasing. Shoulders were granular. There were signal ahead signs with warning flashers. Right turns for expressway traffic were made from the right lane, although there was evidence that vehicles were using the shoulders as well.

Intersection 06: Pleasant Hill

This first of two expressway intersections in Pleasant Hill is on Iowa Hwy 163 at NE 64th Street. Hwy 163 is oriented E/W at this location and has two through lanes in each direction, with a grassed median about 50 feet in width and granular shoulders. Hwy 163 is on an upgrade for east-bound traffic approaching the intersection. The intersection is about $\frac{3}{4}$ of a mile east of the US 65 interchange. To the east of the intersection the highway has a gradual curve to the north. The aerial photography shows a median cross-over and field entrances about 1200 feet to the east of the intersection as well as about $\frac{1}{2}$ mile to the west. There are offset left-turn lanes on Hwy 163. There are right-turn lanes for east-bound and west-bound traffic. There is also what appears to be a field entrance about 2000 feet to the west of the intersection, but with no median cross-over. Development in the area is primarily residential, on large lots. There is what appears to be a cemetery adjacent to the highway in the NE quadrant of the intersection, with its first entrance about 300 feet to the north. The first entrance to the south is about 350 feet south of the intersection. NE 64th has a T-intersection about 800 feet to the north of Highway 163. This intersection is 2 miles west of SE Polk High School and about 7 miles west of the Polk County Sanitary Landfill. The speed limit at the intersection is 55 mph although it changes to 65 just east of the landfill. The AADT on Hwy 163 is 17,400 to the west and 14,000 to the east. The AADT on NE 64th Street is 2,220 to the north and 2,030 to the south. Speed limits on NE 64th are 55 mph. Traffic signals are on mast arms, in the 4 quadrants of the intersection. Left-turns on the expressway are permitted only. West-bound traffic has advance signal warning signs, with a flasher on the right side sign.

Intersection 07: Pleasant Hill

This intersection is on Iowa Hwy 163 at NE 80th Street. Hwy 163 is oriented E/W at this location and as two through lanes in each direction with a grassed median about 80 feet wide. The expressway shoulders are granular. The AADT on Hwy 163 is 14,900 to the west and 13,200 to the east. The AADT on NE 80th is 2,700 to the north and 2,390 to the south. The speed limit on the north approach is 55 mph while on the south approach it is 30 mph. The left-turn lanes (on the expressway) are offset and there are advanced warning flashers with “prepare to stop when flashing” signs. There are entrances to SE Polk High School about 1300 feet east and 600 feet south of the intersection. There are two homes in the NW quadrant of the intersection, with one driveway only about 65 feet north of the north edge of the through pavement and the other driveway about 500 feet north. There is no development in either the NE or SW quadrants. North

of the east entrance to the high school is a residential development with large lots. The intersection is about 2 miles east of the NE 64th Street intersection and about 5 miles west of the Polk County Sanitary Landfill. The speed limit is 55 mph at the intersection and it changes to 65 about 6 miles to the east. There is a public access golf course about $\frac{3}{4}$ of a mile south of Hwy 163. NE 80th Street provides the major access to the high school from Altoona. There are six signal mast arms sets. Signals for through traffic are on far-side mast arms. Signals for east and west bound left-turns are on the ends of mast arms located in the median. Cross-street signals are mounted far-side and in the median. Signal progression for the cross-street is set to prevent trapping vehicles in the median. There are no advance guide signs with the cross-street identification, although the street name is mounted on the cross-arm of the signals.

Intersection 08: Davenport

This intersection is on US 61 at the west ramp terminus (southbound ramps) of I-280. It is located about 800 feet west of the east ramp terminus and about 1,100 feet east of a 4-legged intersection with 118th Avenue. The expressway is oriented E/W and adjacent development appears to be primarily residential. There is no development immediately adjacent to the intersection. The speed limit at the intersection is 55 mph, although it changes to 65 mph about 1.6 miles west. The AADT to the west of the intersection is 17,200 and to the east it is 13,700. The speed limit on the exit ramp is 55 mph and the AADT is 3,770, while the AADT on the entrance ramp is 2,150 and its speed limit is 45 mph. There is a horizontal curve beginning just west of the intersection. The median is raised and it ends about 750 feet east of the east ramp terminus or about 1,600 feet east of the intersection (west terminus). To the west of the intersection the shoulders are granular; there are curbs and gutters to the east. Traffic signals are on mast arms, with a secondary signal for west-bound left-turns in the southwest quadrant. Left-turning traffic has protected plus permitted signal phasing. The intersection is lighted.

Intersection 09: Carlisle

This intersection is on Iowa Hwy 5 at Scotch Ridge Road. The expressway is oriented NW/SE and the intersection appears to be the primary access to Carlisle. In the vicinity of the intersection the median is paved and there are concrete curb and gutters to the south with granular shoulders on the outside to the north of the intersection. The highway is on a slight horizontal curve through the intersection. About 130 feet to the northeast Scotch Ridge Road forms a T-intersection with a frontage road, identified in GIMS as old State Road 983 that runs parallel to Hwy 5. There is a skewed intersection with 8th Street about 900 feet to the southeast of the intersection. There is a median break with driveways on both sides about 1,300 feet northwest of the intersection. According to the GIMS data base the speed limit at the intersection is 55 mph, although the video log shows 40 mph speed limit signs to the north and south of the intersection. The 55-mph speed zone appears to be about 1/3 of a mile north of the intersection. Iowa Hwy 5, just about 3 miles to the northwest, is fully access controlled and has a 65 mph speed limit. The AADT on Iowa 5 is 9,100 to the southeast and 11,500 to the northwest. The AADT on Scotch Ridge Road is 3,690 to the northeast and 1,470 to the southwest. The roadway (to the south) and intersection are lighted. Traffic signals are on mast arms and the left-turn signal phasing appears to be protected plus permitted. There are pedestrian signals for traffic

crossing the expressway. Approaching the intersection from the (route) north, there is a crest vertical curve about a ¼ mile to the north that obstructs the view of the signal heads.

Intersection 10: Waterloo

This intersection is on Broadway Street at Wagner Road. Broadway is on a horizontal curve through the intersection, which is also skewed. To the west Broadway has a depressed median, while to the east the median appears to be paved. The intersection is about ½ mile east of an interchange with US 218, where Broadway ends. There are industries on the south side of Broadway at the intersection with access from Wagner Road about 300 feet south of Broadway. The north side of the highway is undeveloped. An intersection about 330 feet north of the study intersection provides access to a road that parallels the railroad just north of Broadway. The speed limit on Broadway is 55 mph, with the AADT to the east being 8,500 and to the west being 10,000. The north approach on Wagner Road has an AADT of 2,610 and a speed limit of 35 mph. To the south the speed limit is 25 mph and the AADT is 420.

Intersection 11: Muscatine

The intersection is on US 61 at Mulberry Avenue. US 61 is oriented NE/SW and it has a horizontal curve about 800 feet to the SW of the intersection. There is a narrow grass median to the NE and SW of the intersection, although the median at the intersection appears to be raised. The speed limit on US 61 is 55 mph at this location and the AADT is 14,700. The speed limit on Mulberry at this location is 35 mph and the AADT is 3,160. There is a median break about 1,200 feet to the NE of the intersection, with a driveway evident on the aerial imagery. Shoulders are granular. There is an advance street guide sign ¼ ahead of the intersection for both north-bound and south-bound traffic. There is another median break about 1,320 feet to the SW of the intersection, apparently to field entrances. An E/W crossroad forms a T-intersection with Mulberry about 450 feet NW of the expressway. On the SE side of the intersection there is an industrial driveway coming off of Mulberry, about 540 feet from US 61 and heading to the NE. There are advance warning flashers for US 61 traffic, with signs warning drivers to be prepared to stop when flashing; two are located about 1/8 mile ahead and a third is located at the beginning of the turn bays. There are left and right turn lanes for US 61 traffic. The intersection is lighted. Traffic signals are on mast arms, with secondary indications on the poles. Left-turns on US 61 appear to be protected plus permitted. There is an apartment complex to the east and a little north of the intersection.

Intersection 12: Cedar Falls

The intersection is on Iowa Hwy 58, at Viking Road. Iowa 58 is oriented N/S at the intersection, although there is a horizontal curve about 350 feet to the north. The speed limit on Iowa 58 at the intersection is 55 mph and the ADT is 15,500. There are narrow paved medians at the intersection on Iowa 58, with left-turn lanes N and S. The southbound approach appears to have a dedicated right-turn lane. There is a wide sidewalk or trail on the east side and roughly parallel to Iowa 58. Viking Road is oriented E/W on tangent alignment. The speed limit on Viking Road is 45 mph and the AADT is 1,900. The SE quadrant appears to be farm ground, with the

farmstead apparently having access to Iowa 58. There does not appear to be any other access to Iowa 58. There are businesses or industries on the west side of the expressway, with access via backage roads intersecting Viking Road about 500 feet west of the expressway. There is a large building and parking lot in the NE quadrant of the intersection, with its access off of Viking Road about 650 east of the intersection.