Research Report
KTC-08-09/SPR 328-07-1I

KENTUCKY TRANSPORTATION CENTER

OPERATIONAL AND SAFETY EFFICIENCY OF TRAFFIC SIGNAL INSTALLATIONS

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OPERATIONAL AND SAFETY EFFICIENCY OF TRAFFIC SIGNAL INSTALLATIONS

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May 2008

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EXECUTIVE SUMMARY

The basic principle of signalization is the provision of a safe and effective means for time and space allocation at an intersection for both vehicular and pedestrian needs. The safety community concurs on the fact that there is the potential for safety improvements after signalization of an intersection, but there is a great disagreement on their magnitude as well as their potential negative operational impacts. This research reviewed the safety and operational efficiency after the installation of traffic signals at several locations throughout Kentucky. The report presented here mainly addresses the operational impacts from signal installation, since the safety aspects were addressed in a separate report.

This part of the study evaluated a subset of 32 intersections for which detailed traffic volumes were available for the before and after conditions. The basic premise that traffic signals that do not meet the appropriate warrants will have negative operational effects and have the potential for creating safety hazards was supported by the data. Overall, the analysis showed that traffic signal installations will tend to increase delays and create a lower operational efficiency than under the stop control conditions. This was more apparent for the intersections that did not meet any warrants.

The safety analysis for these intersections also showed that for unwarranted intersections safety will decrease. The only group that showed any safety improvements were those intersections where the volume and crash warrant were met indicating that the signal installation was appropriate. It is possible that there are conditions and turning volume combinations that separation of traffic movements and conflicting movements may be needed. It is therefore imperative that other options be evaluated along with the potential for signal installation in order to properly and effectively address the intersection design and requirements.

It is apparent that a more thorough review and study of the alternative options is needed prior to recommending a signal installation where not only the MUTCD warrants are to be evaluated but additional options (do nothing and roundabout) should be evaluated.

INTRODUCTION

Traffic signs and signals are the typical traffic control devices that regulate traffic flow through an intersection. Based on vehicular demands, pedestrian needs, safety concerns, and system requirements, intersections may be signalized. Therefore, the basic principle of the signalization is the provision of a safe and effective means for time and space allocation at an intersection for both vehicular and pedestrian needs.

To signalize an intersection, certain warrants need to be met. A series of such warrants have been developed since the 1920's and most of them deal with vehicular flows. Currently, the Manual on Uniform Traffic Control Devices (MUTCD) provides eight warrants that govern the installation of a traffic signal reflecting current thinking and views regarding travel patterns and traffic flows (1). A basic assumption for the installation of a traffic signal is that the overall safety and/or operation of the intersection will be improved. Warrant 7 also indicates "*1. Adequate trial of alternatives with satisfactory observance and enforcement has failed to reduce the crash frequency.*"(1) Therefore, the installation of a traffic signal should not only improve the safety level of an intersection, but it should also improve it at a level higher than what other measures, non-traffic signal related, would have accomplished. Past research has shown a variety of expected improvements after the installation of a traffic signal or the use of sign control. The installation of a traffic signal will result in a general reduction of crashes, but specific types of crashes, such as right angle and left-turn related crashes, are likely to be reduced more, while other types, such as rear-end, are more likely to increase (2, 3). Therefore, a decision maker should be able to identify associated benefits and costs from traffic signal installations in order to determine their applicability for the existing conditions.

The safety community concurs with the fact that there is the potential for safety improvements after signalization of an intersection but there is a great disagreement on the magnitude of such improvements. Another area of concern is the potential negative operational impacts of signal installations. There is a large number of factors that can influence both safety and operational efficiency after signalization that make the estimation of their efficacy difficult if not impossible. Factors that can affect safety and operational levels at an intersection include past crash history, type of installed traffic control, geometric features of the intersections, and geometric changes with the introduction of the new traffic control. All of these factors need to be considered when determining the efficacy of a traffic signal installation.

Despite the considerable knowledge that has been gained regarding safety and operational issues at intersections and how they relate to the traffic control device used, it is clear that further research should be undertaken. This research reviewed the safety and operational efficiency after the installation of traffic signals at several locations throughout Kentucky. The report presented here mainly addresses the operational impacts from signal installation, since the safety aspects were addressed in a separate report (4).

LITERATURE REVIEW

The typical traffic control devices that regulate traffic flow through an intersection are traffic signs and traffic signals. The first step taken towards intersection control is the use of traffic signs--two-way or four-way stop signs. Based on vehicular demands, pedestrian needs, safety concerns, and system requirements, intersections may be signalized. Therefore, the basic principle of the signalization is the provision of a safe and effective means for time and space allocation at an intersection for both vehicular and pedestrian needs.

Several studies have been completed that attempted to estimate the safety effects of signalizing an intersection. In the 1980's many simple before and after studies were conducted aiming to determine how a new signal affects safety. In the 1990's, the focus shifted in the development of models that could predict safety and operational efficiency at signalized intersections. In recent years efforts have concentrated on the statistical concepts of these models aiming to improve the modeling and predictions of both safety and operational performance of the intersections.

The early studies on the safety effects of intersection signalization simply analyzed the before and after crash data focusing either on intersections in specific cities or conduction statewide comparisons. Shen (5) conducted one of these studies using data from Washington D.C in 1984. Using data from 12 intersections and crash history of three years before and after data, he showed an overall safety improvement after the installation of the traffic signals. The study noted that most of the signals were installed without meeting the warrants and were installed because the citizens demanded the installation of traffic signals based on the assumption that signals will address all safety issues at these intersections. This study also documented that specific crash types increase (rear end crashes increased by 41.4%) while others decrease (right angle decreased by 34.8% and sideswipe by 40%). He also demonstrated that the severity of the crashes reduced with an overall injury decrease of 22.7%. Shen concludes that while the installation of a warranted signal does not necessarily reduce the overall number of crashes, their severity decreases. Most of the signals were installed to accommodate traffic due to the opening of a METRO station and he associated the increase in the number of crashes to the increase of volume around these areas.

While Shen's study focused on just the city of Washington D.C., others deemed appropriate to examine such safety issues statewide. Craven conducted a study in 1986 that focused on intersections in the state of Illinois (6). The study focused on evaluating the relative effectiveness of three different improvements at intersections: 1. signal installation; 2. signal upgrading; and 3. signal upgrading with intersection improvements. To conduct this evaluation he used two years of before data and two years of after data. The signalization of intersections was part of the Hazard Elimination Safety Program (HES) with 33 of 52 projects involving traffic signals. For all 52 projects, the crash rate was decreased by 44% after improvements. The 33 projects involving some type of traffic signal improvements had a decrease in 36%. These were split into the three types of improvements to determine their relative efficiency. Intersections with new signals showed a 45% decrease. Most of the projects (24 of the 33) involved signal upgrading that resulted in a decrease in crashes between 10% and 40% with an overall reduction of 25%. Finally, the third group (with only four intersections), where geometric designs were implemented, the safety gains were the greatest—a 68% decrease. Craven did not examine the effect of signal changes on specific types of crashes. However, he concluded that, in general, there was usually a decrease in crashes after signal installation. He found that the reduction varied significantly between intersections, proving that each intersection is different when it comes to the installation or upgrading of a signal.

Another statewide study used Michigan data with signals installed between 1978 and 1983 (7). The data collected included signal timing permits for the intersections, geometric information from installation diagrams, average daily traffic, and crash history. The before and after crash rates were compared using the paired t-test to test whether the change was significant. The statistical tests showed that there were safety differences due to the signal installation. The total crash rates were decreased by 19 percent while injury rates accident rate decreased by 17 percent. The study also showed that rear-end crashes increased by 53 percent and head-on left turn crashes increased by 50 percent while right angle crash rates were decreased by 57 percent. Crashes at intersections that just had new signals installed with no changes in geometry were also evaluated separately. The results were similar but the actual percent decrease or increase was smaller.

Pernia et al (8) conducted a more in-depth study using signal installations in Florida. The study examined only intersections with newly installed signals as the only improvement to create a more consistent data set with no other variables. The study was conducted on 502 recently installed traffic signals in Florida between the years 1990 and 1997. A three year period for before and after the installation was used to evaluate crash history excluding the 12-month data after the signal installation to avoid any acclimatization effects. An annual number of crashes was considered for the study and models were developed to determine the effects of signalization on the crash patterns of the intersection. The results showed that the total number of crashes increased by 21 percent while both rear-end crashes and crash rates were increased (102 percent and 82 percent, respectively). However, angle crashes showed as 14 percent decrease for number of crashes and 29 percent for crash rate. Similarly, left turn crashes were decreased by 17 percent and crash rates by 28 percent. This study also examined the crash severity. The results showed that the number of fatal crashes was decreased by 13.2 percent and fatal crash rates decreased by 38 percent. On the other hand, injury crashes increased by 17 percent and non-injury number of crashes and crash rates increased by 30 and 15 percent, respectively.

The main finding of this study was that a newly installed traffic signal will decrease the number of angle and left turn crashes, but increase rear-end crashes and number of crashes overall. However the number of fatal crashes decreases with a newly installed signal, while increasing minor injury crashes. There seems to be a trade-off between increasing the number of overall crashes, but as a whole making the crash type safer. The findings of this study contrast the results of the earlier studies in that it demonstrated that the total number of crashes actually increases with the installation of a new signal; however, the crash severity was reduced. This shows that a new signal may in fact increase the number of crashes, but at the benefit of reducing the number of fatalities and severe injuries.

With the general effects that installing a new signal at an intersection will have being known, studies in recent years have changed their focus towards creating specific models that will allow for estimating the safety consequences form signal installations. Abdel Aty and Keller developed a model for predicting overall and specific crash severity at signalized intersections (9). This study explores the hypothesis that crash injury levels are affected by both crash-specific and intersection specific variables. Using Florida data, a total of 832 intersections were considered with 33,592 crashes. The variables found that affect crash severity and type at an intersection included the roadway geometry, such as number of through lanes on the major and minor roads, the number of left turn lanes in all directions, presence of right turn only lanes, presence of a median, the speed limits on both the major and minor road, the average daily traffic on both roads. The models developed predict the severity of the crash using geometric features of the roadways and crash type. The models also included location specific variables that limit their transferability and require calibration for usage in other areas.

Throughout the years there has been an increased focus on determining the effects of signalizing an intersection. From the early before and after studies of the 1980's to the statistical models developed in the 2000's the main goal has always been the estimation of the safety changes due to the signalization. With the ever increasing focus in this area, even better and more accurate models will be developed to even further increase the safety of our roadways.

Despite the considerable knowledge that has been gained regarding safety problems at intersections due to signalization, the operational effectiveness of these signalizations has not been examined and no work has been identified that actually compares the operational effectiveness of signal installations. It is therefore clear that such research should be undertaken. In general, it is assumed that operational efficiency will improve but this has not been documented or demonstrated.

METHODOLOGY

The objective of this study was to evaluate the operational effects of signalizing intersections and determine whether any additional factors should be considered while determining whether an intersection should be signalized. To achieve this objective, intersections where signals were recently installed were to be considered and an operational analysis was required to determine the efficacy of signal installations.

Signals that were installed on state-maintained routes in Kentucky between 2002 and 2004 were identified. Traffic signal installations were limited to these years to allow for an adequate before and after crash analysis. Traffic signals that were installed as part of new developments were excluded, since no before crash data was available for these locations. Once each location was identified, the pertinent files were retrieved to determine the reasons for the installation as well as to identify the documentation of any warrants used for the signal installation. A review of the warrants was completed to determine whether the signal was warranted.

The operational analysis of an intersection utilizes hourly volumes and turning movements. It is therefore important that this data is available before the signalization in order to allow for estimating the level of service of the intersection. The after data could be easily collected if not available and therefore this was of no significant concern. Obviously, the timing plans of the signal are also required to complete the analysis as well as the intersection geometry. All these were either supplied by the various District Offices of the Kentucky Transportation Cabinet or collected in the field.

The approach to be followed was to first estimate the level of service (overall intersection delay) for the current conditions, i.e. under signal operation. The next step involved the estimation of the level of service under sign control using the same (current) volumes and intersection geometry. The comparison between these two estimates would provide an indication of the operational efficiency of the signal installation. In addition to the overall intersection delay, average delays by approach should also be examined to determine the relative effects of the signalization on each approach. An assumption on the benefits of signalization is that a more equitable distribution of delays among the approaches could be achieved and a reduction of the delays for the approaches that were previously controlled by a stop sign could be noted. Therefore, this comparison could provide a more meaningful evaluation of the before/after conditions.

A total of 89 intersections were initially identified where a traffic signal had been installed and the relevant warrants could be determined. Volume data (hourly and turning movements) was available for 33 intersections. A list of these intersections and the type of warrants met are given in Appendix A. Traffic signal information was obtained for each of these intersections and the Highway Capacity Software (HCS) was used to estimate the level of service for the signalized and unsignalized operations. The average intersection delay is used for most of the comparisons. This estimate is obtained directly from the HCS for signalized intersections, while for the unsignalized this is computed as the weighted average of the individual movement delays obtained from the HCS.

RESULTS

The warrant analysis indicates that among the 33 intersections there were four that were unwarranted while the remaining 29 met a combination of warrants. All warranted signals met a volume-related warrant while seven (22 percent) met the crash warrant. It is apparent that not all warrants need to be reviewed at each location and this was true for most of the locations examined here.

The overall intersection delays for each of the locations considered is summarized in Table 1. There are two “After” delays in the table denoting the delays from the signal operation in current conditions (After-S) and those assuming that a sign control would have been in effect (After-U). The data indicate that overall the delays increased with the installation of the signal. This was an anticipated result; since the signal will increase delays for the movements that had no control before while will reduce the delays for the approaches with the stop sign. There was a wide range of values representing increases of only a few seconds (2 sec/veh) to large delays (150 sec/veh). The data for the four unwarranted intersections shows that delays increased for all but one. Finally, there were three intersections that the delays decreased as a result of the signal installation as compared to the stop control.

An examination of the before and after peak hour volumes presented in Table 1 indicates that for most intersections the volumes remain, in general, unchanged. Approximately one third (11 of 32) of the intersections showed a reduction in traffic volumes in the PM peak period and five of these were new installations where the before volumes were most likely overestimated. For the remaining intersections with the increase in volumes most had a relatively small increase over time (under 10 percent) indicating a small change in the traffic patterns. The absence of any significant volume changes over time combined with the observation that the delays increased overall with the signal installation are indicative that sometimes signals, even warranted ones, will not improve the operational efficiency of the intersection.

Table 1 Intersection delays, before and after signalization

ID	Location	County	Warrant	Volume (vph) Before	Volume (vph) After	Delays (sec/veh) Before	Delays (sec/veh) After-S[1]	Delays (sec/veh) After-U[2]
1*	US 127 B @Bellerive	Anderson	Yes	2473	1688	59.58	21.1	10.74
2	US 62 @ Robert B. Turner/Westwood	Boone	No	534	560	0.57	165.8	0.82
6	KY 237 @ Rogers Lane	Boyle	Yes	1040	1200	5.50	38.3	3.43
8	US 150B @ Daniel Drive	Carroll	Yes	1470	1443	4.40	11	8.67
12	KY 227 @ KY 36	Christian	Yes	1211	1324	1.84	6.5	1.52
14	US 41 @ Murray State Ext. Campus	Christian	No	1412	1372	0.11	10.5	0.14
15	US 41A @ Bradford Sqr. Mall Entr.	Daviess	Yes	2208	2214	12.21	71.8	21.81
19	KY 2698 @ Unifirst Drive	Daviess	No	1576	1780	5.95	17.7	60.48
20	KY 2698 @ Tamarck Road	Daviess	Yes	1073	1300	7.70	19.5	20.31
21*	US 431 @ Home Depot Entrance	Fayette	Yes	1506	1088	68.04	16.1	8.70
23	US 25 @ Sandersville Road	Fayette	Yes	1889	2012	25.35	34.3	17.40
24	US 27 @ Old Paris Pike	Fayette	Yes	2172	2386	24.18	58.9	1.00
25	US 421 @ Ruffian Way	Hardin	Yes	809	1236	6.15	12.5	3.88
34	KY 251 @ Panther Lane	Jefferson	Yes	1568	1918	26.49	363.4	9.00
40*	KY 1065 @ Vaughn Mill Road	Jefferson	Yes	2205	1602	5.49	175	37.55
41	KY 1230 @ KY 1934	Jefferson	Yes	1501	1560	10.45	81.6	28.22
43*	KY 1747 @ Home Depot/Target Entr.	Jefferson	Yes	2696	2690	33.97	66.3	14.71
45	KY 3084 @ Nelson Miller Pkwy.	Jefferson	Yes	1563	1644	93.95	86.9	2.04
46*	KY 61 @ Interchange Dr.	Jefferson	Yes	3784	3250	16.43	1841	0.11
47*	KY 864 @ Jefferson Blvd.	Jefferson	Yes	NA	1444	--	246.6	191.27
48	KY 913 @ Plantside Drive	Jefferson	Yes	1611	2842	62.22	161.2	26.05
49	US 42 @ KY 329	Jefferson	Yes	1876	2162	7.19	9.9	14.91
52	KY 321 @ Federal Drive	Johnson	Yes	1374	1416	1.22	36	0.54
55*	KY 17 @ Old KY 17	Kenton	Yes	NA	2411	--	16.1	115.28
58	US 23 @ KY 2565	Lawrence	Yes	815	772	14.13	443.2	12.17
59	KY 52 @ KY 977	Madison	Yes	998	1186	1.63	26.1	2.66
60	US 25 @ KY 1986	Madison	Yes	1759	1834	2.42	17.6	1.31
61	US 25X @ Boggs Lane/Morrow Drive	Madison	Yes	1575	1582	1.60	30.7	2.63
62	US 68 @ Warehouse Drive	Marion	No	1894	1807	0.15	24.9	0.23
67	KY 686 @ Old Owingsville Rd	Montgomery	Yes	1039	1026	6.68	15.6	9.71
78	KY 55 @ KY 43/KY 2268	Shelby	Yes	888	1140	4.24	27.3	8.59
79	US 60 @ KY 1848	Shelby	Yes	1176	1144	39.71	248.3	2.15

Notes: 1. Delay is computed for signalized intersection
2. Delay is computed for unsignalized intersection
* Intersection is new, before volume is either estimated or not available

As noted in the previous section, a parallel evaluation should be conducted to determine whether the signal installation had specific impacts on the operational efficiency on particular approaches. The basic assumption here is that the signal operation will negatively impact the approaches that were not controlled by a sign while improving those that were sign controlled. The data in Table 2 supports this concept in general. For all approaches along the major road, the delays will increase with the signal installation (After-S) comparatively to the delays that would be present if a signal was not installed (After-U). The reverse assumption did not hold for all intersections. There were 13 of the 32 intersections where delay reductions were observed with the signal installation while the remaining 19 showed an increase.

Table 2 Delays by approach with and without signal installation

	Road Delay (sec/veh)			
	Minor		Major	
ID	After-U[1]	After-S[2]	After-U[1]	After-S[2]
1*	53.02	52.29	0.63	13.44
2	5.68	11.53	0.32	189.38
6	11.96	77.30	1.37	33.03
8	54.08	32.07	0.54	7.11
12	13.56	58.00	0.73	3.16
14	7.27	36.33	0.08	10.26
15	199.11	35.56	0.86	74.65
19	408.16	37.64	1.00	13.88
20	87.54	50.14	2.34	12.03
21*	29.42	22.24	0.88	13.66
23	118.16	34.67	0.70	34.20
24	0.00	42.70	1.29	63.58
25	39.03	38.19	0.82	9.64
34	0.98	6.39	11.73	572.88
40*	106.23	17.44	1.74	293.26
41	226.43	550.40	0.41	8.44
43*	124.97	43.67	0.46	69.84
45	0.38	79.30	3.90	89.80
46*	20.70	1970.00	0.11	238.34
47*	221.44	284.27	5.79	64.99
48	90.09	515.63	0.48	25.53
49	313.31	39.80	0.13	8.37
52	2.82	39.21	0.33	35.84
55*	941.58	65.10	0.09	8.84
58	6.75	2006.00	13.59	20.41
59	13.07	7.80	1.10	33.82
60	4.98	74.32	0.77	8.96
61	5.97	32.30	1.56	30.37
62	4.77	25.40	0.00	24.95
67	22.67	26.63	1.01	8.69
78	22.14	64.66	0.91	6.63
79	4.63	7.67	1.07	369.47

Notes: 1. Delay is computed for signalized intersection
2. Delay is computed for unsignalized intersection

* Intersection is new, before volume is either estimated or not available

The availability of traffic counts for the before and after conditions also allowed for the estimation of crash rates. This analysis complements the previous crash evaluation conducted for this report and provides a more accurate evaluation of the safety implications from the signal installation, albeit for a smaller subset than in the earlier report (X). The crash rate is computed as the number of crashes per 100 million vehicles entering the intersection. It was assumed that the PM peak period volume represents 12 percent for the average daily traffic based on the estimates provided in the Green Book for urban areas. There were 25 intersections that had available before data and were considered in this part of the analysis. The intersections were grouped in three categories based on whether and which warrants were met. There were 4 unwarranted intersections, 14 warranted with one or combination of the volume warrants, and 7 intersections where volume and crash warrants were met.

The data in Table 3 provides some clear patterns for two of these categories: unwarranted and crash warranted intersections. All unwarranted intersections showed an increase in crash rates and there were two intersections with no prior crash history but with a crash rate after the installation. Another among these intersections showed a very small increase (2 crashes or 3 percent increase) while the fourth showed a significant increase (3 times more crashes). A different pattern was observed for the intersections that met the crash warrant. All these intersections showed an overall reduction in crashes with substantial reductions ranging from 22 to 88 percent. Finally, the third group with intersections where only some volume warrant was met showed mixed results with one half of the intersections exhibiting an increase while the remaining showed a decrease.

Table 3 Crash rates per intersection

ID	Warranted	Crash Rate (per 100 mill. veh)			Percent Change
		Before	After	Difference	
2	No	0.00	19.57	19.57	--
14	No	7.76	23.96	16.20	208.8
19	No	62.58	64.65	2.06	3.3
62	No	0.00	45.49	45.49	--
6	Volume	110.64	123.29	12.64	11.4
8	Volume	22.37	39.87	17.51	78.2
12	Volume	101.81	49.66	-52.14	-51.2
15	Volume	59.56	44.55	-15.01	-25.2
20	Volume	15.32	50.58	35.26	230.2
23	Volume	34.81	36.77	1.96	5.6
25	Volume	40.64	19.95	-20.69	-50.9
45	Volume	0.00	0.00	0.00	--
49	Volume	74.48	35.48	-39.00	-52.4
52	Volume	127.61	92.87	-34.74	-27.2
59	Volume	115.30	76.23	-39.07	-33.9
60	Volume	56.07	119.51	63.44	113.1
61	Volume	83.50	62.35	-21.15	-25.3
78	Volume	129.58	144.20	14.61	11.3
24	Volume & Crash	131.18	101.05	-30.13	-23.0
34	Volume & Crash	115.32	51.42	-63.90	-55.4
41	Volume & Crash	93.09	10.54	-82.55	-88.7
48	Volume & Crash	132.65	23.14	-109.51	-82.6
58	Volume & Crash	161.36	21.29	-140.06	-86.8
67	Volume & Crash	221.50	96.13	-125.37	-56.6
79	Volume & Crash	153.76	51.73	-102.03	-66.4

A statistical analysis performed for each category using the Student's t-test at the 95-percent level of confidence validated the observations noted above. The tests showed that the crashes indeed increased at the unwarranted intersections ($p=0.05$), decreased at those that met the crash warrant ($p=0.001$) and were the same (i.e. no difference before and after) at the volume only warranted intersections ($p=0.27$). This is further support that the installation of the signals did not improve the conditions (both safety and operations) with the exception of only at those locations where the crash and volume warrants were met.

CONCLUSIONS

This part of the study evaluated a subset of intersections for which detailed traffic volumes were available for the before and after conditions. The after volumes were collected for the PM peak at 32 intersections and this process allowed for estimating the delay conditions for each intersection with and without the signal installation. The basic premise is that traffic signals that do not meet the appropriate warrants will have negative operational effects and have the potential for creating safety hazards.

The data evaluated here for these intersections in general supports this premise. The operational efficiency of these intersections seemed to deteriorate, i.e. higher delays were noted in general that could be attributed to the signal installation. This was apparent with the comparisons between the current conditions and the hypothetical scenario where the intersections currently operate as unsignalized. A balancing concept on such increase in delays is the potential for a more equitable delay among all approaches, where the stop controlled movements will reduce their delays. This assumption did not hold showing that more (19 of 32) intersections will have higher delays at the minor approach after the signal installation. Overall, the analysis conducted here points out that traffic signal installations will tend to increase delays and create a lower operational efficiency than under the stop control conditions. This was more apparent for the intersections that did not meet any warrants.

The safety analysis for these intersections also showed that for unwarranted intersections safety will decrease. The only group that showed any safety improvements were those intersections where the volume and crash warrant were met indicating that the signal installation was indeed appropriate. For those intersections where the volume warrant was met, there was no safety improvement. This supports the basic assumption that signal installation based on volumes only will probably have no effect on safety. An analysis of crash severity was not feasible for these intersections and thus this impact of signal installation could not be evaluated.

An aspect that was not addressed in this research is the potential alternatives that exist to signal installation. It is apparent that even though the operation efficiency of the intersection under sign control is preferable to signal installation, there are conditions and turning volume combinations that separation of traffic movements and conflicting movements may be needed. It is therefore imperative that other options be evaluated along with the potential for signal installation in order to properly and effectively address the intersection design and requirements.

In general, the findings of the study are in agreement with prior literature regarding the operational and safety implications from traffic signal installations. It is apparent that a more thorough review and study of the alternative options is needed prior to recommending a signal installation where not only the MUTCD warrants are to be evaluated but additional options (do nothing and roundabout) should be evaluated.

This study underscores the need for detailed evaluation of all possible design options to better determine the most appropriate traffic control for each intersection.

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