IMPROVING THE SAFETY OF LEFT-TURN OPERATIONS AT SIGNALIZED INTERSECTIONS FOR HIGH-RISK GROUPS

FINAL PROJECT REPORT

by

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Improving the Safety of Left-Turn Operations at Signalized Intersections for High-Risk	July 2018
	6. Performing Organization Code
7. Author(s) Angel Gonzalez and Ahmed Abdel-Rahim	8. Performing Organization Report No.
9. Performing Organization Name and Address National Institute for Advanced Transportation Technology (NIATT), University of Idaho 875 Perimeter Drive, MS 0901, Moscow, Idaho 83844-0901	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Pacific Northwest Transportation Consortium (PACTRANS) University of Washington More Hall 112, Box 352700 Seattle, WA 98195-2700	13. Type of Report and Period Covered
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A total of 1,062 left-turn related crashes at signalized intersections in Idaho (2006-2015) were analyzed to document the underlying factors that affect left-turn crashes and to identify crash types that prevail among different driver groups. Comparative analysis was conducted to compare the characteristics of intersections at which frequent crashes occurred and those at which few crashes occurred to identify intersection design and control elements that might have contributed to left-turn crashes.

The research results showed that no significant difference in left-turn crashes between intersections that used a flashing yellow arrow and intersections that used a doghouse left-turn signal display. The study results suggested that there is there is a need for more emphasis on left-turn permissive operations at signalized intersections in teen driver education programs, as teen drivers represent the most vulnerable group. Protected-only left-turn operations at signalized intersections on routes and in neighborhoods with greater numbers of mature drivers can eliminate significant portion of mature drivers' left-turn related crashes. Protected-only left-turn operations at signalized intersections during inclement weather conditions can eliminate a significant portion of the 8 percent of the crashes that occur during inclement weather.

17. Key Words	18. Distribution Statement
Safety, Signalized Intersections, Left-Turn, mature drivers,	No restrictions. Copies available from PACTRANS: www.pactrans.org

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	13	NA

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ACKNOWLEDGMENTS

The authors would like to acknowledge the Idaho Transportation Department's Office of Highway Operations and Safety staff for their continuing support and guidance throughout this study and for providing the data used in the analysis.

EXECUTIVE SUMMARY

A total of 1,062 left-turn related crashes at signalized intersections in Idaho (2006-2015) were analyzed to document the underlying factors that affect left-turn crashes and to identify crash types that prevail among different driver groups. Comparative analysis was conducted to compare the characteristics of intersections at which frequent crashes occur and those at which few crashes occur to identify intersection design and control elements that might have contributed to left-turn crashes.

An analysis of the 2006-2015 left-turn related crashes at signalized intersections in Idaho revealed the following:

- There was no statistical correlation between the type of left-turn signal display (doghouse versus flashing yellow arrow) and the frequency and severity of left-turn crashes at signalized intersection approaches.
- There was no statistical correlation between the city population and the frequency and severity of left-turn crashes at signalized intersection approaches.
- Younger drivers in Idaho were found to be the most vulnerable driver group to left-turn crashes at signalized intersection approaches. Mature drivers (older than 75) were the second highest risk group.
- Driver impairment was not a major contributing circumstance for left-turn crashes at signalized intersection approaches in Idaho.
- An analysis of 265 signalized intersections in Idaho showed that intersections that had protected-only left-turn operations showed significantly lower left-turn related crashes.

- Intersections that had lead left-turn operations had slightly better safety performance than intersections with lag left-turn operations. The difference, however, was not statistically significant.
- The majority of left-turn crashes at signalized intersections in Idaho occurred between 9:00 AM and 9:00 PM during clear or cloudy weather conditions.
- Inclement weather contributed to approximately 8.0 percent of left-turn crashes in Idaho.

The study results suggested that there is a need for more emphasis on left-turn permissive operations at signalized intersections in teen driver education programs, as teen drivers represent the most vulnerable group. Protected-only left-turn operations at signalized intersections on routes and in neighborhoods with greater numbers of mature drivers can eliminate a significant portion of mature drivers' left-turn related crashes. Protected-only left-turn operations at signalized intersections during inclement weather conditions can eliminate a significant portion of the 8 percent of crashes that occur during inclement weather.

CHAPTER 1 INTRODUCTION

Left-turn operations at signalized intersection approaches pose a safety challenge to transportation system operators. Several factors contribute to this challenge. First, at many intersections, navigating the turn path is not a trivial task, especially during night and low visibility conditions. Second, making a decision to turn left during the permissive left-turn phase requires the ability to judge gaps in the opposing traffic and the speed of oncoming traffic accurately and rapidly. Because these cognitive abilities can deteriorate for reasons of distraction, impairment, or aging, some driver groups—such as mature drivers, young inexperienced drivers, and impaired and distracted drivers—face more difficulties. This research investigated signalized intersection left-turn related crashes, and it related them to intersection geometry and signal timing characteristics.

One major issue of concern with signalized intersection control is the treatment of left-turn phasing at different approaches in the intersection. Left-turn signals can operate as protected-only operations, permissive-only operations (yielding to opposing traffic), a combination of protected–permissive operations, or as a split-phase mode of operations. Most past research and agencies' experiences have shown that protected-only operations and split-phasing operations, in which left-turn vehicles have the right-of-way, can improve safety. However, they have a negative impact on intersection operations, and the green time dedicated to left-turn phases increases the delay for other movements. Permissive left-turn operations can safely serve traffic when traffic flow is lower during off-peak periods, but during high traffic volumes they may cause some safety concerns because of the potential conflict between left-turning vehicles and opposing through-vehicles. In Idaho, approximately 42 percent of all crashes that occur at intersections throughout the state involve left-turning vehicles, even though

left-turning movements represent a disproportionately small percentage of all approach traffic (Abdel-Rahim 2015).

The signal display for left-turn movements varies on the basis of the mode of left-turn operations. For permissive-only left-turn operations, the signal display is a green ball, and the signal head can be dedicated to the left-turn lane or shared between the left-turn lane and the adjacent through-lane. For protected-only operations, the left-turn signal display is typically a signal head dedicated to the left-turn lane, with a green arrow. For protected/permissive operation, the signal display is either the five-head doghouse signal display or a flashing yellow arrow display (FYA).

The primary objective of the research presented in this paper was to investigate, on the basis of the state of Idaho's crash experience, the relationship between left-turn related crashes at signalized intersection approaches, the mode of the left-turn control used at the intersection (protected, permissive, or permissive-protected), and the left-turn signal display used at intersections that operate under protected-permissive operations (dog-house or flashing yellow arrow).

CHAPTER 2 LITERATURE REVIEW

Considerable research has focused on analyzing left-turn crashes at signalized intersection approaches. Wang and Abdel-Aty (2008a) used a series of crash injury severity models to examine left-turn crash injury severity. The authors used partial proportional odds models to identify the prominent cause of crashes. Their analysis showed increasing crash injury severity due to alcohol and/or drugs. Another important conclusion from their analysis was that approach volume and intersection volume did not have an impact on crash severity. Specific vehicle movements were found to affect crashed injury more significantly. For left-turn traffic control, the protected left-turn mode and all-red time on opposing through-movements were the two factors found to have significant influence. The study results also showed that street lights at intersections were associated with lower left-turn crash injury levels. The most significant crash-related factors identified by the study included alcohol/drug use, vehicle type, driver age, impact point, speed ratio, safety equipment, and driver ejection.

In another paper, Wang and Abdel-Aty (2008b) analyzed left-turn crashes occurring at 197 four-legged signalized intersections over sixyears. Nine different intersection operation patterns, based on vehicle maneuvers, were identified and analyzed. Generalized estimating equations (GEE) were used in the analysis, with the negative binomial as the link function. The study results confirmed the findings of other, similar research, that protected left-turn operations provide better safety performance than permissive operations.

Schattler, et. al. (2015) evaluated the safety effectiveness of the flashing yellow arrow (FYA) left-turn signal display. Crashes that involved drivers age 65 and older were analyzed separately. A total of 164 left-turn approaches were considered. FYA was used at 90 approaches, with the other 74 approaches using a standard, five-head signal display. The study results showed

that approaches with a FYA display had fewer crashes than the standard sign. The results also showed that for crashes involving drivers age 65 and older, the same level of crash reductions benefit was not realize.

Chen et. al. (2015) evaluated the safety impacts of changing the left-turn control mode from permissive-only to protected-permissive operations or to protected-only operations. The study sites included 68 intersections in New York City. The authors used a quasi-experimental design and regression modeling to compare the safety performance of the three left-turn control modes. Contradicting the results of other studies, the study results showed that changing from permissive-only operations to protected-permissive operations or protected-only operations did not significantly reduce left-turn crashes at signalized intersection approaches. However, the results showed that protected-only operations reduced both left-turn crashes and pedestrian crashes. In addition, intersections that changed to the protected-only mode of operations experienced an increase in "over-taking" crashes.

CHAPTER 3 STUDY ANALYSIS AND RESULTS

A total of 1,062 left-turn related crashes at signalized intersections in Idaho (2006-2015) were analyzed to document the underlying factors that affect left-turn crashes and to identify crash types that prevail among different driver groups. The characteristics of the signalized intersection crashes in Idaho are presented in table 3.1 through table 3.4 and in figure 3.1.

As can be seen in table 1, the majority of crashes (84.41 percent) occurred during the period from 9:00 AM to 9:00 PM, with only 15.59 percent of the crashes occurring during the night and early morning hours. This can be attributed to the fact that, at night and in the early morning, the traffic volumes for the through-movements that conflict with left-turn permissive movements are very low. Another important conclusion can be drawn from the crash contributing circumstances data presented in table 3.2. Only 2.54 percent of the crashes involved alcohol impairment. This, again, can be attributed to the lower percentages of left-turn crashes during nighttime.

The results presented in figure 3.1 show that inclement weather was a factor in less than 8 percent of the left-turn crashes that occurred at signalized intersection approaches. The majority of the crashes occurred during clear and cloudy weather conditions. Therefore, the use of a weather responsive traffic signal system that eliminates the permissive left-turn period during inclement weather could reduce left-turn crashes at signalized intersections in Idaho by up to 8 percent.

Table 3.1 Time-of-day distributions for signalized intersection left-turn crashes in Idaho

Time of the Day	Hours	Total Crashes	Percent Crashes (%)
Early afternoon	1:00 pm to 3:00 pm	190	23.69
Late Morning	9:00 am to 12:00 pm	183	22.82
Evening	6:00 pm to 9:00 pm	161	20.07
Late Afternoon	4:00 pm to 5:00 pm	143	17.83
Early Morning	5:00 am to 8:00 am	70	8.73
Night	10:00 pm to 4:00 am	55	6.86

Table 3.2 Contributing circumstances for signalized intersection left-turn crashes in Idaho

Contributing Circumstances	Total Crashes	Crash Percentage (%)
Failed to Yield	340	34.52
Failed to Obey Signal	231	23.45
Inattention	176	17.87
Improper Turn	139	14.11
Alcohol Impaired	25	2.54
Failed to Maintain Lane	23	2.34
Speed Too Fast for Condition	20	2.03
Drove Left of Center	17	1.73
Distracted	14	1.42

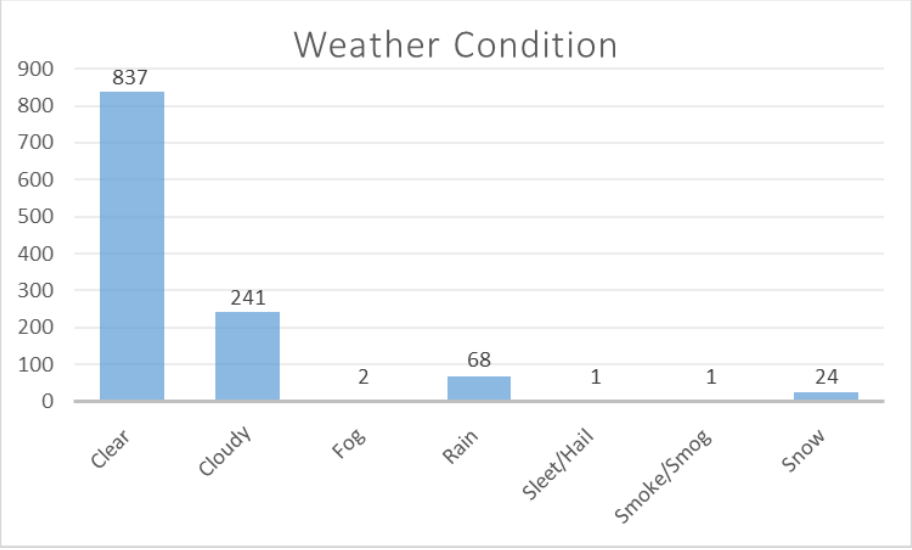

Figure 3.1 Impact of weather conditions on signalized intersection left-turn crashes in Idaho

The relative signalized intersections left-turn crash involvement rates for different age groups are presented in table 3.3. The relative crash rate for each age group was obtained by calculating the ratio between the crash involvement percentage and the percentage of registered drivers in the state for each age group. As found in several previous studies, younger drivers (under 19 years of age) have the highest representation among all other groups. The relative crash involvement rate for mature drivers (older than 74 years) was slightly higher than that of other age groups (drivers between 20-74 years old), especially for fatal and severe injury crashes. These results indicate the need to more effectively teach about left-turn permissive movements at signalized intersection approaches in teen driver education programs.

Table 3.4 lists crash frequencies and crash rates for different cities in Idaho. The city population was used to determine the relative crash rate for each city. Among the ten cities with the highest crash rates (both total crashes and fatal and severe injury crashes), in nine cities more than 82 percent of the signalized intersections operated under the permissive-only left-turn mode.

Table 3.3 Relative signalized intersection left-turn crash involvement rate for different age groups in Idaho

Age Group	Number of Crashes		Crash Involvement Percentage		Registered Drivers		Relative Crash Rate*	
	Total	Fatal and Severe injury	Total	Fatal and Severe injury	Number	Percentage	Total	Fatal and Severe injury
19 or younger	369	21	32.74	25.00	33,005	5.79	**5.66**	**4.32**
20 to 24	625	45	55.46	53.57	431,905	75.71	0.73	0.71
65 to 74	64	10	5.68	11.90	68,346	11.98	0.47	0.99
75 or older	69	8	6.12	9.52	37,184	6.52	0.94	**1.46**
Total	1127	84	100.00	100.00	570,440	100		

*Relative crash rates were computed as the percentage of crash involvement divided by the percentage of registered drivers

Table 3.4 2006-2016 Left-turn signalized intersections crashes in different cities in Idaho

City	Population	Total Crashes	Fatal crashes and A Injuries	Crash Rate (Total Crashes)	Crash Rate (Fatal crashes and A Injuries)
Garden City	10,972	24	13	2.19	1.18
Blackfoot	11,899	25	7	2.10	0.59
Idaho Falls	56,813	163	17	2.87	0.30
Moscow	23,800	11	6	0.46	0.25
Meridian	75,092	78	15	1.04	0.20
Emmett	6,557	10	1	1.53	0.15
Rexburg	25,484	49	3	1.92	0.12
Burley	10,345	34	1	3.29	0.10
Twin Falls	44,125	37	4	0.84	0.09
Coeur D Alene	44,137	76	4	1.72	0.09
Nampa	81,557	66	5	0.81	0.06
Boise	205,671	302	8	1.47	0.04
Ammon	13,816	7	0	0.51	0.00
Caldwell	46,237	26	0	0.56	0.00
Chubbuck	13,922	19	0	1.36	0.00
Eagle	19,908	11	0	0.55	0.00
Hayden	13,294	26	0	1.96	0.00
Jerome	10,890	6	0	0.55	0.00
Ketchum	2,689	5	0	1.86	0.00
Lewiston	31,894	24	0	0.75	0.00
Pocatello	54,255	110	0	2.03	0.00
Ponderay	1,137	9	0	7.92	0.00
Post Falls	27,574	22	0	0.80	0.00
Sandpoint	7,365	6	0	0.81	0.00

To further investigate the impacts of the left-turn operation modes and signal displays, 265 intersections in different cities were selected for in-depth analysis. To account for the impacts of both left-turn volumes and conflicting through-volumes, the crash rate was obtained by dividing the average left-turn daily volume by the average conflicting through-movement daily volume. For each intersection, the type of left-turn control mode (protected only, protected-permissive, or permissive-only), left-turn operation sequence (lead or lag), and the left-turn signal display for protected-permissive mode (dog-house of flashing yellow arrow) for each of the last 10 years were recorded. The results are summarized in table 3.5.

The results showed that intersections that had protected-only left-turn operations had a significantly lower number of left-turn related crashes. This was true for both total crashes and fatal and severe-injury crashes. Intersections with permissive-only operations had the highest left-turn crash rates. Again, this was true for both total crashes and fatal and severe-injury

crashes. Intersections that had lead left-turn operations had slightly better safety performance than intersections with lag left-turn operations. The difference, however, was not statistically significant at the 95 percent confidence level. Similarly, there was no statistically significant difference in left-turn crashes between the two signal display options for protected-permissive operations (dog-house) and flashing yellow arrow.

Table 3.5 Average crashes and crash rates under different left-turn signal control modes and display options

Control/Display Mode	Total Crashes		Fatal and Severe-Injury Crashes	
	Average crashes	Crash rate	Average crashes	Crash rate
Protected Only	0.19	0.063	0.04	0.001
Permissive Only	0.37	0.103	0.11	0.003
Protected-Permissive	0.28	0.090	0.07	0.005
Lead Left-turn*	0.27	0.095	0.05	0.005
Lag Left-Turn*	0.29	0.087	0.08	0.006
Dog-House Display*	0.29	0.093	0.08	0.006
Flashing Yellow Arrow Display *	0.26	0.088	0.06	0.005

*Protected Permissive mode of operations

CHAPTER 4 STUDY CONCLUSIONS

An analysis of 2006-2015 left-turn related crashes at signalized intersections in Idaho revealed the following:

- There was no statistical correlation between the type of left-turn signal display (doghouse versus flashing yellow arrow) and the frequency and severity of left-turn crashes at signalized intersection approaches.
- There was no statistical correlation between the city population and the frequency and severity of left-turn crashes at signalized intersection approaches.
- Younger drivers in Idaho were the most vulnerable to left-turn crashes at signalized intersection approaches. Mature drivers (older than 75) were the second highest risk group.
- Driver impairment was not found to be a major contributing circumstance for left-turn crashes at signalized intersection approaches in Idaho.
- An analysis of 265 signalized intersections in Idaho showed that intersections that had protected-only left-turn operations had significantly fewer left-turn related crashes.
- Intersections that had lead left-turn operations had a slightly better safety performance than intersections with lag left-turn operations. The difference, however, was not statistically significant.
- The majority of left-turn crashes at signalized intersections in Idaho occurred between 9:00 AM and 9:00 PM during clear or cloudy weather conditions.
- Inclement weather contributed to approximately 8.0 percent of left-turn crashes in Idaho.

The study results suggested that there is a need for more emphasis on left-turn permissive operations at signalized intersections in teen driver education programs, as teen drivers represent the most vulnerable group. Protected-only left-turn operations at signalized intersections on routes and in neighborhoods with higher numbers of mature drivers can eliminate significant a portion of mature drivers' left-turn related crashes. Protected-only left-turn operations at signalized intersections during inclement weather conditions can eliminate a significant portion of the 8 percent of crashes that occur during inclement weather.

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