CHANNELIZED RIGHT-TURNING LANES AT SIGNALIZED INTERSECTIONS: A REVIEW OF PRACTICE AND AN EMPIRICAL STUDY

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Civil Engineering

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2011

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ACKNOWLEDGEMENTS

I would like to thank my research advisor, Dr. Ahmed Al-Kaisy for providing appropriate insight and knowledge at all stages of my thesis, from data collection to the thesis organization. I also want to thank Dr. Patrick McGowen and Dr. David Veneziano for serving on my committee and being available to assist where needed.

Next I would like to thank the Western Transportation Institute for funding my project. The financial support I received provided me with all the resources necessary in completing this thesis, such as the equipment for data collection and the computers and software required for analysis.

I also want to thank my family and friends for providing their support and encouragement of my continuing education. Lastly, a thank you to Kathy for her dedication in proof reading my chapters.

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ABSTRACT

This research includes a review of the current literature and practice regarding channelized lanes for right turns and the selection of an appropriate traffic control device. The main goal is to gain a better understanding of channelized right-turning lane guidelines used in practice and the effectiveness of a signal control device to regulate access at the channelization. This thesis presents a literature review and survey investigation into the current practice, the type of traffic control used, and the safety experience of highway agencies. Additionally an empirical study was conducted to examine the driver behavior at channelized right-turn lanes using raised (curbed) islands, where an exclusive signal control is used for the channelized traffic movement.

The literature review revealed an overall lack of knowledge concerning the operational and safety aspects of channelized right turn lanes, especially concerning the type of traffic control used. This may explain, to a large extent, the lack of guidance in practice and the broad range of behaviors demonstrated by drivers during the field investigation.

The survey results suggest a heavy reliance on engineering judgment by highway agencies in the use of channelized right-turn lanes and the selection of traffic control. Further, results confirmed a general perception in practice about the safety benefits of signal control at channelized right-turn lanes, despite the fact that such benefits were not supported in the literature.

Three study sites in the cities of Belgrade and Bozeman in southwest Montana were investigated for the empirical study with approximately seven days of data for the analysis. The three study sites used a signal as the control for the channelization. The results of the investigation showed that over half of the drivers using the channelized turn lane treated the traffic signal as a yield control, while only a very small percentage of drivers treated the situation as a signal control. Further, statistical analyses confirmed that drivers' treatment of control is influenced by light conditions, vehicle type and traffic volume.

This research emphasizes the need for further research into the safety and operational aspects of this right-turn treatment at intersections, particularly the type of control used for the channelization.

CHAPTER 1

INTRODUCTION

This chapter presents an overview of the topic, the problem statement, the impetus of the research topic and provides a summary of the thesis contents.

Background

Turning movements have an effect on the safety and operations at signalized intersections. Therefore, various methods for the treatment of turning movements have been considered in the design and operational analysis at signalized intersections.

Lower volume intersections typically involve a shared lane for the through and right-turning traffic. As traffic levels increase including the right-turning traffic, the need for providing an exclusive right-turning lane also increases. Providing exclusive right-turning lanes at signalized intersections has become common practice at newly constructed intersections and in many improvement and upgrade projects. For right-turn movements, exclusive turning lanes are mostly added parallel to through lanes and continue to the stop bar at the main intersection approach. In fewer instances, the right-turn movement is channelized from the rest of traffic on the main intersection approach using painted or curbed islands. In this treatment, right-turn traffic is channelized through a curved alignment to access the crossing street without the need to proceed to the approach stop bar or use the intersection area. For channelized right-turn lanes using curbed islands, access control for right turning vehicles could be treated in practice using

yield control, stop sign control, traffic signals, or no traffic control device (Dixon, Hibbard, & Slack, 1999).

The primary operational reasons for providing channelized right turns are to increase vehicular capacity at an intersection and to reduce delay to drivers by allowing them to turn at higher speeds and reduce unnecessary stops (Potts et al., 2005).

Channelized right-turn lanes (CRTL) using a raised (curbed) island is the focus of this research. This research is limited to the study of CRTLs at signalized intersections with particular focus on the current practice of use and the type of traffic control used for the channelization. The use of the term traffic control or signal control throughout this report refers to the type of control used for the channelization. The use of the CRTL nomenclature means separated right turning lane with an island. An illustration of a CRTL with an island is provided in Figure 1.

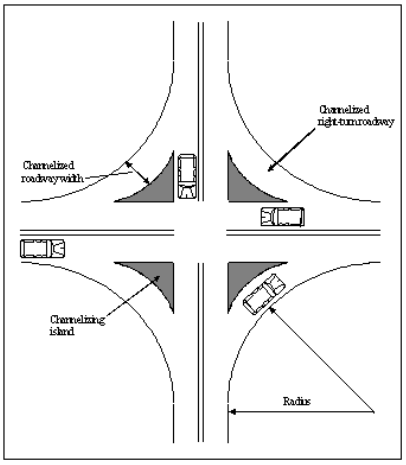


Figure 1: Intersection with CRTLs (Potts et al., 2005)

Pedestrian considerations and safety are important aspects of CRTLs, however this research provides limited coverage of pedestrian and safety issues.

Problem Statement

Historically, the left-turn movement at intersections has received much more attention than the right-turn movement as the latter involve fewer and less severe conflicts and tends to have less influence on traffic operations and safety (Perez, 1995; Hasan & Stokes, 1996). To date, research offers at best minimal evaluation of right-turn treatments at signalized intersections (Dixon et al., 1999). While the limitation in the guidance applies to all aspects of CRTLs at intersections, it is particularly true for the selection of the most appropriate type of traffic control. Drivers expect and, to a degree, anticipate certain geometric and operational situations at intersections. The channelization and traffic control used at an intersection should, as a minimum, avoid violating driver expectations, and should desirably reinforce these expectations (Potts et al., 2005). CRTLs as they are currently used may provide conflicting guidance to the driver and violate driver expectancy.

Research Objectives

The limited guidance concerning the use of CRTL and the selection of traffic control governing access to the crossing roadway was the main motivation for this research. This research has two main objectives. The first is to review the current state of practice as it relates to the use of CRTLs at signalized intersections. This includes the procedures and guidelines in place, and agencies' experience with this treatment from safety and operational perspectives. The aim is to gain a better understanding of the way

this right-turn treatment is used in practice with particular emphasis on the selection of the traffic control device used to regulate the channelized lane.

The second objective of this research is to gain a better understanding of the effectiveness of using a signal head for controlling the CRTL. Specifically, the study aims at examining drivers' reactions when they are confronted with a red signal at CRTL sites. It is believed that the use of an exclusive signal for the channelized right turn may create a confusing situation for drivers, as it may violate their expectations.

Also, the study investigates crash history records for available CRTL sites in the state of Montana.

Research Importance

The current knowledge base and experience of transportation agencies concerning right turning lanes is lacking in regard to CRTL standards and the effectiveness of the type of control used for channelization. This study will provide insight as to the perception of transportation agencies as it relates to the safety and operations of CRTL treatment. Furthermore, the study provides insight into the driver's reaction when confronted with a signal control for the channelized lane. The driver behavior at a control directly impacts the safety.

There is very little quantitative data on the performance of signal control for the channelized right turn lanes. This is one of the areas where there is need for research and investigation due to lack of National guidelines and procedures.

Scope of Work

This research is concerned with the current state of knowledge and practice concerning CRTLs with regards to safety and operations. This understanding was gained by literature review and an agency survey. The other component addressed in this research is driver behavior. The driver behavior was investigated as a field study concerning the effectiveness of signal control use at CRTLs. Lastly, the crash history in the state of Montana was reviewed anticipating insight into the safety performance of various traffic control devices. Unfortunately the data available provided insignificant results. Pedestrian and bicyclist considerations are an important aspects of CRTLs, however are outside the scope of this work.

Thesis Organization

This thesis is organized into eight chapters. Chapter 2, the literature review, will discuss the relevant research that has been conducted on the topic of CRTLs as well as current guidelines in place for practitioners.

The third chapter explains the administration and design of the survey sent to practitioners, while the fourth chapter reports on the results of the survey component.

The fifth chapter addresses the empirical study including study site descriptions and selection, and data collection and processing. The findings of the empirical study are discussed in Chapter 6.

Chapter 7 addresses the safety investigation approach and outcomes. Lastly, Chapter 8 includes major findings and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

This chapter presents an overview of CRTLs and their associated design elements, the guidance provided from national reference materials, followed by the available scholarly research regarding this treatment.

Channelized Right-Turning Lanes Design Elements

The CRTL design elements such as islands, corner radius, lane widths and storage lanes are shown in Figure 2.

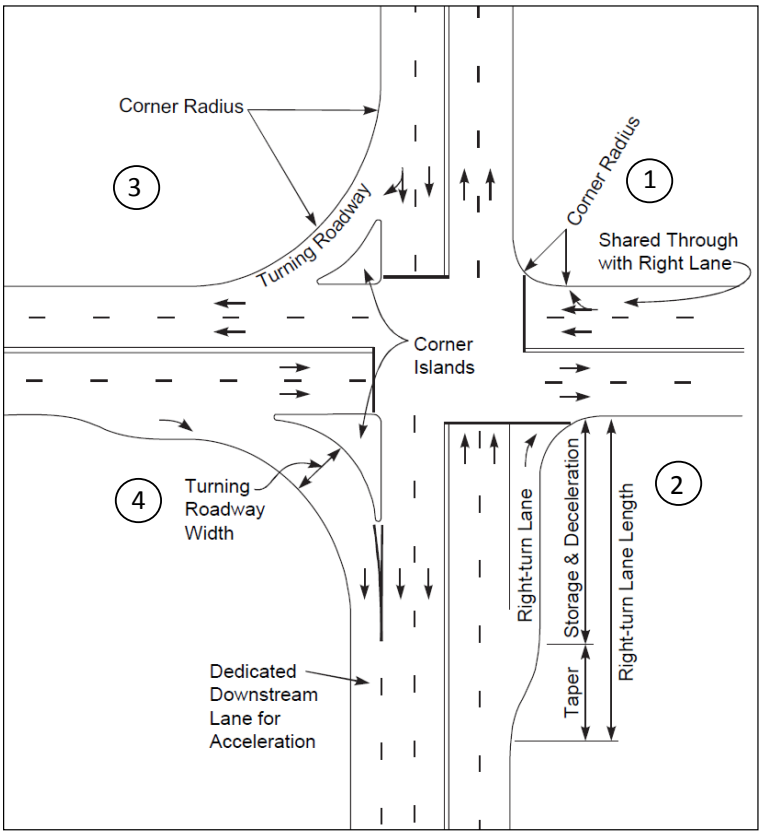


Figure 2: Channelized Right-Turning Lane Design Elements
(Fitzpatrick, Schneider, & Park., 2006)

The design components shown in Figure 2 all have significant effects on vehicle speeds, driver behavior and safety. On the other hand, traffic volumes, percentage of heavy vehicles and level of service dictate the design elements for this treatment.

Right turning lanes can either be designed with or without an island as shown in Figure 2. The west and north approaches (quadrants 3 and 4) show the use of islands and they are channelized while, the east and south approaches (quadrants 1 and 2) do not have islands as part of the turning lane design. Quadrant 1 shows a shared through and right-turn lane with no storgae. Quandrant 2 shows a right-turn lane separate from the through lane allowing for decelerating and storage. This is also known as an exclusive right turn lane without an island. Quandrant 3 shows a CRTL without deceleration or accelration lanes while, quandrant 4 shows a CRTL with a storage and a decelaration lane, and an accelartion lane.

The American Association of State Highway Transportation Officials (AASHTO) *Policy on Geometric Design of Highways and Streets,* known as the Green Book lists the three primary functions of providing an island. These functions are to channelize turning traffic, to divide traffic streams for through movements, and to provide a refuge for pedestrians (AASHTO, 2004). An island also serves several purposes such as separating conflicts, reducing excessive pavement areas (delineating vehicle path) and providing a location for traffic control devices (AASHTO, 2004).

The minimum requirements for the size of an island are also a design component consideration.

The corner radius and lane width are principal design elements of turning roadways. The radius and width affect how drivers traverse the intersection. These design components influence both the operating speed and path of a driver. The combination of the width and radius impacts the amount of pavement area required for the intersection design. As the radius and lane width increases so will the pavement area. This increase in area increases pedestrian crossing distance (and therefore crossing time). A large radius and lane width may be needed to accommodate heavy vehicle traffic. Large radius designs may be more appropriate in areas where land is more available and pedestrian volumes are low. The design of a larger radius can impose the need for an island to meet a compromise for the conflicting needs of users. The choice of design for an intersection where pedestrians are present is a particular concern and it is desirable to keep the intersection area to a minimum (AASHTO, 2004). A large corner radius influences the speed of vehicles and may cause a concern for pedestrian safety. Recommended curve radii and widths based on design vehicles are discussed in the Green Book (AASHTO, 2004).

Right turning vehicles typically need to reduce their speed. The use of a deceleration lane can reduce conflicts with higher speed through vehicles especially in high volume areas. Deceleration lanes have the additional use of providing storage for other right turning vehicles in queue. Likewise, acceleration lanes may be used for vehicles to reach the cross street operating speed particularly in high volume areas.

Pedestrians are an important consideration for turning lanes designs. The main disadvantage of this right-turn treatment is the motorists' higher speeds, which could be a

concern for pedestrian safety. For instance, channelized right-turn lanes are often designed for unimpeded vehicular movements, leaving pedestrians vulnerable to high speed vehicles. Channelized right-turn lane intersections designed to accommodate safe pedestrian crossings using tight curb radii and shorter lane widths can be less problematic to pedestrians (PBIC, 2009).

Although pedestrians are an important consideration for turning lane designs, this topic is outside the scope of work intended for this research project. A synthesis of current literature related to CRTLs was prepared as part of the NCHRP 3-72 project (Potts et al., 2005). The synthesis of information in this report includes a discussion on geometric design considerations as they relate to CRTLs for many design components. The synthesis documents current knowledge and practice concerning the advantages and disadvantages of specific design practices for channelized right turns with an emphasis on pedestrian and bicyclist needs, and particularly the needs of pedestrians with vision impairments.

Reference Material

There are many reference materials made available to traffic engineers, offering comprehensive reference on the principles and techniques in the practice of traffic engineering. These manuals provide traffic engineering standards and guidelines to be used on the highway system. This section provides an overview of the national design practice found in the various reference materials (in addition to the design elements discussed previously) used by traffic engineers and highway designers. These reference materials generally discuss the purpose, considerations and design elements of the CRTL

without addressing justifications for use or the type of traffic control used.

The type of control used has a vast impact on operations and safety, particularly traffic signals. Traffic signals are one of the most restrictive and costly forms of traffic control that can be utilized. Traffic signals should be limited to appropriate situations, hence a series of traffic signal warrants have been developed to define the minimum traffic conditions that should be present before a traffic signal is installed (Hawkins, 2008). However, similar guidelines are not in place for the type of control used for channelizing right-turn movements.

The *Manual on Uniform Traffic Control Devices* (MUTCD) is the guiding document for the selection, design, installation, operation, and maintenance of all types of traffic control devices, including traffic signals. The purpose of the MUTCD is to provide uniformity in traffic control devices across the United States. The MUTCD addresses traffic signal needs studies and the general application of yield and stop control but guidelines specific to channelized right turning lanes are not provided.

The MUTCD guidance is limited to sign (yield and stop) placement for channelized turns. This includes a section providing clarity that a sign (yield or stop) used in conjunction with a traffic control signal is allowed “if a channelized turn lane is separated from the adjacent travel lanes by an island and the channelized turn lane is not controlled by a traffic control signal”(Federal Highway Administration [FHWAa], 2009).

States have the option of adopting the national MUTCD or developing a state MUTCD or state supplement that is in substantial compliance with the national MUTCD. It is worthy to mention that the 2003 MUTCD has been adopted by all states; 25 states

with complete conformance, 20 with state supplements and 7 with substantial conformance (FHWAb, 2009). The adoption status is published on-line and prepared by the FHWA's Operations Council MUTCD Work Group. The MUTCD for 2009 has been published at the time this thesis is written, however conformance is not mandated until January of 2012.

Montana has adopted the National MUTCD, 2003 Edition, and has no state supplement according to the MUTCD adoption status posted on-line (FHWAb, 2009). The *Montana Traffic Engineering Manual* provides guidelines for exclusive right turning lanes based on the speed, number of lanes and volume of the road (MDT, 2007). The term exclusive right turning lane in this document does not necessarily mean a CRTL. There is no mention of when to make the right lane channelized or what type of control to use.

Island channelization is discussed as being useful or needed where complex signal phasing is used to aid and protect pedestrians. The *Montana Traffic Engineering Manual* discusses when to use flush islands versus a raised island for channelization . The reasons to use a raised island include:

- Locations that require positive delineation
- Primary function is to provide pedestrian refuge
- Allow space for signal installation
- Where channelization is meant to prevent traffic movements
- On low/moderate speed highways to separate high volumes of opposing traffic movements

The AASHTO *Green Book* provides guidance on the design of channelized right turns (AASHTO, 2003). The *Green Book* was the main reference source of the preceding section discussing the design elements. The policy describes the geometric design elements and criteria for turning roadways but does not give guidance as to when this type of treatment should be used, the *Green Book* also specifies that the type of traffic control used at the cross street influences the desirable angle of intersection between the right-turn roadway and the cross street. The AASHTO *Guide for the Planning, Design, and Operation of Pedestrian Facilities* recommends turning lanes to be kept as narrow as the turning path of the design vehicle will allow and be kept as close to 90 degrees as the effective turning radius will allow (AASHTO, 2004).

The Intersection Channelization Design Guide (NCHRP 279) recommends using CRTLs for the purposes of safe pedestrian refuge, safe merging for right turn movements operating under yield control or no control, and to separate right-turn merge conflicts (Neuman, 1985). It provides the most extensive discussion of considerations found for right-turn lanes but offers no quantifiable guidelines (Perez, 1995). Report 279 addresses topics such as the functional objectives of channelization, safe merging, principle of channelization and guidelines for design. Design hour volumes, right-turning rear end collisions and pedestrian crossing volumes are factors listed for justifying the use of exclusive right-turning lanes. In fact, the report states “No warrants or guidelines for exclusive right turning lanes are apparent for urban intersections” and “Previous research offers little indication of the expected safety effectiveness of exclusive right turn lanes”.

The *Traffic Engineering Handbook* (ITE, 1992) refers the user to the Intersection Channelization Design Guide for a detailed description of the techniques that have proven effective and lists nine principles of intersection channelization. It also provides warrants for right turning lanes based on daily hourly directional volumes versus right turn volumes.

The following 9 principles of channelization apply:

- Undesirable or wrong way movements should be physically discouraged.
- Desirable vehicle paths should be clearly defined.
- Desirable or safe vehicle speeds should be encouraged.
- Points of conflict should be separated if possible.
- Traffic streams should cross at right angles and merge at flat angles.
- High priority traffic movements should be facilitated.
- Desired traffic control scheme should be facilitated.
- 8. Decelerating, stopped or slow vehicles should be removed from the through traffic stream.
- 9. Provide Safe refuge for pedestrians and other non-motorized vehicle users.

Right on Red laws

The layout of CRTLs is such that it presents a different geometry than what drivers may typically encounter at an intersection approach. As a result, the behaviors exhibited by a driver are likely to differ from that recommended or anticipated by legal or guidance documents. For example, because a CRTL is essentially separated from other

intersection movements by an island, it presents drivers with more of a merging situation as opposed to a right turn on red scenario. This is further the case as a driver is typically presented with a signal control structure/indication that is separated from other signals on the approach.

The Uniform Vehicle Code (UVC) of the National Committee on Uniform Traffic Laws and Ordinances' sets forth the meanings of signal indications for both drivers and pedestrians. The guidance from this document forms the basis of the information provided by the MUTCD. Regarding red indications, of interest here, MUTCD Section 4D.04 *Meaning of Vehicular Signal Indications* states that vehicular traffic facing a steady red ball signal indication shall remain stopped until a green indication. However if the vehicle wants to make a red turn, this is permitted during a red ball signal except when a sign is in place prohibiting a turn on red or a red arrow signal indication is displayed (FHWAa, 2009). As the study sites employed in this research were located in Montana, an examination of Montana's state's code was made. Montana's Annotated Code states essentially the same guidance provided by the MUTCD (Legislative Services Division, 2009).

The text in each of these references provides basic instruction related to driver behavior when confronted with a red ball or arrow. The challenge presented by these documents is that the guidance provided has been developed for a typical signalized intersection approach scenario and does not necessarily address other distinct situations such as the CRTL treatment. For this treatment, the right turn movement is usually removed from parallel lanes and the situation more closely resembles a merging

movement, and therefore right turn on red becomes less relevant to this situation. It is important to note that right turn on red (RTOR) is permitted in the State of Montana.

Existing Research

The main reasons for providing channelized right turns are to increase vehicular capacity at an intersection and to reduce delay incurred by motorists. However, no existing data and no established methodology are available to directly compare the operational performance of urban intersections with and without channelized right turn lanes (Potts et al., 2005). Other studies in the literature specific to CRTLs have addressed topics such as the effect of skewness of CRTL intersections on driver performance (Tarawneh & McCoy, 1996), the effects of channelization on older drivers (Staplin, Lococo, & Byington, 1998) and the effects of right turn movements on traffic operations (HCM, 2000 and Stover at al., 1970).

It is also believed that right turn lanes can minimize collisions between vehicles turning right and following vehicles, particularly on high-volume and high-speed major roads or where a high number of rear-end collisions on a particular approach occur (Antonucci, Hardy, & Slack., 2004). There is limited research to verify the safety benefits and the research available is lacking in right-turning volume data.

A study in the state of Georgia concluded traffic islands appear to reduce the number of right-turn angle crashes and that the addition of an exclusive turn lane appears to correspond to an increased number of sideswipe crashes given the introduction of a lane change, however future research evaluating specific treatments using traffic volumes and varying scenarios were recommended (Dixon et al., 1999). A Texas study set out to

evaluate the safety associated with various right turn lane designs (i.e. right turn lane no island, right-turn with island, shared through right-turn lane and shared through-right turn lane with island) and to determine the variables that affect free flow speeds of turning vehicles (Fitzpatrick et al., 2006). The Texas study found the variables that affected the turning speed at an exclusive right turn with island design include corner radius, right-turn lane length, and island size at the beginning of the turn and corner radius, right-turn lane length, and turning roadway width near the middle of the turn (Fitzpatrick et al., 2006). The treatment with the highest number of crashes in a Georgia study and the second highest number of crashes in the Texas study was the right-turn lane with raised islands (Fitzpatrick et al., 2006). The Texas and Georgia studies used intersections with either yield or no control. The use of signal control does not appear to be investigated in the research.

Gaps in Existing Research

In summary warrants for the use of channelized right-turning lanes are not identified in the literature, although the purposes and considerations are discussed. Warrants for the use of exclusive right turning lanes are based on volume and is also limited. The type of traffic control selected to use for the channelized right turn is rarely mentioned in the literature and data is unavailable for operational or safety performance between control types. There is also limited data to demonstrate CRTLs provide increase safety to motor vehicles.

CHAPTER 3

PRACTICE SURVEY-STUDY DESIGN

One major goal for this research was to review the current practice of transportation agencies concerning CRTLs by conducting a survey. This chapter discusses the survey design, the target audience and administration of the survey, and the collection of survey results.

Survey Design

The objective of the survey was to gather information on the state of practice as it relates to the use of channelized right-turning lanes at signalized intersections. Included within the survey was an investigation into the procedures and guidelines in place, and the agency experience with this treatment from both a safety and operational perspective. The survey included nine questions and was estimated to take 5-8 minutes of a participant's time.

The survey was designed to address the following three key aspects.

1. The use of CRTLs in intersection design;
2. The selection of traffic control devices for access control at the location where the channelized right turn lane meets the crossing roadway; and
3. Agency experience with safety and operations for this type of treatment.

The questions were designed in such a way that a participant could select more than one choice. When designing the survey, the choices to each question were determined based on the findings in the literature and considering the important elements. For

example, oblique angles create a good case to use a CRTL and were one of the choices provided for the survey question regarding CRTL use. A central issue present in the literature was pedestrian considerations consequently; this element was included as an integral component of the survey design. The survey questions are provided in Appendix A for reference.

Survey Target Audience

The survey was sent to two groups of highway agencies requesting their participation in the study. The first group involved all the 50 state departments of transportation (DOTs) while the second group involved 109 cities and municipalities across the United States. The contact information for prospective participants for the state agencies was identified using the roster available for the AASHTO subcommittee on traffic engineering, while the ITE traffic engineering council was used for local agency contact information. The local agencies were selected based on the size of the city. The two largest cities in each state with contact information available were selected as the best candidates for participation.

The list of potential participants was selected because it was determined they would be the most appropriate audience and would provide the most accurate responses. However, the potential participants from AASHTO and ITE were not necessarily the most qualified within their agency to answer the survey, therefore those receiving the survey were encouraged to forward the survey to the most qualified respondent within their agency.

Survey Administration

An online survey software package was used to create a web based survey. After the survey was completed, it was posted online and an email was sent to each person from the prepared lists. The email provided a link to the published survey, a username or password was not needed. The email also informed the recipient of the estimated time required to complete the survey and a requested date of completion. The distribution lists were separated between the local and state agencies for ease in analyzing the responses separately.

When the completion date had passed some agencies were contacted by telephone requesting their participation. This increased the response rate. Those phoned opted to complete the survey online, rather than by telephone. Not all persons on the list were contacted by telephone as that information was not available.

Collecting Survey Results

The survey software was used to summarized and export the survey responses into a spreadsheet. Each question allowed the user to give more information or provide a comment. This information was also summarized into a spreadsheet. The results were analyzed and are discussed in Chapter 4.

CHAPTER 4

PRACTICE SURVEY - RESULTS

A total of 37 state DOTs answered the survey representing a 74-percent response rate. However, only 38 local agencies answered the questionnaire in the second group representing approximately a 34-percent response rate. It is believed that the lack of the respective expertise at small local agencies may partly explain the much lower response rate for the second group.

The survey responses were analyzed and results are provided in the following sections of this chapter. The figures showing the results throughout this chapter have the percentage on the y-axis and the choice to each question on the x-axis.

The Use of Channelized Right Turn Lanes at Signalized Intersections

Although the reference material and tools available provide some high-level guidelines for the design of channelized right-turn lanes, guidance for the use of CRTL remains limited in general. Specifically, no detailed procedures for making this determination are available to the practitioners involved in the planning and design of at-grade intersections. Given the implications of this treatment on safety and operations, such a determination should be based on well-established design procedures or a reliable analysis of those safety and operational impacts.

Survey participants were asked whether CRTLs are used by their agencies as part of intersection design. The majority of agencies reported the use of this treatment with around 95-percent of state DOTs and 90-percent of local agencies. Reasons for not using

this treatment as reported by some agencies include snow plowing and the right-of-way required by channelized right-turn lanes. One agency noted that CRTLs are used heavily in roundabout designs but there has not been a benefit to implementing this treatment at signalized intersections. Another agency reported the tendency for drivers to use excess speeds due to the use of "smooth" curves.

When asked about the guidelines for the use of channelized right turning lanes in intersection design, 62-percent of the state agencies that use CRTLs reported using national guidelines versus 50-percent state guidelines. Moreover, 74-percent reported the use of engineering judgment while only 9-percent reported the use of other guidelines. The corresponding percentages for local agencies were 50-percent national guidelines, 33-percent state guidelines, 73-percent engineering judgment and 16-percent other guidelines. The higher percentage of agencies that use engineering judgment besides other guidelines may be partly due to the lack of detailed procedures and guidelines for this type of intersection treatment. Figure 3 shows the questionnaire results regarding the guidelines followed by state and local agencies.

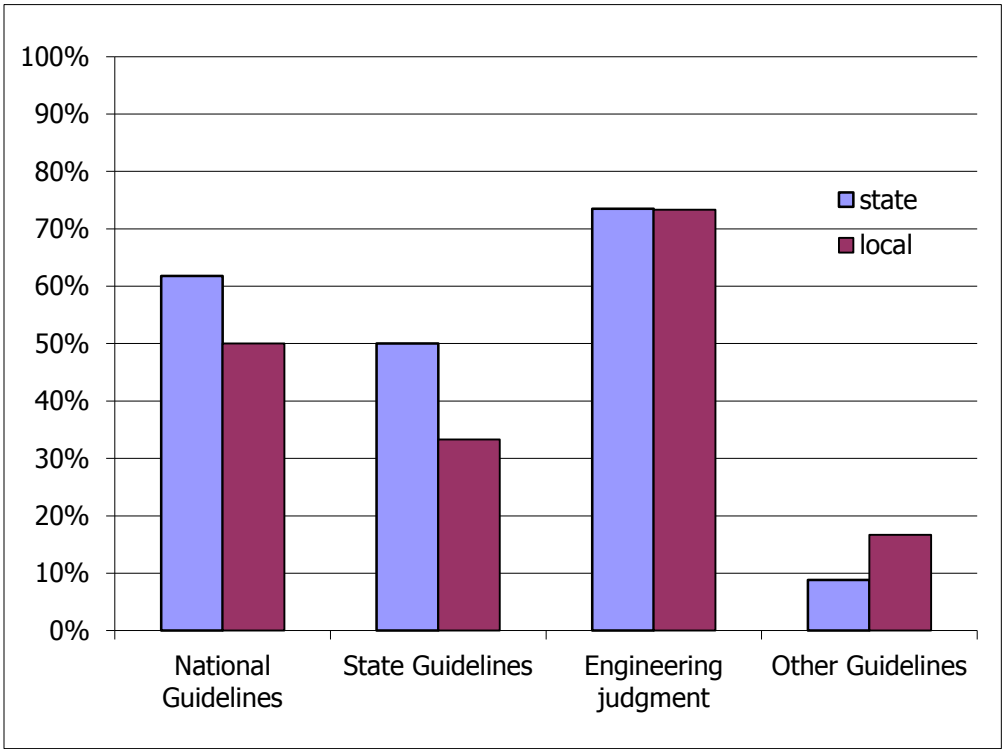


Figure 3: Guidelines used by state and local agencies for the use of CRTLs

One state agency specified NCHRP 457 (Bonneson & Fontaine , 2001) as a source of guidelines for the use of CRTLs in intersection design while another state agency reported the use of "basic intersection design tools" for the same purpose without providing specifics about the design document. The NCHRP 457 report is limited as it provides guidelines only for determining the need of a turning lane at a two-way stop controlled intersection.

One local agency has implemented their own master thoroughfare plan and design standard based on AASHTO and National guidelines while another local agency has adopted its own guidelines as part of its access management plan which follows typical design standards. Further, another agency reported the use of context sensitive solution

(CSS) guidelines as a source of guidance in making the determination on the use of CRTL at signalized intersections.

As for the major considerations for use of CRTL at signalized intersections, high right-turn volume was the most frequent consideration reported by both state and local agencies (88 and 96 percent respectively). For state agencies, oblique angles between intersecting roadways was reported as the second most frequent consideration followed by vehicular crashes and pedestrian crashes respectively. For local agencies, vehicular crashes were reported as the second most frequent consideration followed by the oblique angle between intersecting roadways and pedestrian crashes respectively. The summary of responses for state and local agencies is shown in Figure 4.

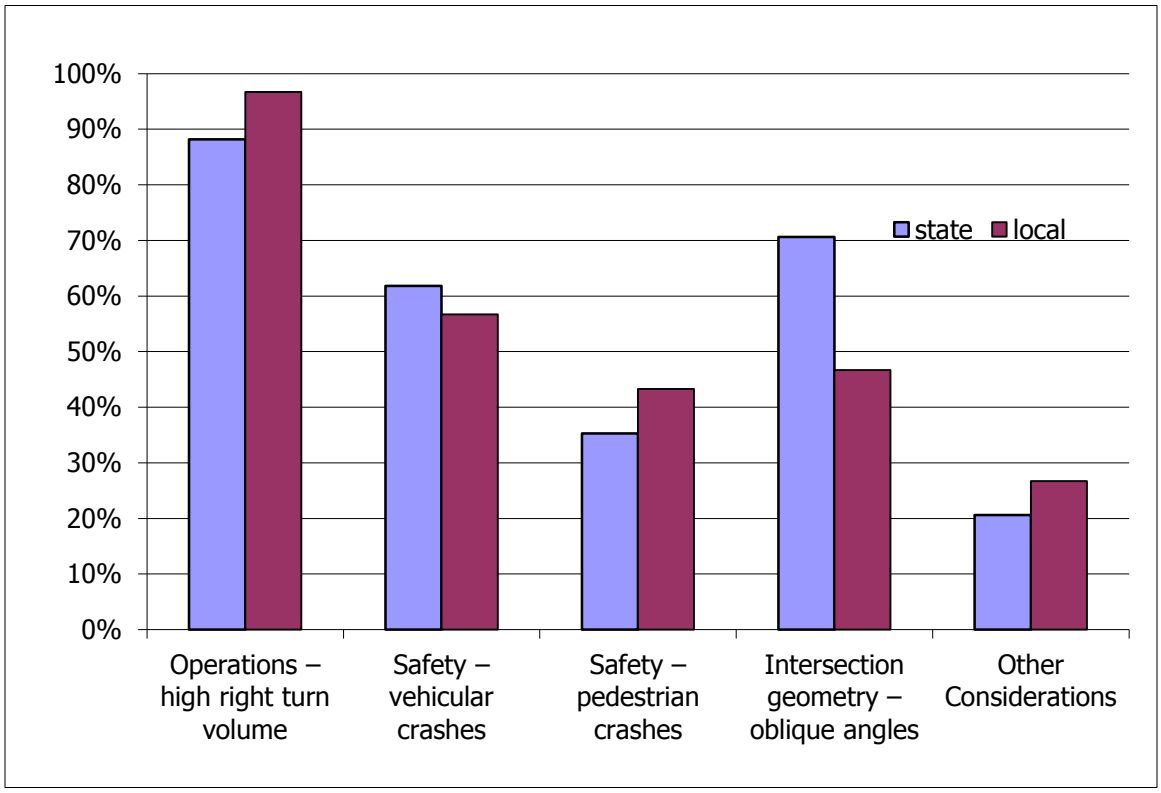


Figure 4: Considerations for the use of CRTLs

Among other considerations specified by state and local agencies were the presence of bicycle facilities, corridor coordination improvement, pedestrian traffic, vehicle mix, and large amount of pavement area, traffic queuing, lane crossing maneuvers and location for installation of signal heads and other street hardware.

Access Control at Channelized Right-Turn Lanes

Various types of traffic control devices may be used to control access at CRTLs including yield control, stop control, traffic signals, and no control (Dixon et al., 1999). The selection of the most appropriate type of traffic control is of utmost importance for the safety and operations of this right-turn treatment.

Highway agencies were asked about the guidelines they use in selecting the traffic control devices which control access to the intersecting roadway. Around two thirds of state DOTs reported the use of national guidelines versus 56-percent among local agencies. The use of state guidelines was reported by around 44-percent of state agencies and 33-percent of local agencies. Engineering judgment was the most frequently reported source of guidance by state and local agencies (67-percent and 83-percent respectively). Figure 5 shows the questionnaire results for the guidelines used by state and local agencies in the selection of traffic control at CRTL.

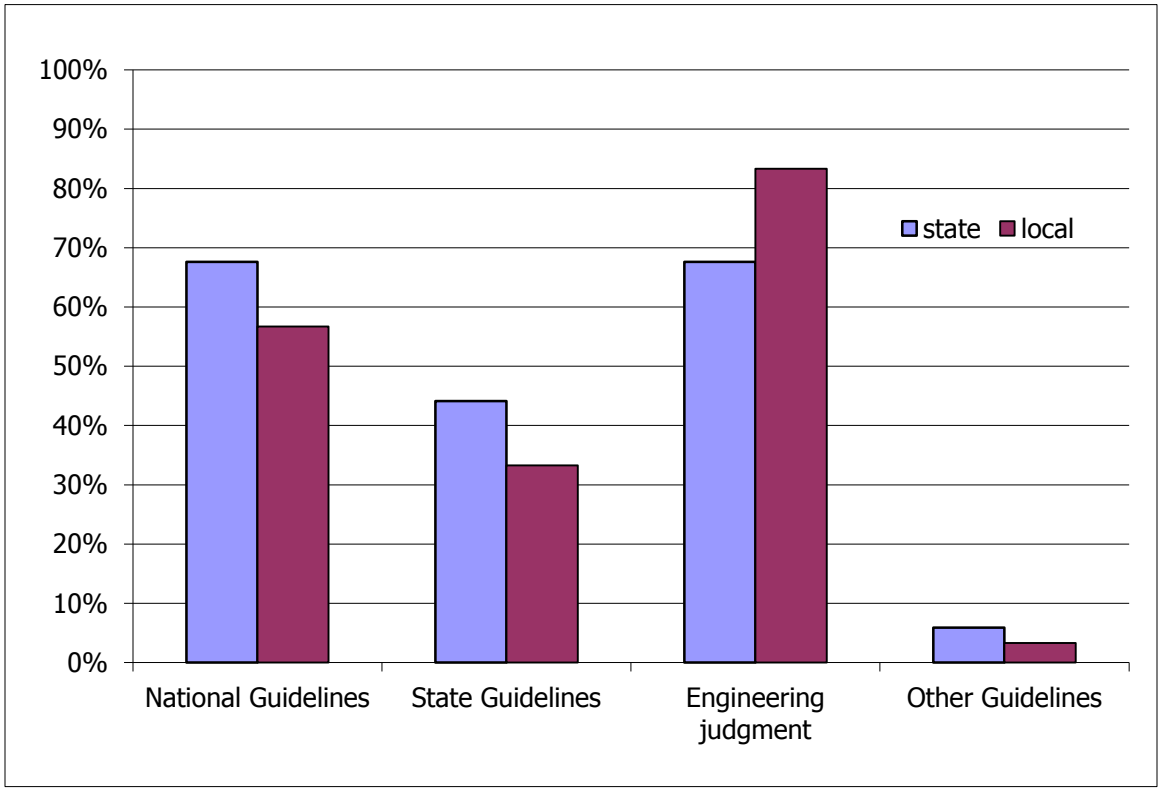


Figure 5: Guidelines used by state and local agencies for traffic control at CRTLs

The fact that 50-percent of the state DOTs use the MUTCD in complete conformance (FHWAb, 2009), and that the selection of traffic control for CRTL is not addressed in this document leaves no surprise that engineering judgment is used extensively for traffic control selection by most highway agencies.

The comments made by survey participants generally confirm the common practice, i.e. the yield control being the most appropriate traffic control at this particular intersection treatment. It was interesting to receive a comment from one state agency stating, "Typically if we get to a point where the channelized right turn is problematic, it would most likely be studied for being placed under signal control…" since there are no justifications for signal use and signal use is potentially more confusing.

The survey also included a question about the major considerations used by highway agencies in the selection of traffic control at CRTL at signalized intersections. Vehicular traffic was the most frequently reported consideration by both state and local agencies (88- and 97-percent respectively). Vehicular crashes were the second most reported consideration by state agencies followed by pedestrian traffic and pedestrian crashes respectively. On the other hand, pedestrian traffic was the second most frequently reported consideration by local agencies followed by vehicular crashes and pedestrian crashes respectively. The summary of responses for state and local agencies is shown in Figure 6.

Other considerations provided by survey participants included bicycle activity, vehicular traffic character and composition, available sight distance, speed, and geometric layout considerations. Interestingly, one agency specified that CRTLs are designed for yield control, confirming that yield control is the expected control type for this treatment.

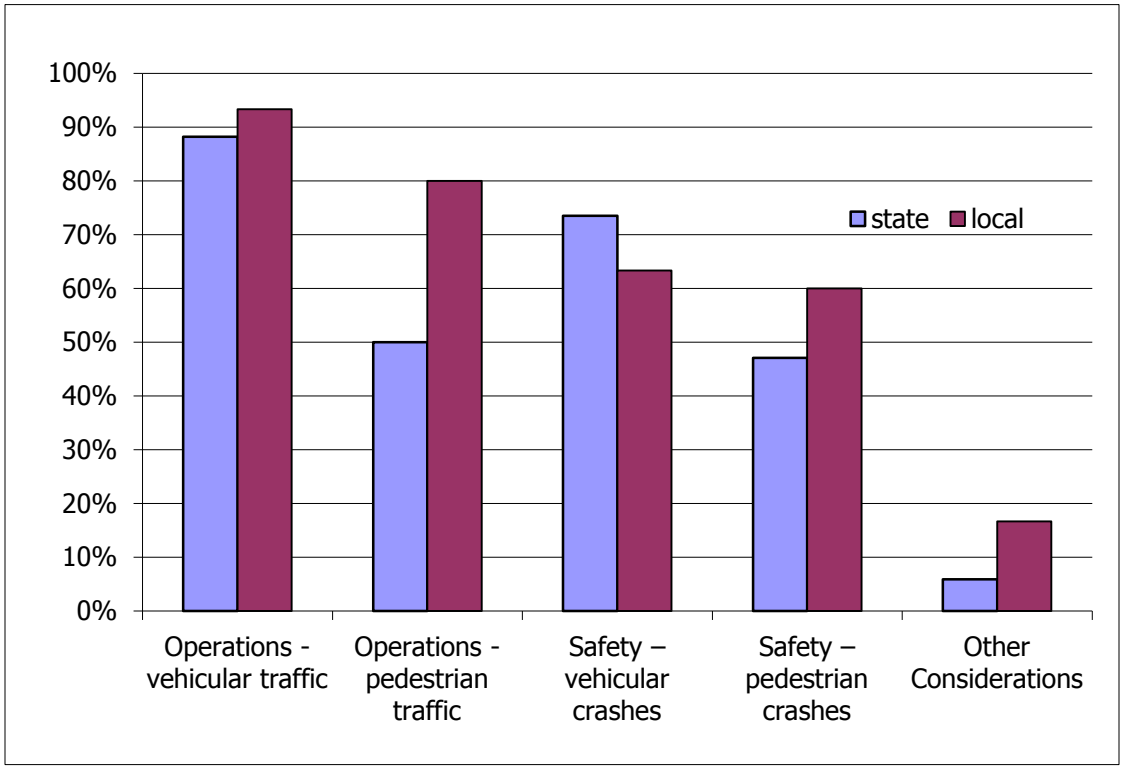


Figure 6: Considerations for traffic control device selection at CRTLs

One of the questions in the survey was more specific in asking highway agencies whether they use formal warrants for the installation of exclusive signal control at CRTLs. Surprisingly, around 12-percent of state and 27-percent of local highway agencies reported the use of such warrants in installing signal control at channelized right-turn lanes. These percentages are very low given the fact that similar warrants are always required when traffic signals are installed at unsignalized intersections. This attests to the fact that exclusive warrants for signal installation at CRTL do not exist at the national level.

Among other considerations reported by highway agencies for using signal control at this intersection treatment are high crash rates, simulation operational studies, and engineering judgement.

Agency Experience with Safety

Safety is an important issue to consider when it comes to the use of CRTL at signalized intersections. Channelization separates traffic movements and minimizes conflict between different movements at an intersection approach. On the other hand, adding a CRTL to an intersection layout creates a merge area where right turning vehicles have to merge with the mainline traffic of the crossing roadway. Drivers, especially older drivers, may not be comfortable with the higher speed of the turn when trying to turn their head to look upstream while making the merging decision. Some drivers may prefer to slow or stop at the end of the lane. This behavior could result in rear-end collisions, as more familiar drivers who are more comfortable with the higher speed may not anticipate the stopped vehicles (Fitzpatrick & Schneider, 2004). There is also a potential for right of way conflicts from drivers on the cross street. Furthermore, pedestrian safety could be an issue given the free-flow right-turn movement using the channelized lane and the extra pedestrian crossing created by this lane.

Therefore, safety experience of this intersection treatment was an important aspect to examine as part of the survey. It is worthy to mention here that responses to this part of the survey were based in most instances on personal observations, opinions, and perceptions. The lack of relevant data or studies was mentioned explicitly several times in the comments provided by survey respondents. This partly explains the high

percentage of survey participants who chose not to answer the survey questions related to the agency safety experience.

When asked about their safety experience with CRTL at signalized intersections, around 49-percent of state agencies and 67-percent of local agencies believed that this treatment improves vehicular safety. On the other hand, much lower percentages were reported for state and local agencies who believe that this treatment decreases vehicular safety (15-percent and 3-percent respectively). It is obvious that the majority of highway agencies perceive CRTL at signalized intersections to improve vehicular safety. Relative to vehicular safety, there is less agreement among agencies in regards to pedestrian safety, as fewer agencies thought of this treatment to improve pedestrian safety (30-percent of state and 37-percent of local agencies) and more agencies thought this treatment decreased pedestrian safety (9-percent of state and 27-percent of local agencies). The summary of responses for state and local agencies is shown in Figure 7.

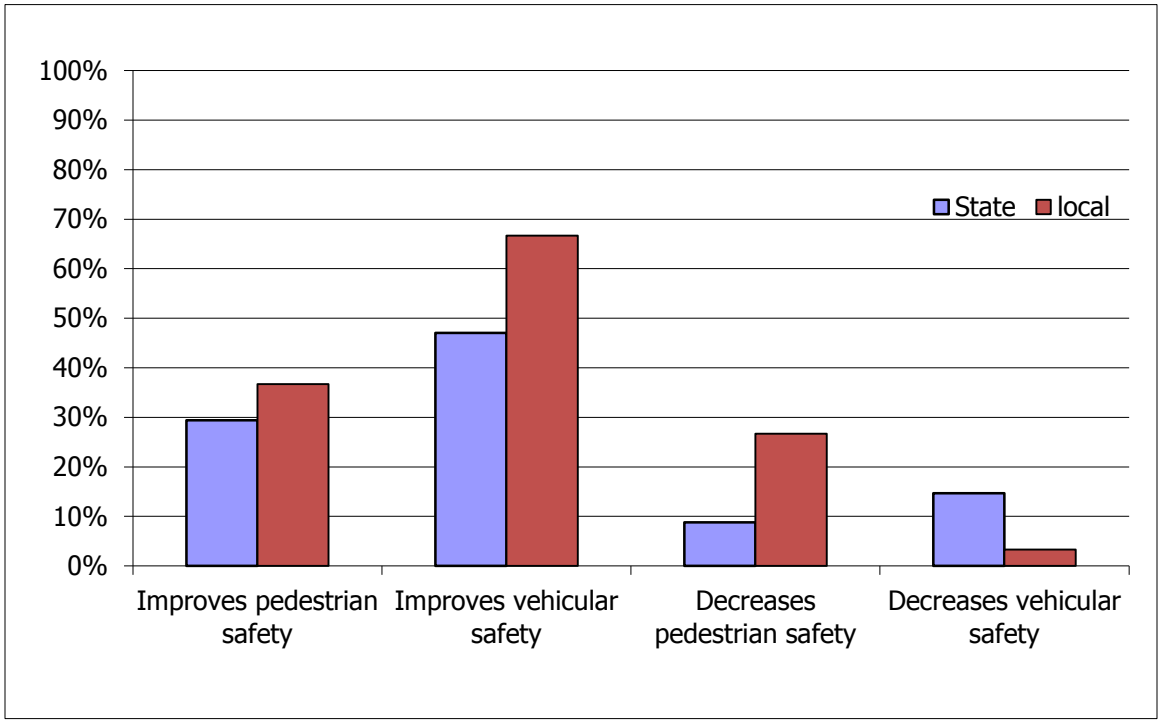


Figure 7: Agency saftey expereince with the use of CRTLs

Many comments were made in response to the survey question pertaining to agency safety experience with CRTLs. The comments provided additional insights into the agency experience or perception of the safety and operational benefits of this intersection treatment. One agency stated that they occasionally receive complaints from pedestrians about right-turning vehicles not yielding to pedestrians. Another agency stated that the use of CRTL increases vehicle speeds, and in an effort to maintain pedestrians' safety, a speed hump was installed at one of their intersections. One comment specified radius and raised islands have an impact on vehicular safety and another specified vehicle needs are mostly considered since RTOR allows pedestrians to cross. This comment suggests that vehicle will stop for the control used at the channelization and that a yield sign is not the control in place. The statement also

assumes a driver will behave accordingly. While there was overwhelming agreement among participants about the operational benefits of channelized right-turn lanes, numerous comments were made that safety data and studies simply do not exist to answer this question. This shows the need for future research into the safety aspects of CRTL at signalized intersections.

It is also interesting that CRTLs are regarded as increasing pedestrian safety. There seems to be a conflicting message in the guidelines of whether CRTLs are safe for pedestrians. On one hand the use of islands (therefore channelization) provides pedestrian refuge and shortens the crossing distance. On the other hand the use of turning roadways is generally discouraged in high pedestrian areas (AASHTO, 2003).

Another important safety aspect concerned with CRTLs is the type of traffic control devices used to control access to the crossing roadway. Survey participants were asked to evaluate their agency's safety experience with the two most common traffic controls used: yield control and signal control.

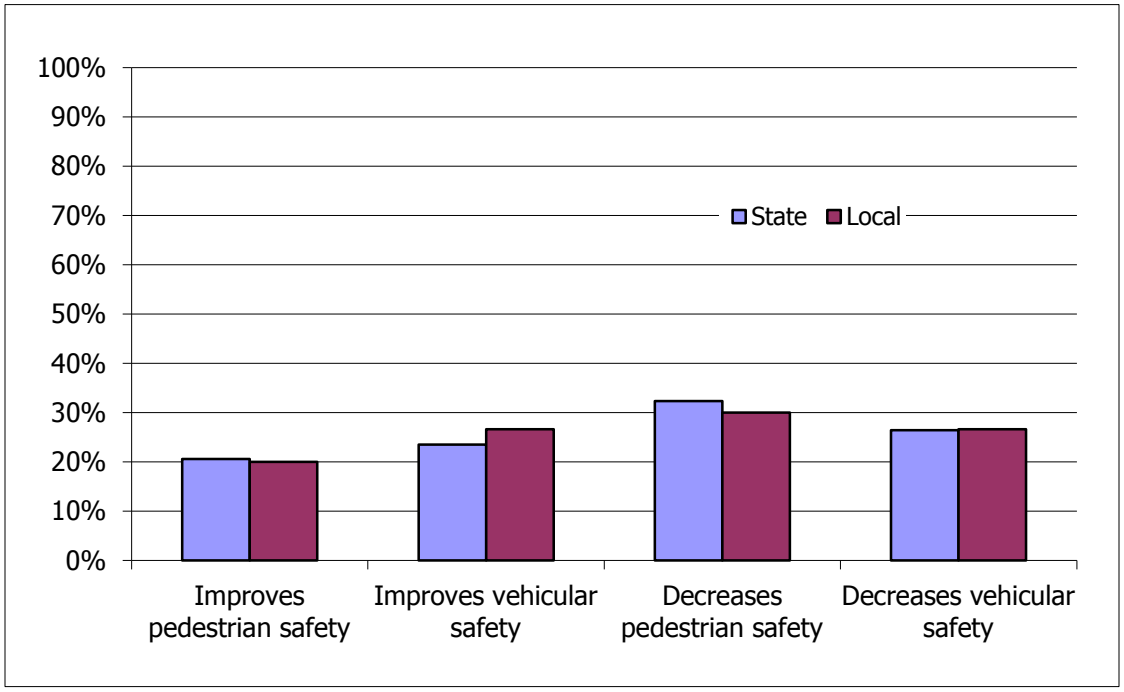


Figure 8: Agency saftey expereince with the use of yield signs at CRTLs

In regards to yield control, there is a relatively high agreement among state and local agencies concerning its safety effect at CRTL as shown in Figure 8. In general, more agencies (32-percent of state and 30-percent of local agencies) perceive yield control to decrease pedestrian safety than those who percieve it otherwise (around 20-percent of both state and local agencies). As for vehicular safety, the numbers are more evenly split. Specifically, around 27-perecnt of state and local agencies percieve yield control to decrease vehicular safety versus 27-percent of local and 24-percent of state agencies that perceive it otherwise.

Figure 9 shows agency safety experience with signal control at CRTLs. Again, there is a high level of agreement among state and local agencies about the safety aspects of using signalization to control access at channelized right-turn lanes. It is important to

note that most of the respondents in the two groups targeted in this study thought of signal control as contributing to pedestrian and vehicular safety. Specifically, around 55-percent of state and 53-percent of local agencies thought that signal control improves pedestrian safety versus 44-percent of state and 40-percent of local agency respondents who thought of signal control as improving vehicular safety. Only a few respondents (4 total) in the two groups thought of signal control to have negative safety impacts on pedestrian and vehicular traffic.

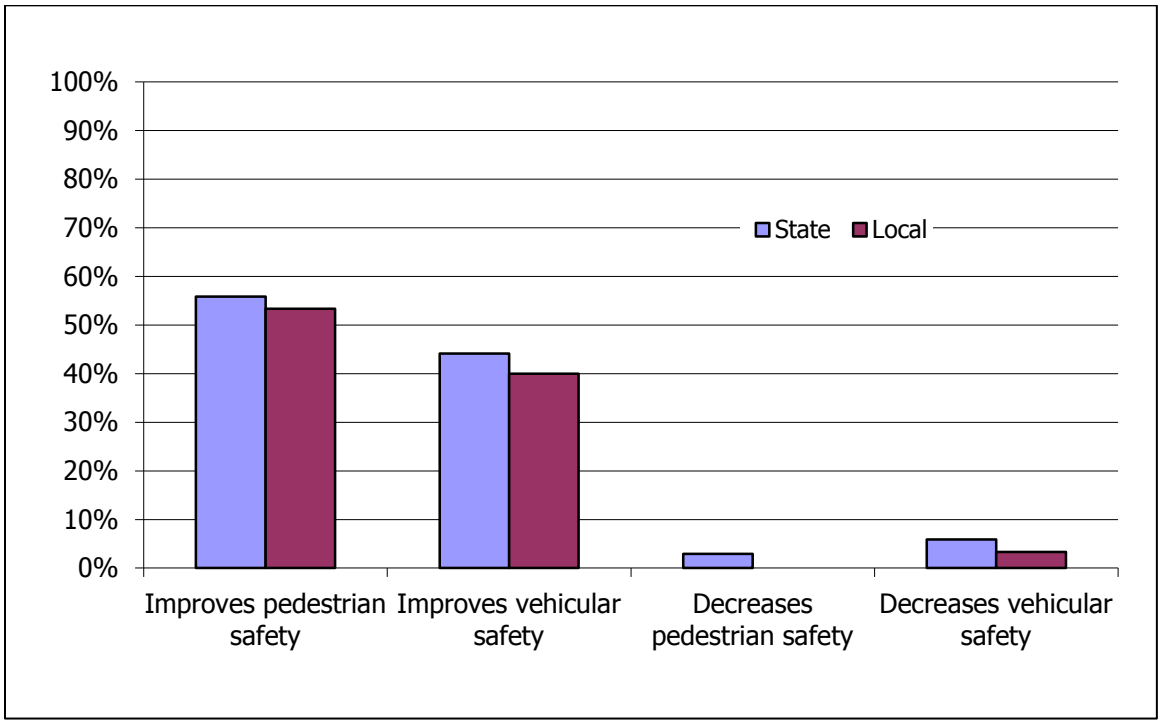


Figure 9: Agency saftey expereince with the use of signals at CRTLs

Survey Participants' Comments

The final question allowed particpants to leave additional information or comments. The comments provided are listed in Table 1. These comments are noteworthy as they suggest the lack of guidance and reliance on engineering judgement.

Table 1: Survey Participants Comments

1	From a safety perspective, we prefer channelized right turn lanes to include acceleration lanes which eliminates the need for any traffic control including the yield signs. otherwise, we prefer eliminating the channelized turn lane creating a 90 degree angle for the turn lane at the intersection.
2	one of the biggest problems with signalized intersections is who has the right of way. The CRTL acts as a merge not a intersection and this complicates matters. Of the opinion to keep it simple.
3	The greatest benefit of signalizing a channelized right turn lane is that the driver's attention is focused forward toward the signal rather than left toward the approaching traffic. Channelized right turns under yield control can lead to many rear end crashes.
4	A complete guidance document for the operation and design of channelized right turns hasn't been developed. I believe there is a need and significant interest within the department.
5	In general, we utilize channelized right-turn lanes to provide for increased capacity at an intersection and to better provide for the right-turn maneuver. The additional splitter island provides a refuge place for pedestrians that actually shortens the crossing distance versus keeping the right-turn lane parallel with the through lanes. We evaluate pedestrian demand and accessibility issues on a case-by-case basis to determine if it is necessary to signalize the right-turn movement. The operational benefit of the channelized right-turn lane disappears with the introduction of the traffic signal control.
6	There are locations where after some period of initial operation channelized right turns are modified and returned to being under signal control. Particularly as vehicular and pedestrian patterns develop/ mature/stabilize.
7	The MUTCD should be updated to provide guidance on appropriate traffic controls for channelized right turn lanes for both unsignalized and signalized intersections.
8	We use both signalized and yield at channelized right turn locations. Pedestrian operation and safety differences not apparent.
9	We use channelized right turn lanes where we expect or have high turn volumes that without a turn lane would adversely impact the through lane.

Summary of Survey Results

A questionnaire survey was conducted to review the current practice concerning channelized right turning lanes at signalized intersections. The survey was sent out to the 50 state DOTs and more than one hundred cities and municipalities across the United States. The three major focus areas in the survey were the use of CRTLs for intersection design; the selection of traffic control devices for access control at the crossing roadway; and agency experience with safety and operations for this type of treatment. The most important findings of the practice survey are summarized below:

- The decision to use CRTL and the type of traffic control heavily relies on engineering judgment by most state and local agencies. This is somewhat expected given the limited guidance available in the national design documents and standards used by most agencies.
- The lack of guidance is particularly true for the selection of traffic control, as only 12-percent of state and 27-percent of local agencies reported the use of warrant studies in installing signal control at channelized right-turn lanes.
- There is an overwhelming perception by most state and local agencies about the safety benefits of signal control at channelized right-turn lanes. Surprisingly, this notion is not supported by studies or statistics showing these benefits.
- Vehicular traffic operation was the most prevalent consideration for using the

CRTL and for the selection of traffic control.

The literature review (as discussed in Chapter 2) revealed lack of guidance in general, and a focus on the volume warrants, and delay benefits of right-turning lanes. This was confirmed with most agencies selecting operations as the most common consideration for the use of CRTL. However, capacity and delay benefits may well be affected when signals are used in controlling access to the crossing roadway. The survey also revealed the lack of safety data concerning the CRTL and the type of control used. This data is useful in developing guidelines for the use of this treatment as well as for the selection of the most appropriate control type at channelized right-turn lanes.

CHAPTER 5

FIELD STUDY DESIGN

In addition to the survey, an empirical study was another major task for this research. The goal of the empirical study was to discern driver behavior in the treatment for CRTLs when confronted with a red signal. This chapter describes the study sites, data collection and processing of the data.

Study Sites

Three intersections with a CRTL and an exclusive signal control for the right turning traffic were selected for the empirical investigation. The criteria used for considering a CRTL site applicable for data collection were:

- An urban setting within Southwest Montana
- The use of curbed (raised) islands
- A traffic control used exclusively for the channelization

Given the above criteria and constraints, three sites were selected. A high-level summary of each site is provided in Table 2.

Table2: Study Site Design Elements

Site #	Intersection Name and Location	Geometry	Deceleration Lane	Acceleration Lane	Island Type
1	Jackrabbit and Main, Belgrade MT	<90 ˚	Yes	No, Merge Required	Raised
2	Jackrabbit and Madison, Belgrade MT	90˚	Yes	No, Merge Required	Raised
3	West Kagy and South 3rd, Bozeman MT	< 90˚	Yes	No, Merge Required	Raised

Study Site #1 - Jackrabbit and Main

This is a major intersection of two important arterials in Belgrade, Montana. The two intersecting roadways cross each other at an oblique angle. The channelized right-turn lane has an overhead signal (placed on the cross street at the end of channelized lane). The signal head has a red ball, yellow ball and green ball indications. The stopping location is at the downstream end of the channelization. Figure 10 is an aerial photo showing the geometry of the channelization and the placement of the cross walk. Figure 11 is a photograph showing the overhead signals used for the channelization.



(Source: 45°46’48.46” N and 111°11’05.28”W GOOGLE EARTH, 2007. May 18, 2010)

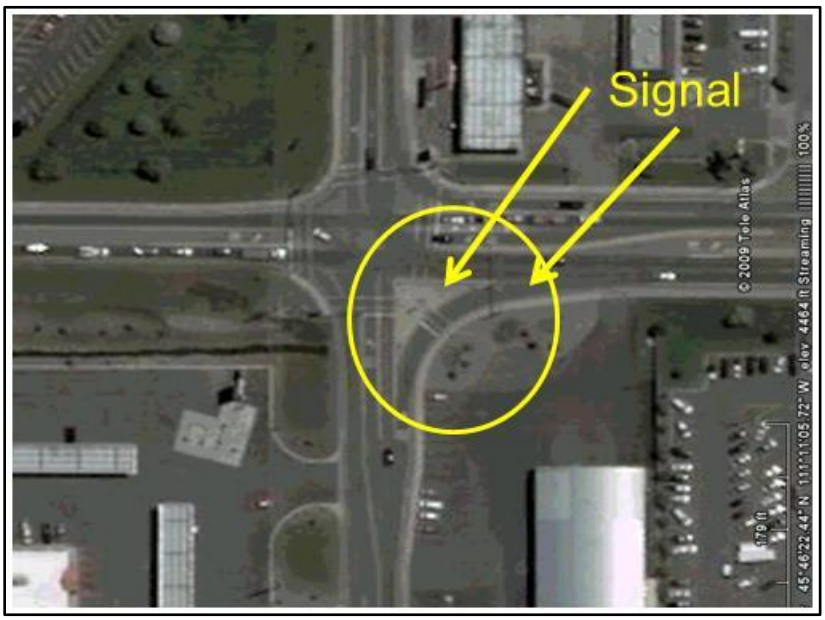
Figure 10: Aerial image of study site # 1



Figure 11: Photograph of the channelization for study site #1

Study Site #2- Jackrabbit and Madison

This is another major intersection of two important street arterials in Belgrade, Montana. The two intersecting roadways are major arterials that cross at a right angle. The channelized right-turn lane has two signal heads with a red ball, yellow ball and green ball indications, one is located on the left within the island (placed coincident with the stop bar) and the other is overhead facing the merging traffic (placed at the end of the channelized lane). The stopping location is at the center of the channelization. Figure 12 is an aerial photo showing the geometry of the channelization and the placement of the cross walk. Figure 13 is a photograph showing the locations of the signals used for the channelization.



(Source: 45°46’22.44” N and 111°11’05.72W” GOOGLE EARTH, 2007. May 18, 2010)

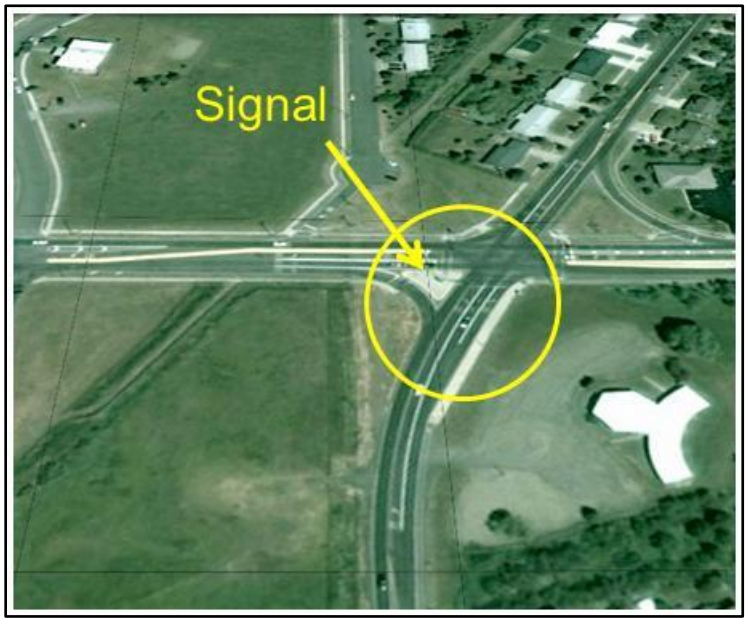
Figure 12: Aerial image of study site # 2



Figure 13: Photograph of the channelization for study site #2

Study Site #3 – West Kagy and South 3rd

This is an intersection of a major and a minor arterial in Bozeman, Montana. The two intersecting roadways cross each other at an oblique angle. There is only one signal head located on the left within the island (placed a few feet following the stop bar). The signal is a red ball, yellow ball, green ball and a green arrow for right turning traffic. The stopping position is at the upstream end of the channelization. Figure 14 is an aerial photo showing the geometry of the channelization. The image shown in Figure 14 is the most current available on-line, however this intersection currently has multiple business located on the southeast corner. Figure 15 is a photograph showing the signal placement used for the channelization. Figure 15 also shows the crosswalk location and a sign placed prior to the crosswalk indicating where to stop on red.



(Source: 45°39’38.74” N and 111°11’30.39”W GOOGLE EARTH, 2007. May 18, 2010)

Figure 14: Aerial image of Study Site # 3



Figure 15: Photograph of the channelization for study site #3

Data Collection Technology

The data used in this research was collected using surveillance cameras on mobile traffic monitoring trailers. The camera locations were placed in the least visible location as to not attract attention and alter driver behavior. The surveillance cameras were deployed during May 2009. Table 3 shows the duration and dates for each site. A seven-day period of video records was used at each study site. This period was deemed an appropriate trade-off between the time consuming nature of video data processing, project resources and acquiring a reasonable number of observations for the analysis.

Table 3: Dates of Video Surveillance

Site #	Intersection Name and Location	Start Date	End Date
1	Jackrabbit and Main, Belgrade MT	May 25	June 1
2	Jackrabbit and Madison, Belgrade MT	May 7	May 21
3	West Kagy and South 3rd, Bozeman MT	May 8	May 19

The video footage was then reviewed and analyzed using digital video recording (DVR) software. The software allowed the video to be watched at four different speeds. The speeds were 0.5x, 1.0x, 2x or 4x. The time stamp and date for the footage were provided in the bottom left corner of the screen. A snap shot of the video footage for sites 1 thru 3 are shown below in Figure 16 thru 18, respectively.



Figure 16: Video of Jackrabbit and Main, Site #1



Figure 17: Video of Jackrabbit and Madison, Site #2



Figure 18: Video of Kagy and South 3rd, Site #3

Data Processing

A systematic methodology was developed for processing the data to ensure the driver reaction was properly understood. Specifically, in order to be consistent in

extracting the required data from video records, a set of rules were developed to clearly identify the reaction of any driver to the signal control at the CRTL. The rules were used as a guide to decipher each observation recorded accurately and insure repeatable results.

Rules and Methods Developed

As the reaction to signal control is only an issue during the red signal indication, this study focused only on the time when the red indication was in effect. A pilot study was performed in developing rules using limited video records from one of the study sites. The set of rules and associated definitions were developed as part of the pilot study to determine the process needed to accurately account for driver behavior.

For the rules to be easily understood, it is necessary to define several terms used throughout the field study. The definitions and rules are described in the following:

- A *conflict* is defined as the presence of another vehicle on the cross street creating a need for the motorist utilizing the CRTL to completely stop to avoid a collision. In this situation, it is impractical to ascertain the driver behavior in response to signal control.
- A *complete stop* at a stop control is defined as an observed stop of 1 to 2 seconds in the absence of a conflict.
- Second vehicle to arrive (SVA) is defined as the vehicle waiting behind the first vehicle when the first vehicle is in a stopping position. In this situation, it is impractical to ascertain the driver behavior in response to the signal control. The SVA occurred when the first vehicle was either stopped due to the presence of a conflict or

due to the driver's own volition. A SVA did not exist if the first vehicle was a yield or signal situation. The SVA observations were not used in analysis unless specified.

- Transition to green (TTG) is a condition when the vehicle arrives at red signal indication but the signal immediately changed to green. In this situation, it is impractical to ascertain the driver behavior in response to signal control. This was not used in analysis unless specified.
- Heavy Vehicle (HV) was designated for large trucks, buses or recreational vehicles (RVs). If a school bus was observed during the red indication, this was not included as they are required to stop on red.
- The driver behavior (reaction to signal control) was defined by five rules as follows:
  - *Rule 1: Treatment as a signal*

    The driver stops at signal and waits until the light changes to green before proceeding. If the driver encounters a conflict for the entire duration of the red light, it is considered an unknown.
  - *Rule 2: Treatment as a yield sign*

    The driver's wheels never come to a complete stop. Driver slows down or maintains the same speed through the channelization. The slowing down could be due to the presence of a conflicting vehicle but a stop was not required due to an acceptable gap.
  - *Rule 3: Treatment as a stop sign*

    The driver approaches the channelized intersection, completely stops and then proceeds in the absence of any conflict.

- *Rule 4: Extended Stop*

  The driver approaches channelized intersection, completely stops for duration greater than 2 seconds and then proceeds. This is thought of as a driver initially treats the control as a signal but changes mind during the wait as he or she may perceive stopping unnecessary for the situation. The entire process needs to happen without a conflict.

- *Rule 5: Treatment Unknown*

  This is the situation where driver reaction to signal control cannot be identified. The behavior of the motorist is unknown due to an existing conflict. It is important to note that the two terms "unknown" and "conflict" are used interchangeably throughout this document.

It is important to state that the reaction to signal control during the green indication was not collected or processed as discussed earlier.

Data Recorded for Analysis

Figure 19 shows a sample log sheet of the data recorded and collected for analysis. Each line (row) in the spreadsheet is one observation of a driver that encountered a red signal. As shown in Figure 19, the reaction to the signal was recorded (i.e. stop, yield, signal, conflict or extended stop) according to the rules discussed in the previous section. In addition to this information day, date, time, light condition, weather (pavement condition), stopping position and vehicle type was documented.

Day	Date	Road Conditions			Stop		Yield	Signal		Stop w/Conflict		Extended Stop		Comments
		Time	lighting	weather	Stop Bar	Merge Pt		Stop Bar	Merge Pt	Stop Bar	Merge Pt	Stop Bar	Merge Pt	
Monday	05/25/09	3:57 PM	daylight	dry			1							
Monday	05/25/09	3:59 PM	daylight	dry						1				TTG
Monday	05/25/09	4:03 PM	daylight	dry			1							
Monday	05/25/09	4:03 PM	daylight	dry			1							
Monday	05/25/09	4:03 PM	daylight	dry			1							
Monday	05/25/09	4:04 PM	daylight	dry			1							
Monday	05/25/09	4:07 PM	daylight	dry			1							
Monday	05/25/09	4:08 PM	daylight	dry			1							HV
Monday	05/25/09	4:11 PM	daylight	dry			1							
Monday	05/25/09	4:12 PM	daylight	dry				1						
Monday	05/25/09	4:14 PM	daylight	dry						1				
Monday	05/25/09	4:15 PM	daylight	dry		1								SVA
Monday	05/25/09	4:17 PM	daylight	dry			1							
Monday	05/25/09	4:20 PM	daylight	dry	1									TTG

Figure 19: Sample log sheet used for the empirical study

The day, date and time were taken from the video footage. The other variables (the column headings) shown in Figure 19 are discussed below.

The light condition was not easily determined from the video footage for the hours that the sun was rising or setting, therefore official sunrise, sunset and twilight times were used. The website for the Astronomical Applications Department of the U.S. Naval Observatory was used to determine the official times (www.usno.navy.mil). The designation of twilight is defined as the time before sunrise and after sunset that some outdoor activities would need to be conducted using artificial light. The light conditions were therefore either daylight, dark or twilight. This information was entered in the "lighting" column in Figure 19.

The weather conditions (pavement conditions) were based on precipitation data for each hour of each day. The days observed had merely trace precipitation, hence weather was not considered a factor in the analysis. This was verified using the National Climatic Data Center which is an active on-line resource that provides archives of weather data (www.ncdc.noaa.gov, 2011).

The stopping position was recorded for each observation as either “Stop Bar “or “Merge Point”. A driver who stopped prior to or at the stop bar was marked in the “Stop Bar” column, and those drivers who stopped after the stop bar were marked as “Merge Point”.

The comment column was used to track other data such as vehicle type (for heavy vehicles (HV)), the second vehicle to arrive (SVA), and if a driver experienced a transition to green (TTG).

Based on the findings from the literature review and in the opinion of the author, this study is one of the most comprehensive analyses of driver behavior and treatment of signal control at CRTLs. However, it is important to state that pedestrians were not a consideration in the data collection or analysis. Although pedestrians are a significant factor influencing safety and driver behavior at CRTLs, the volumes of pedestrian activity at these site locations were considered very low (roughly less than 20 per day were observed). In those rare occurrences, vehicle arrivals that encountered a pedestrian were not included in the study observations.

Challenges

The video footage for Kagy and South 3rd (site #3) was difficult to discern during certain times depending on the lighting of the day. During some periods, the video was either blacked out or had too much glare making it impossible to see any footage. Further difficulty was encountered because the signal head at site #3 has a green arrow and the surveillance camera was set far enough back that during certain lighting conditions the arrow was not visible. During the times that the signal head was not identifiable, there were no observations made.

Site #2, Jackrabbit and Madison had a blinking red light during the hours of 12 a.m. and 6 a.m., therefore there were no observations made during this period.

CHAPTER 6

FIELD STUDY RESULTS

The information gathered during the course of this investigation was analyzed to examine trends in the results as they relate to driver choices in response to the red signal indication. Graphs were generated to illustrate the driving behavior observed at the three study sites. The association between driver response and other variables (those discussed in Chapter 5) were tested using the Pearson Chi Square test.

The Pearson Chi Square test is a tool for testing the association (or independence) between categorical variables (e.g. the association between columns and rows in tabular form), such as the data collected for this study. The null hypothesis assumes that there is no association between variables while the alternative hypothesis assumes that association does exist when the p-value calculated is less than the significance level used for analysis.

For data analysis purposes, the observations that involved a conflict on the cross street, a SVA situation or a TTG situation were considered unknown. These categories were eliminated from analysis unless specified.

Overall Driver Reaction to Signal Control

The data for each site was compiled to determine the overall driver reaction to the red signal indication at the CRTL. The results for each site are shown in Figure 20. Confronted with the red signal, the majority of drivers treated the situation as a yield control. These drivers constituted 80%, 78% and 83% at study sites #1, #2, and #3

respectively. Much smaller proportions treated the situation as a stop control at the three study sites with percentages near 10%. Interestingly, drivers who treated the situation as a signal constituted a very small percentage of the observations at study sites. This percentage was found to be around 4-6% at study sites #1 and #2, and only around 2% at study site #3. It is very likely that traffic volume and the geometric layout of the study sites accounts for the notable difference in percentage between sites 1 and 2 on one hand and site 3 on the other hand. Regardless of the difference among study sites, the percentage of drivers who treated the situation as a signal control is extremely low, this was somewhat unexpected. As anticipated, only a few drivers at all sites reacted as an extended stop at the red signal. Those constituted 0.8%, 1.9%, and 0.7% at study sites #1, #2, and #3 respectively.

The number of drivers that did come to a complete stop before proceeding was relatively the same at each site (approximately 14 %, 13%, and 13% at sites #1, #2 and #3, respectively). It is interesting to note that site #3 has a "stop here on red" sign; however drivers stopped at the same percentage as the other sites. The number of driver's that did stop at each site may be due to the belief that a RTOR maneuver is the correct treatment in this situation.

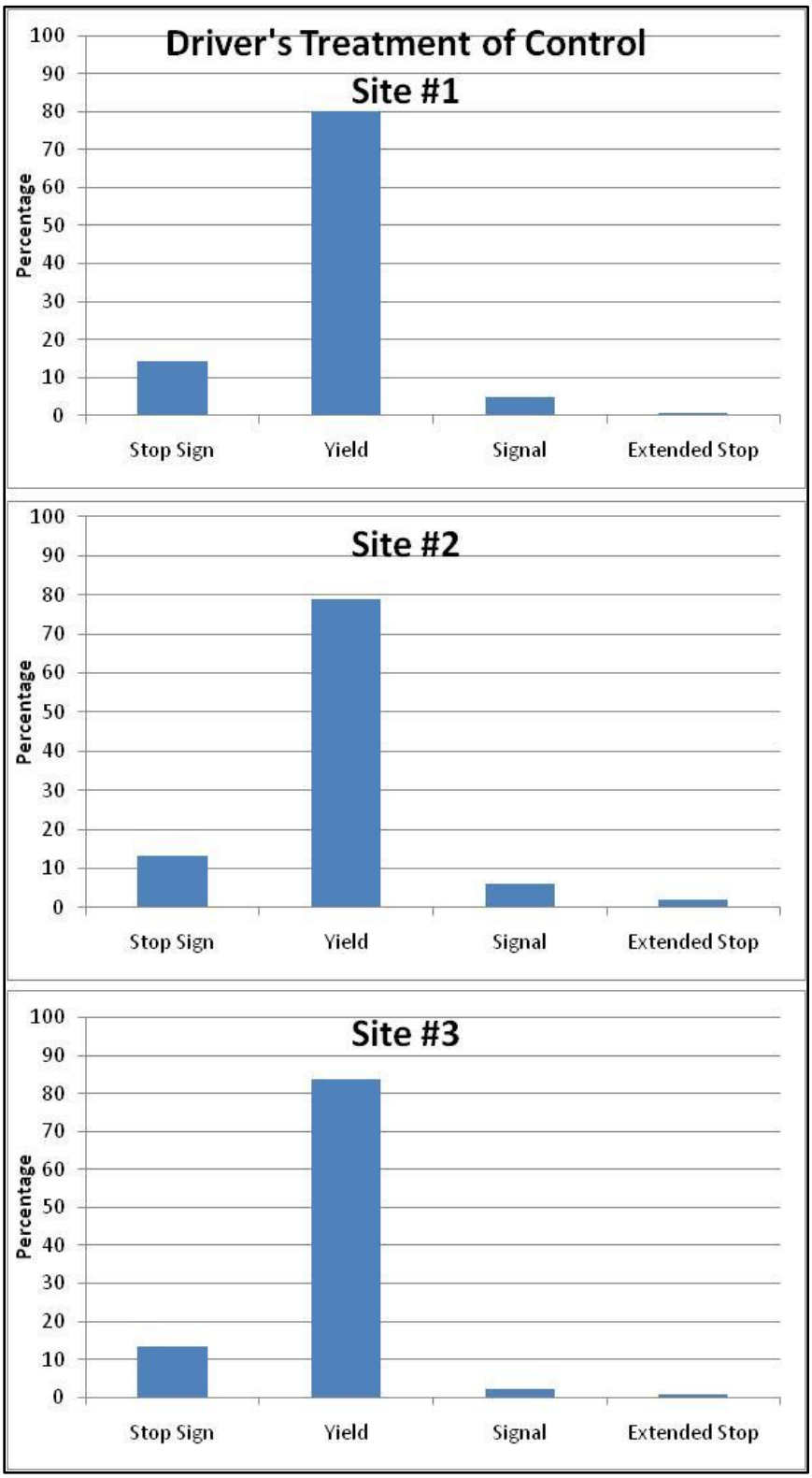


Figure 20: Driver's treatment of control

In summary, Figure 20 shows that most drivers disregarded the channelized right-turning lane's red signal and treated the situation primarily as a yield or stop control, something drivers are used to doing at similar merge situations.

Driver's Stopping Position

The drivers who reacted to the red signal by stopping varied in the stopping position. These are the drivers who treated the red light as signal control, stop control, or performed extended stopping as discussed earlier. Some drivers stopped at the stop bar while others stopped at the merge point (these terms were discussed in Chapter 5). This may be related to the varying layouts of the sites and the driver's intention. In other words, the stop bar at each location was placed in different positions. For instance the stop bar at site #3 was close to the beginning of the channelization where the stop bar for site #1 was at the furthest point downstream. Table 4 shows the stopping position for all drivers who stopped at the red signal at the three study sites. In this analysis, the drivers that encountered a conflict were included while those who were the SVA or arrived at the TTG were excluded.

Table 4: Driver's Stopping Position

Stopping Position	% Stop Sign	% Signal	% Conflict	% Extended Stop
Site #1				
Stop Bar	34.8	11.1	41.1	1.8
Merge Point	1.6	0.8	8.6	0.3
Site #2				
Stop Bar	17.7	8.6	3.0	15.2
Merge Point	4.4	1.7	0.2	49.2
Site #3				
Stop Bar	28.0	4.8	10.7	1.5
Merge Point	4.6	0.4	49.8	0.2

Those that treated the CRTL control as a stop sign mostly stopped at the stop bar, those that encountered a conflict mostly stopped at the merge point. It could follow that many drivers encountering a conflict would have yielded. In other words if a driver intends to stop, the "stop bar" is used, therefore if the conflict did not exist the drivers would have yielded, although this could not be determined by the video. The difference in stopping position could also be attributed to the various locations of where the signals are placed.

Vehicle Type

Heavy vehicles were investigated due to the difference in capabilities as compared with a passenger car (PC). Heavy vehicles need a greater turning radius, more braking time and are typically driven by professionals required to obey traffic regulations by their employers. All of the above could contribute to a behavior difference. Figure 21 shows drivers reaction to the red signal at channelized right-turn lanes for heavy vehicles

and passenger cars. Site #3 was not included in analysis due to the lack of heavy vehicle occurrences.

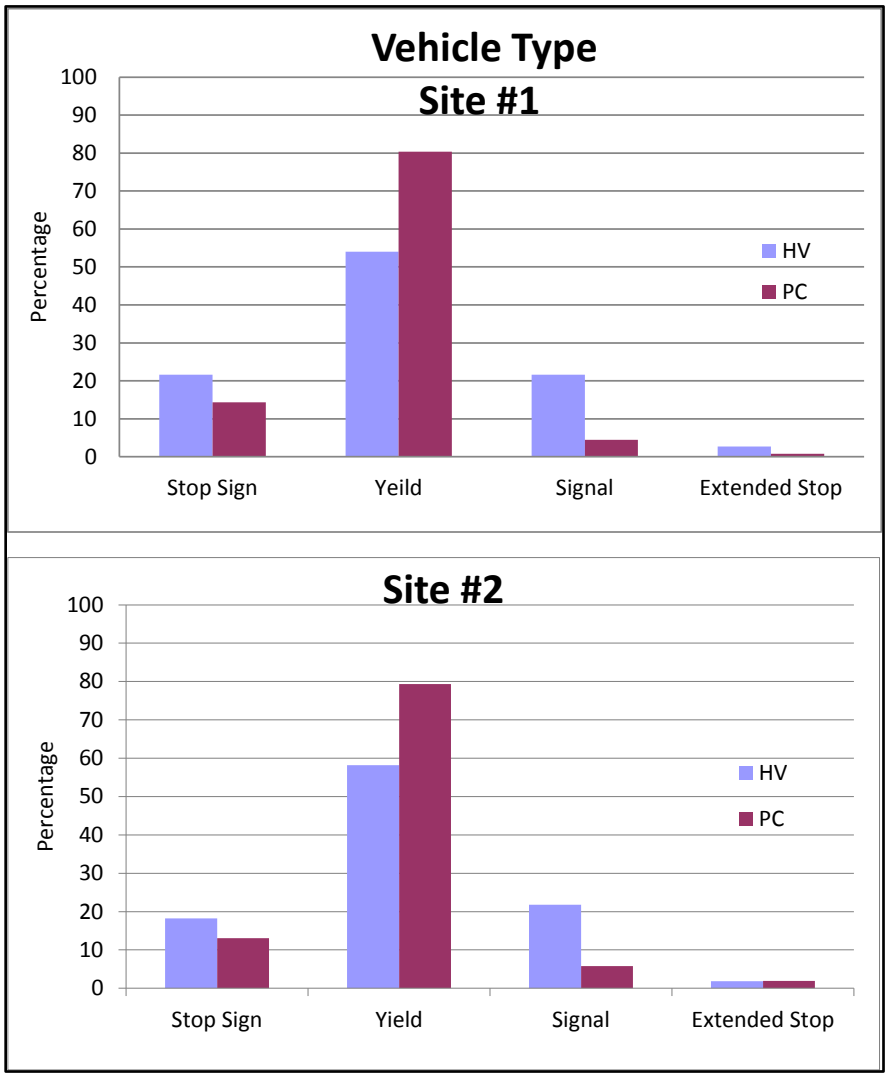


Figure 21: Heavy vehicle and passenger car treatment

As shown in Figure 21 heavy vehicles were found to be more likely to stop compared with passenger cars (i.e. treated the red light as a stop sign, signal control, or performed an extended stop). Of particular importance, the percentage of heavy vehicle drivers who treated the situation as a signal control was about four times the percentage

of PC drivers. Moreover, the percentage of HV drivers who treated the situation as a stop sign was more than the corresponding percentage for PC drivers by around 50% and 38% at study sites #1 and #2 respectively. The Pearson Chi-Square test was performed and results found a significant relationship between the driver treatment of control and vehicle type at the 95% confidence level. Two possible factors are thought to be behind this phenomenon. The first is the fact that HV drivers may be more careful about adhering to traffic rules and regulations. The second possible factor could be due to heavy vehicles requiring a larger time gap between vehicles on the cross street to perform the merge.

Light Condition

The amount of light and visibility provided to drivers may have an implication on their comfort in yielding versus stopping when encountering a red signal at a CRTL. Figure 22 shows the drivers' treatment of control under day and night conditions at the three study sites.

One trend that is evident at all three sites in this figure is that drivers are less likely to treat the red signal as a yield control during the night. The decline in the percentage of drivers treating the situation as a yield control was approximately 27%, 13%, and 14% at study sites #1, #2, and #3 respectively.

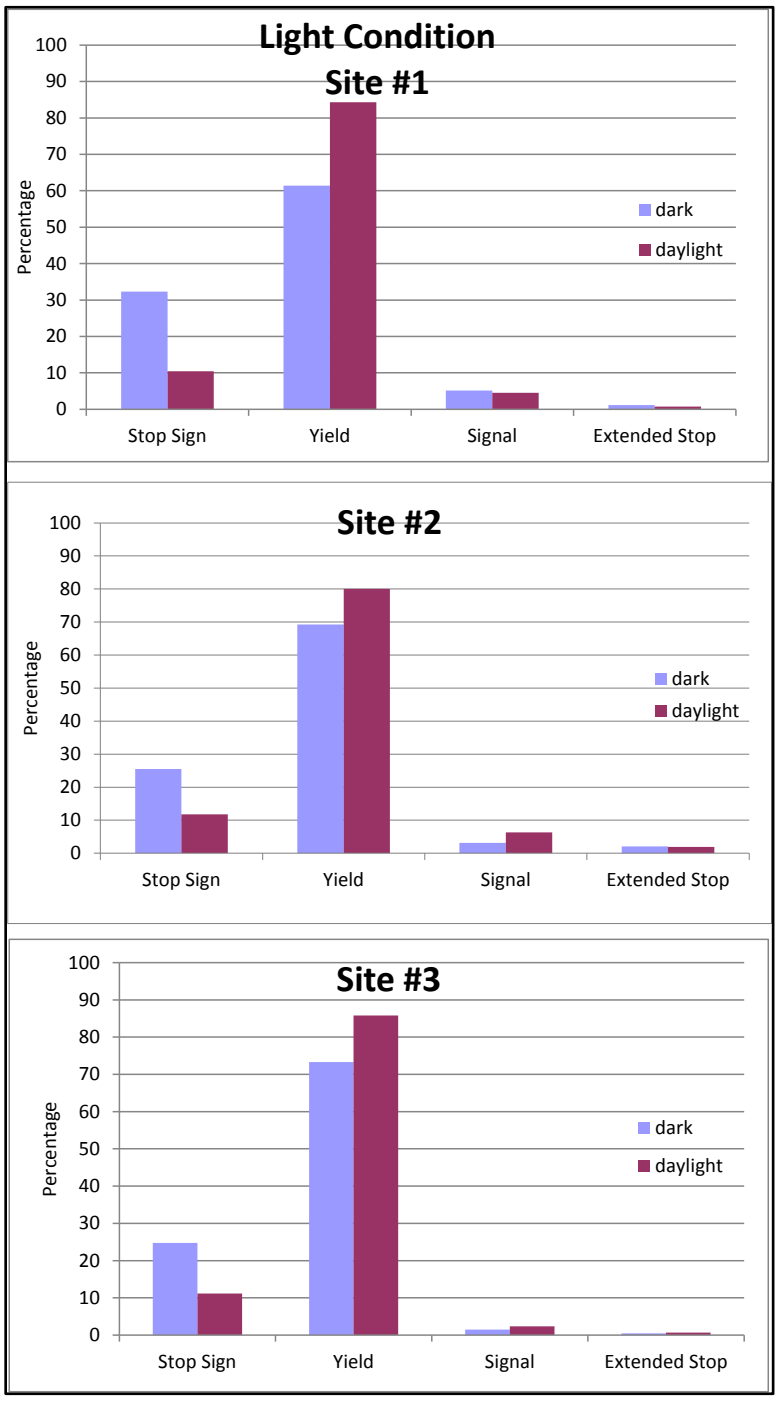


Figure 22: Driver's treatment for dark vs. daylight conditions

Another common trend at the three sites is the increase in the percentage of drivers who treated the situation as a stop control during the night. Specifically, this

increase was in the order of 220%, 127%, and 118% at study sites #1, #2, and #3 respectively. Mixed patterns are exhibited when it comes to treating the situation as a signal control at the three study sites. While the percentage of drivers who treated the situation as a signal control remained roughly the same at study site #1, this percentage declined at site #3 and notably increased at site #2.

The number of observations in the dark was less than those observed in the daylight due to the higher volumes during the day. The Pearson Chi-Square test found the association between drivers' treatment of control and light condition to be significant at the 95% confidence level for all sites. Possible reasons for this finding could be a sense of higher law enforcement in the evening or drivers proceed with more caution in the dark.

Time of Day

Time of day was also of curiosity, as drivers who commute through the sites on a daily basis at approximately the same time (peak hour) may exhibit different behaviors than drivers passing during the off peak. For the purpose of this study, the peak hours were defined to be from 7:00-9:00 am and 4:00-7:00 pm. The research hypothesis is that if a driver is familiar with the operations of the site, they may be more likely to treat the signal as a stop or yield control. Similarly, if a driver is at the head of a stopped queue waiting at the CTRL during a peak hour, they may feel pressured to treat the signal as a stop or yield sign in order to avoid delaying the vehicles behind them. Conversely, drivers during off peak hours may not feel so pressured, or they may exhibit more caution if they do not regularly pass through a site.

Figure 23 shows drivers' treatment of the signal control at the CTRL during peak and off-peak hours at the three study sites.

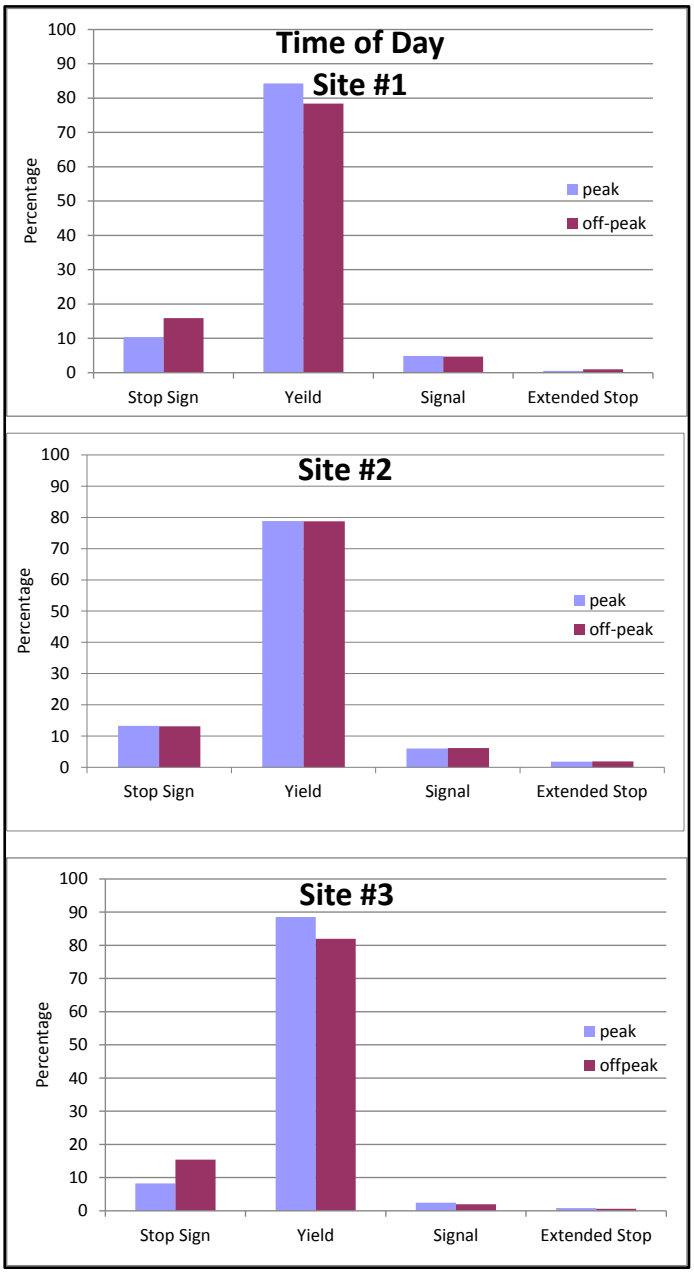


Figure 23: Driver's treatment at peak vs. off-peak hours

In general, drivers exhibited similar behaviors during both the peak and off-peak hours at all sites. A slightly higher percentage of drivers at sites #1 and #3 exhibited a

tendency to yield during the peak hours, while during the off peak hours, a higher percentage of drivers treated the signal as a stop sign. However, those differences are minimal. Results of the Pearson Chi-square confirmed an association between drivers' treatment of control and time of day at the 95% confidence level at site 1 and 3. These sites are located along a commuter route, and are likely to be used by familiar drivers, likely contributing to this finding.

Day of Week

The behavior of drivers on weekdays versus weekends was also of attention, as this may provide further insight into different populations. The motivation behind this evaluation was to further differentiate between driver populations who may regularly pass through the site (weekday commuters) versus those who traverse the intersection less frequently (weekenders). The results are shown below in Figure 24.

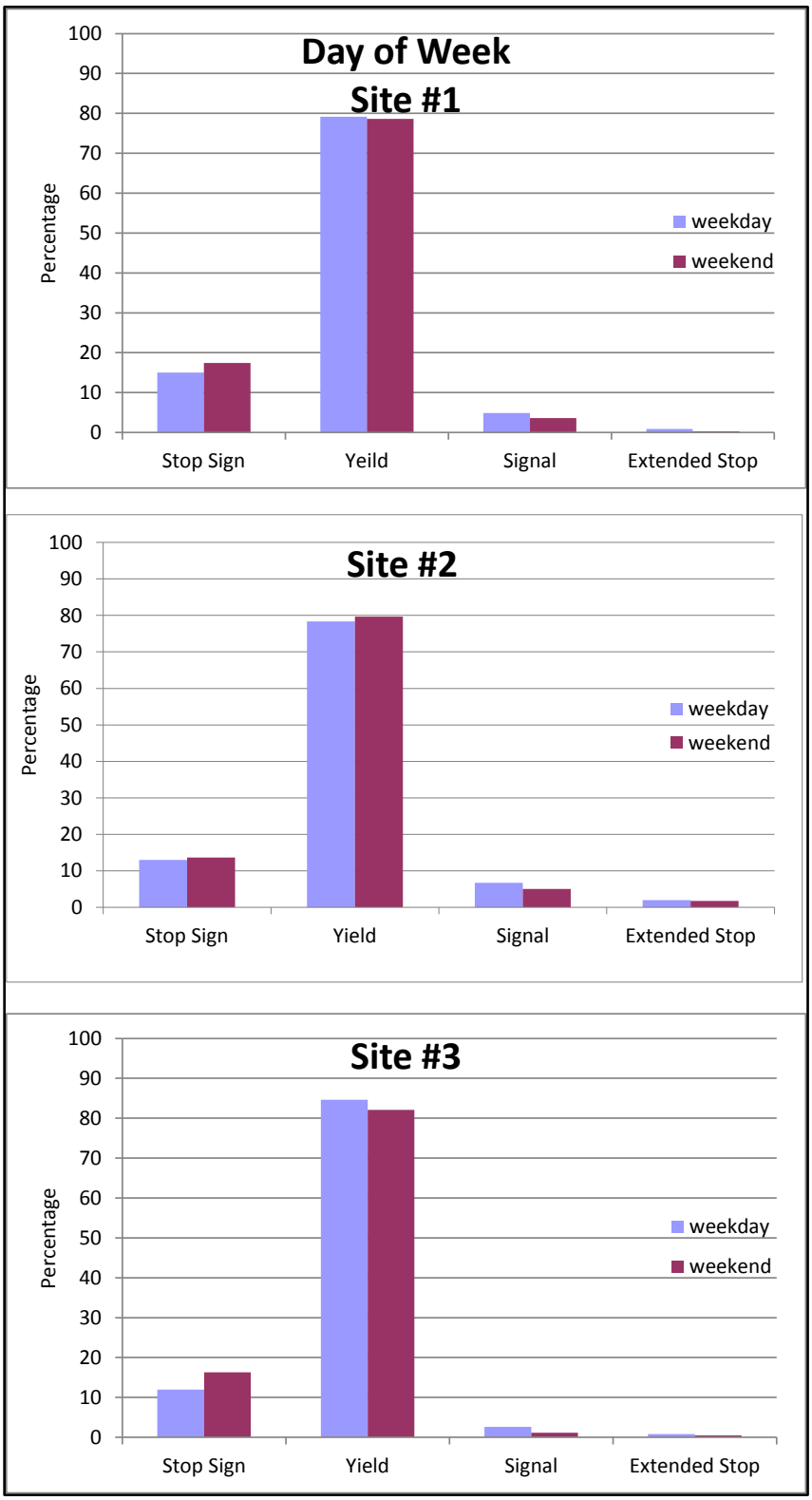


Figure 24: Driver's treatment for weekdays vs. weekends.

A significant relationship did not exist between driver treatment of control and day of week. In fact, only minimal percentages of drivers at site #3 remained stopped for the duration of the signal or any extended period of time. This is somewhat surprising, as this site is located near a museum and serves as a route to other recreational activities; one would assume that drivers traveling to these attractions would be less familiar with the site and exhibit greater caution. One possible explanation is that lower weekend traffic volumes allow for a greater opportunity to proceed through the CRTL unimpeded.

Second Vehicle to Arrive

Another analysis consideration was the behavior of a vehicle following the first vehicle to arrive (FVA). In theory, the second vehicle to arrive (SVA) may be more likely to imitate the behavior of the FVA. This results in the question: How does the SVA treat the control at a site as the result of the FVA stopping?

Note that an SVA condition only occurs if there is a FVA which treats the CRTL as a stop. Following the departure of the FVA, the SVA may treat the CRTL as a stop, signal or yield situation. The results were analyzed to see if the SVA reacted with the same or different behavior. In some instances the behavior was unknown. The possible conditions used to determine the behavior are presented in Table 5 whereas the results of the analysis are shown in Table 6.

Table 5: Second Vehicle to Arrive Conditions

FVA treatment	SVA treatment	Behavior
Condtion 1		
stop	stop	same
	yield	different
	signal	different
	conflict	unknown
	extended stop	different
Condition 2		
stop w/conflict	stop	same
	yield	different
	signal	different
	conflict	unknown
	extended stop	different
Condition 3		
extended stop	stop	different
	yield	different
	signal	different
	conflict	unknown
	extended stop	same

Table 6: SVA Following Behavior

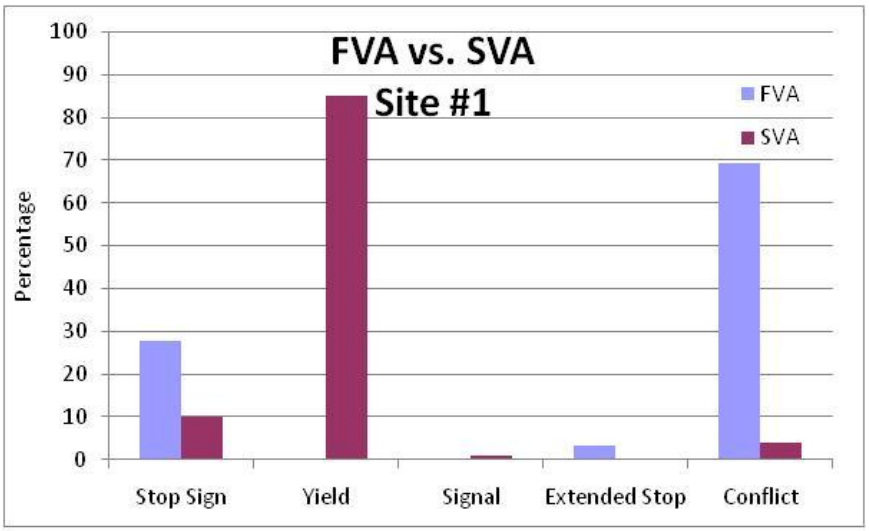
Site	Behavior		
	same	different	unknown
1	22.6	75.5	1.9
2	15.0	70.1	15.0
3	13.3	80.0	6.7

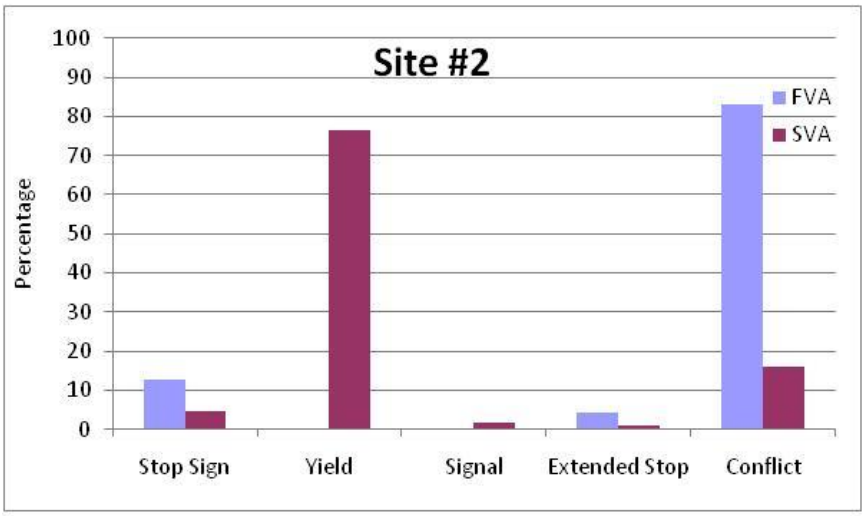
At site #1, 75% of SVA drivers behaved in the same manner as the FVA, while 23% behaved differently, and 2% of SVA behaviors were unknown. Similarly, at site #2, 70% of SVA drivers treated the signal control differently than the FVA, while 15% treated it in a similar manner and 15% of behaviors were unknown. Site #3 behaviors were similar as well with 80% of SVA drivers treating the signal control differently from the FVA, while 13% treated it in the same manner and 7% of behaviors were unknown. The difference in the treatment of the signal control between the FVA and SVA clearly illustrates the differences that exist between driver reactions to CRTL. It emphasizes the

fact that when presented with a CRTL, drivers often do not understand what their expected reaction should be, and tend to behave in a manner that varies from location to location, likely depending on factors such as geometrics, traffic and past experience.

In examining FVA versus SVA behaviors, it is interesting to consider how the presence of an SVA may have influenced the behavior of the FVA. The FVA may have reacted correctly to the signal indication but instead decided to proceed based on the presence of the SVA (concerned with delaying a following vehicle, assuming it was safe to proceed). The potential for this to occur is highlighted by the information presented in Figure 25.

Most FVA drivers initially encountered a conflict and were required to wait before proceeding. SVA drivers consequently treated the control as a yield, as they were likely to simply follow the FVA once the conflict was no longer present. In a limited percentage of cases (less than 2% at each site) SVA drivers treat the CRTL as a signal control. This further emphasizes the lack of understanding by drivers on how to react to CRTL situations.





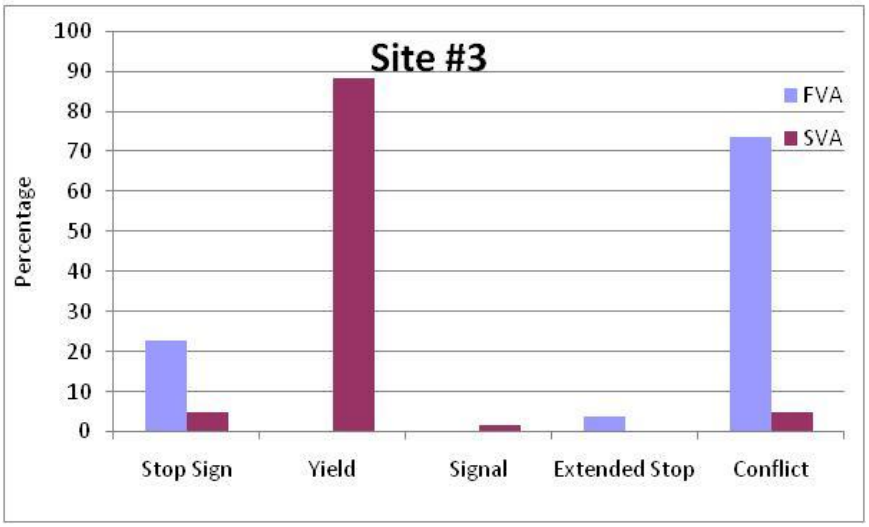


Figure 25: First versus second vehicle behavior

Pearson Chi Square Analysis

The contingency tables associated with each variable and their results are provided below in Table 7 thru 9 for completeness. The use of the Chi-Square tests is inappropriate if any expected frequency is below one, as was the case with the number of observations for the "extended stop" category in some instances. In the cases that the expected frequency was less than one, the category was eliminated from the test. The Pearson Chi Square test was done using online interactive software (Preacher, 2001).

Table 7: Pearson Chi Square Results Site #1

Site #1							
Variable	Treatment				Total	Results	
	stop	yield	signal	extended			
HV	8	20	8	n/a	36	x2=	30.27
PC	412	2311	120	n/a	2843	p=	2.7E-07
					2879		
daylight	242	1952	105	17	2316	x2=	170.11
dark	169	321	27	6	523	p=	0
					2839		
peak	81	658	38	4	781	x2=	16.076
off-peak	338	1667	100	21	2126	p=	0.00109
					2907		
weekday	362	1905	117	22	2406	x2=	6.43
weekend	120	541	25	2	688	p=	0.09222
					3094		

Table 8: Pearson Chi Square Results Site #2

Site #2						
Variable	Treatment				Total	Results
	stop	yield	signal	extended		
HV	10	32	12	n/a	54	x2= 26.64
PC	284	1725	125	n/a	2134	p= 1.64E-06
					2188	
daylight	228	1553	123	37	1941	x2= 31.08
dark	49	133	6	4	192	p= 8.2E-07
					2133	
peak	88	522	40	12	662	x2= 0.05
off-peak	206	1235	97	30	1568	p= 0.99707
					2230	
weekday	191	1155	99	29	1474	x2= 2.757
weekend	103	602	38	13	756	p= 0.43062
					2230	

Table 9: Pearson Chi Square Results Site #3

Site #3						
Variable	Treatment				Total	Results
	stop	yield	signal	extended		
HV	Not Applicable for Site #3					
PC						
daylight	120	920	25	n/a	1065	x2= 27.13
dark	50	148	3	n/a	201	p= 1.28E-06
					1266	
peak	30	323	9	3	365	x2= 11.921
off-peak	146	776	19	6	947	p= 0.007658
					1312	
weekday	105	742	23	7	877	x2= 7.766
weekend	71	357	5	2	435	p= 0.0511
					1312	

Summary of Empirical Study Results

A number of findings of interest have been identified by this research. First, the majority of drivers (more than 70%) treat the CRTL control as a yield, while only a small percentage (less than 7%) treat the CRTL as a signal. This gives emphasis to the lack of driver understanding regarding the expected behavior at CRTLs. Heavy vehicles are more likely to treat the signal as a stop sign, signal control or extended stop at a rate approximately four times the percentage of passenger cars. The Pearson Chi-square confirmed a significant relationship between vehicle type and treatment of control (95% confidence).

Drivers were less likely to treat the signal as yield control at night. Correspondingly, percentages of drivers treating the site as stop control increased at night. The association between drivers' treatment and light conditions was found significant by the Pearson Chi-square (95% confidence). When examined by time of day (peak versus non-peak), drivers exhibited similar behaviors during each period, with significant associations found between treatment of control and time of day (95% confidence). Examining the day of the week (weekday versus weekend) found that weekend drivers showed a greater tendency to treat control as a yield case.

The behavior of the SVA behind a lead vehicle indicated that the second vehicle often treated the control differently from the first vehicle.

CHAPTER 7

SAFETY INVESTIGATION

This chapter documents the original goal and outcomes in regards to a safety investigation at CRTLs.

Before-After Safety Analysis

The safety investigation was envisioned to study crash history at several study sites. The study sites selected would have been those sites with similar estimated traffic exposure as the sites used for the empirical study. The fact (thought) that presumably some traffic control devices were installed in recent years would present a great opportunity for conducting a before-after safety analyses at those locations. Due to the information received regarding concurrent geometry (channelization) and signal installation, the sites were deemed inappropriate for a before and after study.

The before-after analysis would have investigated the crash history of CRTLs before a signal installation and after the signal installation (or vice versa). This would have provided insight into the safety associated with signal control at CRTL versus some other control.

A before-after study could have provided valuable insights into the safety performance of various traffic control devices at channelized right-turn lanes. The following details of the data search are provided for completeness.

Crash summary records were provided by MDT's Safety Management Office for the three study sites used for this research along with other additional sites. The sites and the associated range of dates with data available are listed below:

1) Jackrabbit & Main, Belgrade: July 23, 2003 – December 31, 2008

2) Jackrabbit & Madison, Belgrade: January 1, 2006 – December 31, 2008

3) Kagy & South 3rd/Willson, Bozeman: January 1, 2006 – December 31, 2008

4) 10th Avenue South & Fox Farm/6th Street SW, Great Falls: January 1, 2006 – December 31, 2008

5) 57th & 2nd Avenue N, Great Falls: January 1, 2006 – December 31, 2008

6) Reserve & Mullan, Missoula: January 1, 2006 – December 31, 2008

7) 1st Avenue N & Main, Billings: January 1, 2006 – December 31, 2008

With the aim of conducting a before and after study the "turn on" date for the signal at the CRTL needed to be known. This was provided by the MDT Traffic Engineering Department. Unfortunately, most of these intersections were signalized at the same time the right turn was channelized or the channelized right turn was built and signalized together. The information for each of the intersections is listed below:

1) Jackrabbit & Main, Belgrade: The north bound (NB) right turn lane was channelized before the whole traffic signal was installed, and turned on in 2006.

2) Jackrabbit & Madison, Belgrade: The east bound (EB) right turn was not channelized before the signal was installed in 1999. The right turn lane was channelized and signalized during the 1999 project.

3) Kagy & South 3rd/Wilson, Bozeman: The EB right turn was not channelized before

the 1997 signal project. Plans found before the signalization were from 1983, and verify the right turn was not channelized.

4) 10th Avenue South & Fox Farm/6th Street, Great Falls: Project plans from 1980 indicate that the south bound (SB) and west bound (WB) right turns were channelized and signalized with installation of the whole intersection.

5) 57th & 2nd Avenue N, Great Falls: This signalized intersection was upgraded during a project in 2002. Prior to that project, the NB right turn lane was channelized without signals for the lane.

6) Reserve & Mullan, Missoula: A project in 1998 upgraded the existing traffic signal. The intersection did not have channelized right turn lanes prior to the project.

7) 1st Avenue N & Main, Billings: The earliest plans found were from construction in 1992, and the right turn was channelized and signalized prior to that. There were no project plans showing the existing channelized right turn without signals.

Comparative Analysis

The next logical analysis appropriate for this research was thought to be a comparative analysis since the before-after study was not possible. The comparative analysis study would review the crashes at CRTLs using signal controls paralleled with those CRTLs that had a yield, stop or no control. This required further contact with MDT traffic engineering and safety management departments. An email was sent to many safety management engineers in various counties throughout the state. The email requested location information for sites with CRTLs within the state of Montana. The geometry was verified using Google Earth, since the sites would not be seen in person.

The sites provided that could not be verified as CRTLs using Google Earth were not considered for site selection. The additional sites generated from the email correspondence are listed below:

1) US 93 (Main Street) & Airport Road, Kalispell

2) US 93 & MT 37, Eureka

3) Secondary 486 & Railroad Street, Columbia Falls

4) Route 206 & Montana 35, Kalispell

5) US 2 & MT 40, Columbia Falls

6)P-48 & Crawford Ave, Hardin

7) 1st Ave N & P-16 to I-90,Billings

8) Main St & 6th Ave N, Billings

9) P-4 & P-72, Bridger

The collision diagrams were then provided by the MDT Safety Management division for all the intersections mentioned thus far. In conjunction with the collision diagrams the type of control at each intersection was needed. Unfortunately, a database is not maintained or available by MDT to provide the control type at the intersections or channelization. The lack of information pertaining to control type made further analysis challenging.

The study attempted to use Google Earth as a tool to decipher the control at each CRTL, this however was deemed unacceptable. The date of the intersection viewed from Google Earth was unknown and the type of control was not known with absolute certainty in many instances. Furthermore, the volume data was not available at these sites

and the number of crashes observed in the three year period that involved a right turn movement at the channelization was extremely low or non-existent in most cases.

Crash History at Study Sites

Site #1 had a total of four crashes involving a right turn movement from January 2008 thru December 2010. Three of the four were rear-end collisions with one involving an injury. The other accident at this location involved a bicyclist and a right turning vehicle.

Site #2 had a total of three crashes involving a right turn movement from January 2008 thru December 2010. Two of the three were rear-end collisions and one was a side swipe collision with a vehicle on the cross street.

Site #3 had a total of one crash at the CRTL and was a rear end collision. The crash record dates for this site was the same as the previous. All the rear-end collisions at each site were with both vehicles in the channelized lane, turning right.

Volume data is needed to access the risk at these intersections. The volume for Sites 1 and 3 were able to be estimated using Montana Traffic Count Data available on-line (MDT, 2009). The volumes for sites #1 and #3 were 16,575 vehicles/day and 19,940 vehicles/day, respectively.

There does not appear to be a high level of exposure at these sites however rear-end collisions seem to be the most common.

CHAPTER 8

CONCLUSIONS

Major Findings

Among many findings, perhaps the one with the most confirmation is the violation of driver expectancy. Driver expectancy and consistency is an integral part of the operations and safety of the highway system.

Major findings of this research are listed here:

- Most agencies use volume warrants for use of CRTLs and their control type.
- Capacity and delay benefits may be affected when signals are used with CRTLs.
- The survey revealed the lack of safety data concerning CRTLs and the type of control used.
- Use of CRTLs and the selection of traffic control greatly relies on engineering judgment.
- Only a few agencies reported the use of warrants for signal installation at the CRTL.
- Agencies believe in the safety benefits of signal control at CRTL. No comprehensive studies exist to support this notion.
- Vehicular traffic operations was the most prevalent reason for CRTL use and traffic control selection.

- The field study suggests driver confusion exists when facing a red signal at CRTLs. This could create potential safety concerns.
- When confronted with a red signal indication at a CRTL, more than 70% of drivers yield, approximately 13% stop and less than 7% treat the situation as a signal.
- Drivers yield at the CRTL red signal for two possible reasons:
    1. Drivers do not expect the obligation to stop.
    2. Drivers do not deem the signal appropriate for the CRTL situation.
- Drivers tend to yield less and stop more at a CRTL red signal when the lighting conditions are dark, perhaps proceeding with more caution.

Recommendations for Future Research

This study indicates the need to have comprehensive guidelines concerning the installation of signal control at CRTLs. Further research into the safety and operational aspects of using signal control at CRTL sites is recommended.

Traffic engineering seeks to avoid the violation of driver expectancy and maximize safety. To this end, minimizing driver confusion by traffic control strategies is required. One case where driver confusion seems to exist, as evidenced by this research, is at channelized right turn lanes. This confusion may stem from a lack of understanding on the part of drivers as to the proper response when confronted by a red signal indication for a CRTL. These indications are often presented on a separate mast structure due to the separated nature of the lane from the remaining traffic lanes.

The MUTCD and Montana State Code specify vehicular obligation when confronted with a red signal indication (a red ball and red arrow) but not for a CRTL. As these are an atypical geometric and control case, there is no clear guidance stating the expected behavior of drivers when confronted by a CRTL situation, thus further confusing the issue.

As the results of this work have shown, most drivers do not remain stopped when presented with a red indication in a CRTL. Instead, most appear to violate even the most basic guidance of stopping, verifying that no conflicts exist and then proceeding; instead, most drivers pass through CRTL by performing a yield maneuver. This creates a potential safety concern, and illustrates the need for guidance specific to CRTL.

While further study may be necessary to develop more substantial guidance related to CRTL, some preliminary recommendations are provided here. First, rather than installing a signal control and structure to govern CRTL movements; it may be more feasible to simply install a yield sign. This recommendation is based on the primary finding of this research, which indicated that drivers treat CRTL as yield control a majority of the time. Of course, pedestrian safety considerations would need to be addressed in the case of a yield sign being used.

Second, based on the guidance provided by the MUTCD and modified/adopted at the state level, a change from a red ball to a red arrow might be considered. The red arrow indicates that a motorist may not proceed until they are provided with a permissive indication. In applying a red arrow to CRTL sites, it may be more evident to drivers that they should not proceed until they receive a green arrow. This may increase overall

driver understanding of the appropriate behavior expected in a CRTL situation. A "no turn on red" sign may also convey the same message to motorist.

Further analysis into the safety at CRTLs is needed to fully develop guidance as it relates to CRTLs. It is important to note that the pedestrian levels at these intersection (although an urban setting) were low with volumes of 10 to 20 persons per day. As a future study it would be interesting to investigated driver behavior at a signal controlled CRTL with high pedestrian level.

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APPENDIX A

PRACTICE SURVEY

The following survey is being conducted by the Western Transportation Institute at Montana State University as part of an ongoing project to investigate safety and operational aspects of channelized right-turning lanes at signalized intersections.

The survey is estimated to take 5-8 minutes of your time. Your participation in this survey is essential to the success of the project and is greatly appreciated by the research team.

While you are always encouraged to fill out the questionnaire at your earliest, please make sure to do so by June 26, 2009. Thank you!!

Name _____

Title _____

Agency _____

Telephone number _____

1. Does your agency use channelized right –turning lanes?

yes

no

If no, please explain the considerations/reasons

_____

2. What are the guidelines followed by your agency for the use of channelized right – turning lanes at signalized intersections? Check all which apply.

National guidelines

State guidelines

Engineering judgment

Other guidelines, please specify -

_____

3. In your agency, what are the considerations for the use of channelized right – turning lanes at signalized intersections? Check all which apply.

Operations–high rights turn volume

Safety – vehicular crashes

Safety– pedestrian crashes

Intersection geometry–crossing at oblique angle

Other considerations, please specify

_____

4. What are the guidelines followed by your agency for the selection of traffic control devices for channelized right –turning lanes at signalized intersections? Check all which apply.

National guidelines

State guidelines

Engineering judgment

Other guidelines, please specify -

_____

5. In your agency, what are the considerations for the selection of traffic control devices for channelized right –turning lanes at signalized intersections? Check all which apply.

Operations-vehicular traffic
Operations-pedestrian traffic
Safety – vehicular crashes
Safety– pedestrian crashes
Other considerations, please specify

_____

6. Does your agency follow specific warrants/guidelines for the installation of exclusive signal control at channelized right- turn lanes?

Yes
No
If yes, please specify _____

7. What has been your agency's safety experience with channelized right –turning lanes at signalized intersections?

Improves pedestrian safety
Improves vehicular safety
Decreases pedestrian safety
Decreases vehicular safety
Other, please comment

_____

8. What is your agency's safety experience regarding the use of a yield sign versus a signal control at channelized right –turning lanes at signalized intersections?

Yield Sign:

Improves pedestrian safety
Improves vehicular safety
Decreases pedestrian safety
Decreases vehicular safety
Other, please comment

_____

Signal Control:

Improves pedestrian safety
Improves vehicular safety
Decreases pedestrian safety
Decreases vehicular safety
Other, please comment

_____

9. Please provide any other observations or comments in the space provided below.

_____

_____