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# Channelized right-turn lanes at signalized intersections: the U.S. experience

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**Abstract**

This paper presents an investigation into the current U.S. practice regarding the use of channelized right-turn lanes at signalized intersections, the type of traffic control used, and the safety experience of highway agencies. The study involved a literature review and a practice survey, which was distributed to all state and selected local agencies in the United States. The literature review revealed the overall lack of knowledge about the operational and safety aspects of channelized right-turn lanes explaining, to a large extent, the lack of guidance in practice. 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 by studies or statistics. The study emphasized the need for further research on the operational and safety aspects of this right-turn treatment at intersections.

*Keywords – right-turn, signalized intersections, channelization, survey*

## 1. Introduction

Turning movements have a determining effect on the safety and operations at signalized intersections. Therefore, various treatments of turning movements have been the focus of attention of those involved in the design and operations of intersection signal control. The focus of the current study is channelized right-turning lanes (CRTL), which is one of the treatments of the right-turning movement at intersections.

Right-turn movements at signalized intersections are subject to multiple treatments. Lower volume intersections typically involve a shared lane for the through and right-turning traffic. As traffic level increases including the right-turning traffic, the need for providing an exclusive right-turn lane also increases. Providing exclusive turning lanes at signalized intersections has become common practice at new intersections as well as in many improvement and upgrade projects at existing older intersections. 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 the 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. While CRTL using raised (curbed) islands is the focus of this investigation, an overview of CRTL general design elements is provided in the subsequent section.

Among the benefits of using channelized right-turning movements are increased capacity, reduced delay and number of stops, improved safety particularly at skewed intersections, and a better accommodation of heavy vehicles by using larger turning radii without unnecessarily increasing the pavement area. 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 [1].

Other benefits of CRTL may include reducing right-turn queues and lowering emissions [2].In the case of channelization using curbed islands, it also provides an area of refuge for pedestrians and a location for traffic control devices [3].

For CRTL using curbed islands, access control for right turning vehicles is typically treated in practice using yield control, stop sign control, traffic signals, or no traffic control device [4]. Further, channelized right turn lanes may be used with either deceleration lanes, acceleration lanes or both, depending on vehicle speeds, traffic volumes, percentage of trucks or the type of service provided [3].

The subject of right-turn movements has not been as much a focus as left-turn lanes, as the right-turn movements involve fewer conflicts [5]. This lack of attention was evident in the initial literature review conducted in the course of this study. While the limitation in the guidance applies to all aspects of CRTL at intersections, it is particularly true for the selection of the most appropriate type of traffic control. The type of control used has a significant impact on operations and safety, particularly traffic signals. Traffic signals are one of the most restrictive forms of traffic control that can be used and should be limited to favorable situations [6]. Therefore 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 at intersections, yet similar guidelines are not in place for the type of control used for channelized turning movements. This may present a safety concern as driver's expectancy may be violated and either the driver takes longer to respond properly or he/she may respond incorrectly. The channelization and traffic control used at an intersection should, as a minimum, avoid violating driver expectations, and should desirably reinforce these expectations [1].

## 2. Background

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

### *2.1. CRTL design elements*

The CRTL design elements such as islands, corner radius, lane widths and storage lanes are shown in Figure 1.

These design components shown in Figure 1 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 define the design elements for this treatment. Right turning lanes can either be designed with or without an island as shown in Figure 1.

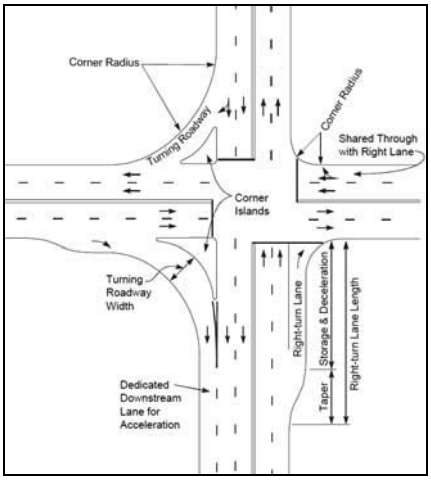


Fig. 1 - Right turning lane design elements [2]

The west and south approaches show the use of islands while, the east and north approaches do not have islands as part of the turning lane design. Islands are typically designed to be triangular, with the turning lane side curved to match the alignment of the roadway.

Three primary functions of providing an island are to channelize turning traffic, to divide traffic streams for through movements, and to provide a refuge for pedestrians [3]. An island also serves the following purposes:

- Separation of conflicts
- Control of angle of conflict
- Reduction in excessive pavement areas
- Regulation of traffic and indication of proper use of intersection
- Arrangements to favor a predominant turning movement
- Protection of pedestrians
- Protection and storage of turning and crossing vehicles
- Location of traffic control devices

The corner radius and lane width are principal design controls of turning roadways. The radius and width affect how drivers traverse the intersection. These design components determine both the operating speed and path of a driver. The combination of the width and radius relates to 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) but accommodates heavy vehicle traffic. This can impose the need for an island to meet a compromise for the needs of conflicting users. A large corner radius influences the speed of vehicles and may cause a concern for pedestrian safety.

Right turning vehicles typically need to reduce their speed. The use of a deceleration lane can be used to reduce conflicts with through vehicles especially in high volume areas or if there is large speed differentials for turning vehicles. Likewise, acceleration lanes may be used for the vehicles to reach the cross street operating speed particularly in high volume areas. The length of the deceleration lane should consider that the queue from the through-movement traffic may block the entry to the right-turn lane; therefore, both the right-turn and the through-movement queues should be reviewed when the length of the right-turn lane is being established [2].

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, CRTL are often designed for unimpeded vehicular movements, leaving pedestrians vulnerable to high speeds. Therefore, CRTL intersections designed to accommodate safe pedestrian crossings using tight curb radii and shorter crossing distances can be less problematic to pedestrians [7].

### *2.2. Design guidance in the U.S.*

This section provides an overview of the national design practice in the U.S. found in the various reference materials 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.

States generally refer to American Association of State Highway Transportation Officials (AASHTO) *Policy on Geometric Design of Highways and Streets* (known as the Green Book) for guidance on highway design. The AASHTO is a non-government organization that publishes specifications and guidelines for use in highway design and construction throughout the United States. The AASHTO Green Book provides guidance on the design of channelized right turns under the topic of turning roadways [3]. 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 indicates 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 [8].

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 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. The manual states 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" [9].

The National Cooperative Highway Research Program (NCHRP) conducts research in problem areas that affect highway planning, design, construction, operation, and maintenance nationwide. The Intersection Channelization Design Guide (NCHRP Report 279) recommends using CRTL 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 [10]. It provides the most extensive discussion of considerations found for right-turn lanes but offers no quantifiable guidelines [5]. This guide addresses topics such as the functional objectives of channelization, safe merging, principle of channelization and guidelines for design elements. 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 [1] published by the Institute of Transportation Engineers (ITE) refers the user to the Intersection Channelization Design Guide, NCHRP Report 279 for a detailed description of the techniques that have proven effective and lists nine principles of intersection channelization. It also provides warrants for turning lanes based on daily hourly directional volumes versus right turn volumes.

The following nine principles of channelization apply to intersection design:

1: Undesirable or wrong way movements should be physically discouraged.
2. Desirable vehicle paths should be clearly defined.
3. Desirable or safe vehicle speeds should be encouraged.
4. Points of conflict should be separated if possible.
5. Traffic streams should cross at right angles and merge at flat angles.
6. High priority traffic movements should be facilitated.
7. 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 fro pedestrians and other non-motorized vehicle users.

### *2.3. Existing CRTL research*

Several other studies in the literature have addressed other topics such as the effect of skewness and channelization on drivers performance [12] and the effects of right turn movements on traffic operations [13, 14].

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 [15]. 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 [4] concluded that channelization 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.

A recent study in Texas [2] evaluated the safety associated with various right turn lane designs (i.e. right-turn lane with lane line, right-turn with island, shared through and right-turn lane, and shared through and right-turn lane with island). The designs were assessed to determine the variables that affect free flow speeds of turning vehicles [2]. This study found that the variables that affect the turning speed at an exclusive right-turn lane with an island 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 [2]. The treatment with the highest number of crashes in the Georgia study and the second highest number of crashes in the Texas study was the right-turn lane with raised islands [2].

The aforementioned studies in Texas and Georgia used intersections with either yield or no control, the use of signal control does not appear to be investigated in the research.

## 3. Research motivation

The limited guidance in practice concerning the use of CRTL and the selection of traffic control controlling access to the crossing roadway was the main impetus for the current study. The main objective of the study is to review the current state of practice as related to the use of

CRTL at signalized intersections, 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 traffic control devices intended for vehicles entering the channelized lanes.

## 4. Survey of highway agencies

The state of practice was examined regarding various aspects of the use of the CRTL at signalized intersections. An online questionnaire 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 transportations (DOTs) while the second group involved 109 cities and municipalities across the United States. Prospective participants at those agencies were identified using the AASHTO subcommittee on traffic engineering and the ITE traffic engineering council. A total of 37 state DOTs answered the questionnaire representing a 74-percent response rate. On the other hand, 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 addressed the following aspects of the current practice in using CRTL at signalized intersections:

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

Despite the relatively high number of agencies who participated in the practice survey, survey results on the current practice are only accurate for those agencies that chose to participate. The generalization in the discussion of results implies a reasonable representation of respondent agencies to other highway agencies in the U.S.

### *4.1. The use of channelized right-turn lanes at signalized intersections*

Although the national design documents and tools provide some high-level guidelines for the design of CRTL, 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 the CRTL 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 CRTL. One agency noted that CRTL are used heavily in roundabout designs but there has not been a benefit to implementing this treatment at signalized intersections.

When asked about the guidelines for the use of channelized right turning lanes in intersection design, 62-percent of the state agencies that use channelized right turning lanes reported using national guidelines versus 50-percent state guidelines. Moreover, 74-percent reported the use of engineering judgment while only 9-prercent 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.

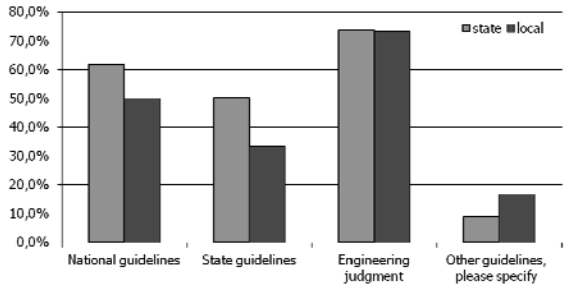


Fig. 2 - Guidelines used by state and local agencies for the use of CRTL

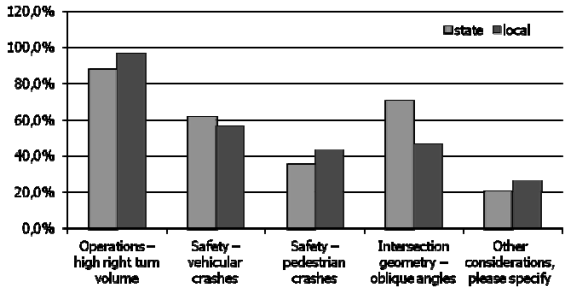


Fig. 3 - Considerations for the use of CRTL

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 2 shows the questionnaire results regarding the guidelines followed by state and local agencies. One state agency specified NCHRP 457 [16] as a source of guidelines for the use of CRTL 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 was reported as the second most frequent considerations 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 3.

Among other major considerations stated by state and local agencies are presence of bicycle facilities, corridor coordination improvement, pedestrian traffic, vehicle mix, and location for installation of signal heads and other street hardware.

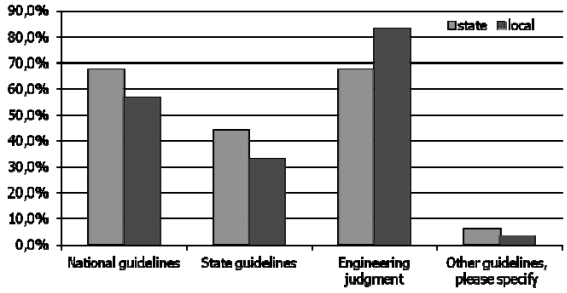


Fig. 4 - Guidelines used by state and local agencies for traffic control at CRTL

*4.2. Access control at channelized right-turn lanes*

Various types of traffic control devices may be used to control access at CRTL including yield control, stop control, traffic signals, and no control. 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 4 shows the questionnaire results for the guidelines used by state and local agencies in the selection of traffic control at CRTL.

The fact that 50-percent of the state DOTs use the MUTCD in complete conformance [17], 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. However, it was interesting to get 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…”

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 was 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 5.

Other considerations provided by survey participants included bicycle activity, vehicular traffic character and composition, available sight distance, speed, and geometric layout considerations. One question in the survey was more specific in asking highway agencies whether they use formal warrants for the installation of exclusive signal control at CRTL. Surprisingly, only around 12-percent of state and 27-percent of local highway agencies reported the use of such warrants in installing signal control at CRTL.

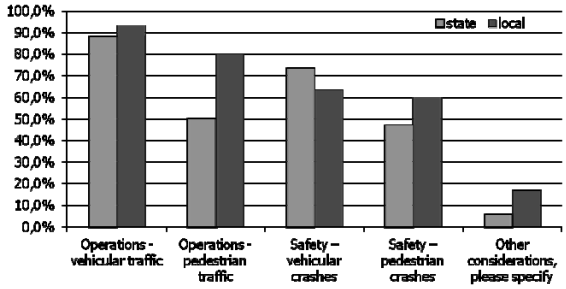


Fig. 5 - Considerations for traffic control device selection at CRTL

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.

*4.3. Safety experience*

Safety is an important issue to consider when it comes to the use of CRTL at signalized intersections. Channelization separate traffic movements and minimize 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 [18]. 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.

It was therefore important to examine the practice for the safety experience of this intersection treatment. 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 pedestrians safety, as fewer agencies thought of this treatment to improve pedestrians safety (30-percent of state and 37-percent of local agencies) and more agencies thought of this treatment to decrease 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 6.

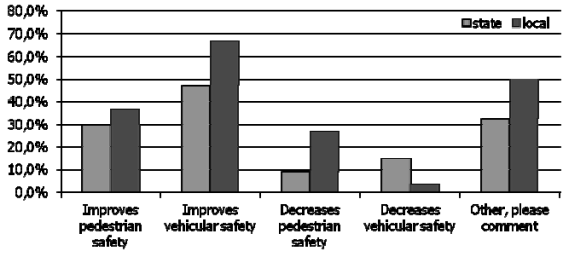


Fig. 6 - Agency saftey expereince with the use of CRTL


Fig. 7 - Agency safety experience with the use of yield signs at CRTL

Many comments were made in response to this question which 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. While there was overwhelming agreement among participants about the operational benefits of CRTL, numerous comments were made that safety data and studies simply does not exist to answer this question. This shows the need for future research into the safety aspects of CRTL at signalized intersections.

Another important issue concerned with the safety at CRTL 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.

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 7. 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 8 shows the agency safety experience with signal control at CRTL. Again, there is a high level of agreement among state and local agencies about the safety aspects of using signalization to control access at CRTL. It is interesting 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.

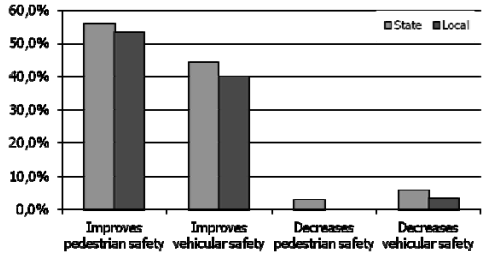


Fig. 8 - Agency saftey expereince with the use of signals at CRTL

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.

## 5. Summary of findings

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 a hundred cities and municipalities across the United States. The three major focus areas in the survey were the use of CRTL 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 on using 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 CRTL.
- There is an overwhelming perception by most state and local agencies about the safety benefits of signal control at CRTL. 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 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 essential in developing guidelines for the use of this treatment as well as for the selection of the most appropriate control type at CRTL. As such, further research is needed on the operational and safety aspects of using this treatment and the type of traffic control used.

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