Right-Turn Treatment for Signalized Intersections

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ABSTRACT

Historically, engineers have designed intersections characterized by sizeable right-turn volumes using a variety of strategies. For example, channelization in the form of a painted island, small raised island, or a large raised island is one element often incorporated into the design. In addition, traffic control may be addressed using right-turn-on-red, dedicated turn lanes with stop control, or dedicated turn lanes with yield control.

This paper focuses on how Cobb County, Georgia, located in the metro-Atlanta area, handles these right-turn movements. The study identifies application of various right-turn strategies based on observed field operation conditions. A comparative analysis of applications based on a two-year crash history helps to identify (preliminarily) possible safety limitations associated with the various right-turn strategies. The primary objective of this study is to share considerations, strategies, and limitations of the various right-turn configurations and to identify strategies appropriate for further in-depth analysis.

INTRODUCTION

A challenging issue transportation engineers responsible for the design of urban roads must address is the optimal design and operation of signalized intersections. Previous research has focused on many elements of intersection design including left-turn configurations, signal timings, proximate driveway placement, and heavy-vehicle maneuverability; however, to date research offers at best minimal evaluation of right-turn treatments at signalized intersections. The objective of this paper, therefore, is to identify candidate single right-turn treatments, summarize the limited research regarding these treatments, report on observations of each right-turn treatment, and evaluate operation of select treatments based on a two-year crash history. The ultimate goal of the research described in this paper is to identify specific right-turn treatments that warrant in-depth study as a result of preliminary indicators determined in this analysis.

The sites identified for right-turn treatment evaluation are located in Cobb County, Georgia. Cobb County is a north metro-Atlanta county. In recent years, Cobb County has experienced rapid growth with direct impacts upon the roadway infrastructure and its operation. Over the past 13 years, Cobb citizens have voted collection of a 1 percent special purpose local-option sales tax for transportation improvements. As a result of the tax revenues coupled with nonlocal leveraged funding, in excess of $1 billion in transportation improvements have been invested in the rapidly growing Cobb County area. Numerous right-turn treatment scenarios have been implemented throughout Cobb County during this rapid development. These single right-turn treatments are the focus of this study.

PREVIOUS RESEARCH AND CURRENT GUIDELINES

Four specific focus areas must be evaluated when considering the proper design of right-turn movements at signalized intersections:

1. The suitability of the intersection for a right-turn-on-red (RTOR) movement;
2. The right-turn lane configuration (shared with other movements, exclusive lane, etc.);
3. Traffic islands; and
4. Cross street lane merge characteristics/configurations and supplemental traffic control devices.

Right-Turn-on-Red Movement

By the late 1970s, the individual states in the United States had each adopted a RTOR policy whereby right-turn movements were permitted after the driver stopped unless specifically prohibited by a sign. Several studies have shown that RTOR increased the frequency of right-turning crashes at signalized intersections, especially crashes involving pedestrians and bicyclists (*1*). When a right-turn movement at a signalized intersection is "shadowed" by a protected left-turn signal on the cross street, RTOR movements can be completed successfully without any concern for cross street gaps in traffic. Since RTOR drivers are required to come to a stop before making the turn, the driver must incur delay as a result of this enforced stop condition. Right-turn vehicles often use shared lanes where the vehicles may occupy the same lane as vehicles turning left or progressing straight through the intersection. The use of shared lanes will often impede the RTOR movement. Narrow or sharp roadway geometry may also be counterproductive to the RTOR movement. Lin (*2*) determined that a small increase in the approach width of an intersection would drastically raise the rate of RTOR use.

The *Highway Capacity Manual* (*3*) identifies seven factors that influence optimal use of RTOR movements as:

- Approach lane (shared or exclusive);
- Demand (generally based on hourly volumes);
- Sight distance at the intersection approach;
- Degree of saturation (elevated conflicting movements);
- Arrival patterns;

- Left-turn signal phasing on conflicting street; and
- Conflicts with pedestrians.

These seven items not only offer understanding on how well a RTOR movement may function, but generally are factors that should influence which type of right-turn treatment should be considered. It is important to note the seventh influence identified above refers to pedestrian conflicts. As previously stated, this item should be extended to bicycle traffic if appropriate for the candidate site.

Lane Configuration

Often the right-turn movement must occupy a lane shared with vehicles that are left-turn or through movement vehicles. Clearly, the likelihood for a right-turn vehicle to proceed through the intersection unimpeded after the driver stops and perceives an acceptable gap is directly dependent upon where the driver's vehicle occurs in the traffic queue and what vehicles (straight or left-turning) are positioned between the driver and the intersection. Often an exclusive right-turn lane may be warranted to minimize the delays incurred due to vehicles on the same intersection approach. Right-turn lane warrants are suggested in the *Traffic Engineering Handbook* (*4*) as:

- Volume of right turns;
- History of right-turning rear-end crashes;
- Speed of the highway; and
- Land-use availability.

The taper and lane-length design are also based on deceleration, storage, or both. Lin (*2*) concurs with these warrants and also suggests that the ability of an auxiliary right-turn lane to reduce vehicle delays also depends on the RTOR policy, type of signal control and signal timing settings, and the pedestrian flows. McCoy, Bonneson, Ataullah, and Eitel (*5*) offer right-turn lane guidelines for urban two-lane and four-lane approaches. Their guidelines suggest appropriate thresholds for right-turn lanes based on the design hourly volume for the roadway, the minimum right-turn volume, and the roadway speed. They also suggest alternative lane requirements based on the need to acquire right-of-way and the associated expense of the right-of-way.

Islands

The use of channelization or traffic islands is common for delineation of right-turn movements. *A Policy on Geometric Design of Highways and Streets* (*6*) identifies three primary functions of islands. These include channelization (to control and direct traffic movement, usually turning), division (to divide opposing or same direction traffic streams, usually through movements), and refuge for pedestrians. Most islands combine more than one of the functions suggested. The *Traffic Engineering Handbook* (*4*) also recommends channelization to facilitate high-priority traffic movements and traffic control schemes. The handbook also recommends the use of channelization to remove decelerating, stopped, or slow vehicles from high-speed through-traffic streams.

Traffic islands can be painted or raised (curbed). Painted or flush islands are often used in lightly developed areas, at intersections where approach speeds are relatively high, at locations with very little pedestrian traffic, where fixed-source lighting is not available, and only where signals, signs or lighting standards are not needed on the island (*6*). Painted islands can also delineate turning lanes where room is not available for a raised island (*4*). Though painted islands are convenient for locations where snow removal may be required on a regular basis, the inclement weather decreases the effectiveness of the marked channelization.

Raised or curbed islands offer a more restrictive channelization of the right turn than flush islands. The raised island can be used as a refuge for pedestrians, a location for safe sign and traffic control device placement, a physical restriction for prohibiting undesirable traffic movements, and a technique for reducing excessive pavement areas that may permit and encourage uncontrolled vehicle movements. The used of curbed islands generally should be reserved for multilane highways or streets located in or near urban areas (*6*).

Cross-Street Lane Merge Characteristics

Little is known about how cross-street lane geometry should be modified to accommodate right-turn volumes. The most common right-turn movement facilitates a simple merge with the cross-street traffic in a shared lane. For high-volume right-turn movements, an additional lane is often added to the cross street in an effort to facilitate unimpeded right-turn movements. A third scenario is a cross-street acceleration lane for vehicles to complete the right-turn movement unimpeded and then accelerate parallel to the cross-street traffic prior to merging.

For signalized intersections, the right-turn movement operates under the traffic control of the traffic signal; however, when the right turn is physically separated from the adjacent approach traffic, alternative traffic control measures are often implemented. For example, a yield sign is commonly positioned for a right-turn movement that coincides with a signalized intersection. The use of these supplemental signs is one of the treatment influences that will be discussed in further detail in this paper. The authors were unable to locate previous research evaluating the influence of these supplemental signs in combination with right-turn treatments.

COMMON RIGHT-TURN TREATMENTS

For purposes of this effort, a right turn at a signalized intersection is considered a combination of entrance and exit treatments. "Entrance" will be used to describe the upstream, or entry point, geometric feature used by vehicles executing a right turn. This entrance treatment includes type of island (if used) and turn lane configuration. "Exit" will be described as the geometric condition and/or the traffic control device at the point at which the right-turning vehicle enters the conflicting stream of traffic. While it may seem unusual to combine geometric conditions and traffic control devices into the single category of "exit treatment," exit geometry and traffic control devices are dependent upon each other and must be evaluated as a combination of both influences.

Entrance Treatments

Five specific entrance treatments occur commonly for conventional right-turn movements in Cobb County. Figure 1 depicts a graphic representation of each of the following entrance treatments.

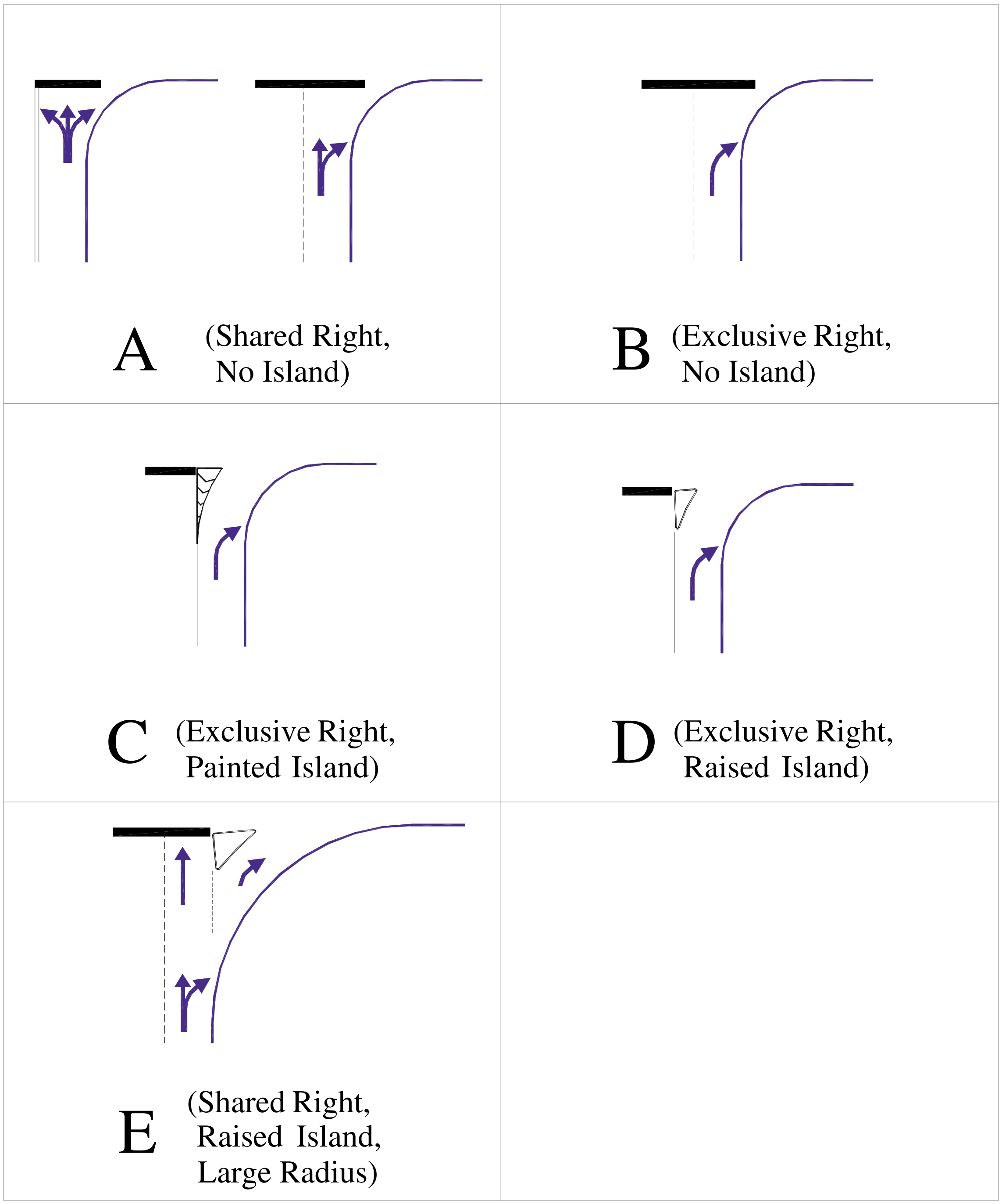

FIGURE 1 Entrance treatments.

1. Treatment A occurs when the right turn is executed from a shared lane. There may be one or multiple approach lanes. No islands (painted or raised) are present in conjunction with this treatment.
2. Treatment B has an exclusive right-turn lane. No islands (painted or raised) are present in conjunction with this treatment.
3. Treatment C has an exclusive right-turn lane, as in Treatment B, and a painted triangular island constructed as a separation between the right-turn and the through movement.
4. Treatment D is similar to treatment C but has a raised island rather than the painted island in Treatment C.
5. Treatment E is not an exclusive right-turn lane, as in treatments B, C, or D, but is simply a raised triangular island used to minimize the area of surface pavement resulting from a large right-turn radius. While right-turn vehicle storage is not a primary objective of this treatment, the treatment can accommodate two to three right-turning vehicles due to its unique geometry if same-approach, through-movement vehicles do not prohibit access to the turn.

Exit Treatments

Figure 2 depicts six right-turn exit treatments common to Cobb County, summarized as follows:

1. Treatment 1 occurs when the right turn is used to add a through lane to the cross street. Typically there will be no additional traffic control associated with this exit treatment, as there is no explicitly conflicting movement.
2. Exit treatment 2 includes a Yield sign as additional traffic control for the right-turning vehicle to assign right of way separately from the traffic signal at the intersection. The right-turn movement, in this treatment, merges with the cross street through traffic.
3. Exit treatment 3 includes a Stop sign as traffic control for the right-turning vehicle to assign right of way separately from the traffic signal at the intersection. The right-turn movement, in this treatment, merges with the cross street through traffic.
4. Treatment 4 is the explicit signalization of the right-turn lane, possibly as an overlap movement. This signal control is not simply concurrent with the adjacent through movement green cycle, but provides some additional right-turn "green time." The right-turn movement, in this treatment, merges with the cross street through traffic.
5. Treatment 5 is characterized by the absence of any supplemental traffic control devices (such as those described in treatments 2, 3, and 4). The right-turning vehicle must merge with through traffic on the conflicting street. In "right-turn-on-red" jurisdictions, the right-turning vehicle must yield right of way to all cross street traffic at this exit treatment.
6. Treatment 6 is similar to exit treatment 1 but in addition a Yield sign is provided as supplemental traffic control. Since the right-turn movement is directed into an additional cross street lane the use of a Yield sign does not appear necessary; however, this scenario is appropriate in regions where the cross street through movement traffic may be characterized by frequent lane changes due to adjacent land use. For example, the presence of a driveway proximate to an additional lane may create elevated lane changes for cross street traffic. Interestingly, this exit treatment was also observed in regions where other intersection legs required this specific scenario but the turn in question did

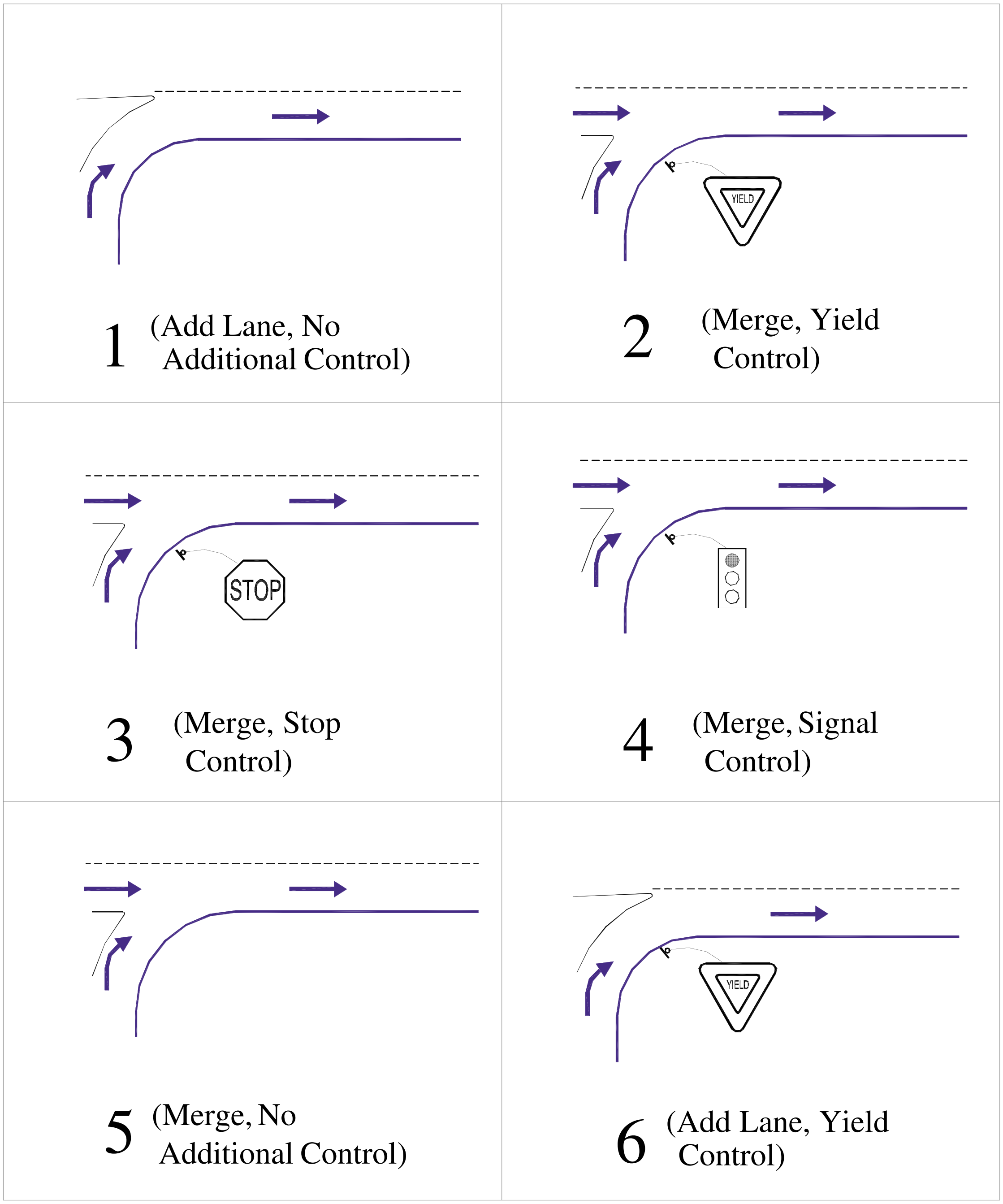

FIGURE 2 Exit treatments.

not. This use of the Yield sign may be due to an effort by the engineer to maintain consistency between similar legs at the same intersection.

POTENTIAL PERCEPTIONS AND ISSUES

Some of the above-described treatments bring with them the potential for misconceptions and confusion on the part of the motoring public. Motorists, for example, often misuse entrance treatments B or C, during periods of high right-turn traffic (especially in conjunction with low concurrent through traffic), where they might attempt to make dual right-turn lanes involving the right-turn lane and the adjacent through lane. Entrance treatment E can often be misconstrued as treatment D, if pavement width on the intersection approach is generous. During congested traffic periods, motorists may elect to "make the most" of unstriped right-turn storage that entrance treatment E might unintentionally provide.

Exit treatment 1 is often a source of confusion for motorists who anticipate a merge with conflicting traffic and assume the existence of a "Yield" sign (or yield condition). A "Keep Moving" sign positioned where the "Yield" sign typically is located may be an appropriate alternative to no sign at locations characterized by high right-turn volumes. Exit treatment 6 situations have a "Yield" sign (where perhaps one may not be expected) to assign right of way to the through movement on the cross street due to the presence of a proximate driveway or cross street. This condition often introduces a weaving traffic movement.

Exit treatments 2 and 3 are potential sources of confusion if the right-turn channelization does not adequately direct the right-turning traffic away from the traffic signal. If this redirection is not adequate, it may not be clear which traffic control device (traffic signal or "Yield"/"Stop" sign) governs this movement. Exit treatment 5, in contrast, could be a source of confusion if the physical intersection geometry redirects right-turning traffic in such a manner that the signal is no longer within the driver's cone of vision. Exit treatments 2, 3 and 5 can also create confusion in terms of assigning right of way between right-turning vehicles and conflicting left- or U-turning vehicles. Figure 3 depicts this conflict, often observed between the opposing left-turning vehicle with the right-turning vehicle.

TREATMENT EVALUATION

As previously stated, one of the purposes of the analysis here was to identify common exit and entrance treatment combinations typical to Cobb County right-turn movements

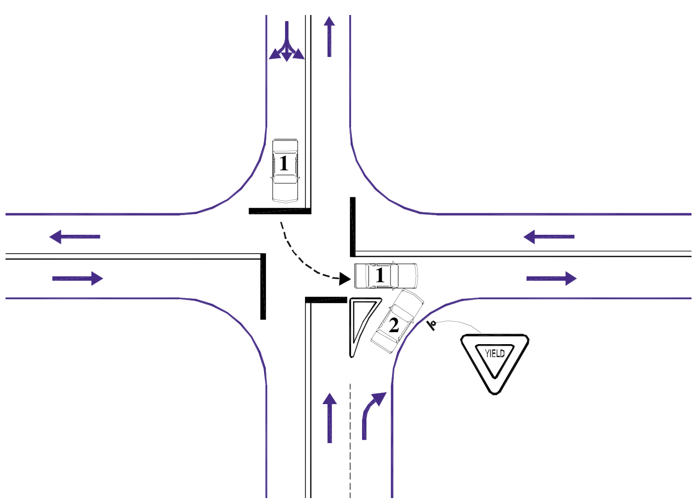

FIGURE 3 Common right-turn conflict.

and to perform a preliminary crash history evaluation for these common scenarios. The authors randomly selected 17 signalized intersections for analysis. The intersections ranged from minor to major arterial roads. One intersection location occurred between a freeway ramp and a major arterial at a diamond interchange. The interchange intersection included only two right-turn movements due to the one-way movements characterizing the freeway ramps. Other typical intersections included four right-turn movements. As a result, a total of 70 right-turn movements were identified for evaluation. Fifty-seven of the movements were identified as one of five common treatment scenarios. These included:

- A5–shared right, no island, merge, no additional control;
- B5–exclusive right, no island, merge, no additional control;
- D1–exclusive right, raised island, add lane, no additional control;
- D2–exclusive right, raised island, merge, yield control; and
- E2–shared right, raised island, large turning radius, merge, yield control.

Table 1 summarizes the number of right-turn crashes for each scenario. The analysis contained in Table 1 used frequency of crashes directly and does not include exposure as a factor of traffic volume. The primary objective of the summary in Table 1 was to identify variability in types of right-turn crashes for different treatments. Crash statistics for a two-year period (October 1, 1996, through September 30, 1998) were used. Consistent traffic volumes for the same time period were not available. Due to the current rapid growth of Cobb County, average daily traffic values for the sites differ significantly from 1996 to 1998.

As shown in Table 1, scenario A5 experienced fewer crashes per site than the other four common treatments. This observation is largely due to the use of A5 at minor arterials typically characterized by lower traffic volumes. Seventeen of the 29 right-turn movements initiated from a minor arterial leg. Approximately 50% of the observed crashes were right angle crashes. This type of crash is generally more severe than the rear-end and sideswipe crashes.

TABLE 1 Five Commonly Observed Right-Turn Scenarios

Treatment	**A5** Shared Rt., Merge, No Island, No Additional Control	**B5** Exclusive Rt., Merge, No Island, No Additional Control	**D1** Exclusive Rt., Lane Add, Raised Island, No Additional Control	**D2** Exclusive Rt., Merge, Raised Island, Yield Control	**E2** Shared Rt. With Large Radius, No Island, Merge, Yield Control
Crash Type	**Percent of Right-Turn Crashes Observed**				
Right Angle	50%	31%	22%	23%	0%
Rear-end	28%	23%	64%	59%	90%
Sideswipe	17%	31%	7%	18%	0%
Other	5%	15%	7%	0%	10%
Number of Sites Evaluated	29	8	5	7	8
Number of Rt. Turn Crashes for Two-Year Period	18	13	14	22	10
Avg. Number of Rt. Turn Crashes per Site per Year	0.31	0.81	1.40	1.57	0.63

The addition of an exclusive right-turn movement (scenario B5) increased the proportional distribution of crashes so that the number of sideswipe crashes is similar to the number of right-angle crashes (31 percent each). This scenario is commonly used for higher right-turn traffic volumes than those typical for scenario A5 approach legs. Though the total number of right-turn crashes per two-year period decreased in scenario B5 compared to A5, the number of crashes per site increased by a factor greater than 2.5, resulting in an actual increase of right-angle crashes for scenario B5. The increase in sideswipe crashes is not unexpected due to the introduction of a lane change with the exclusive right-turn lane.

Scenarios D1 and D2 both exhibited the largest number of right-turn crashes per location with the rear-end crash the prevalent crash type. Theoretically, scenario D1 (where a lane is added on the cross street and no additional control is introduced) should be characterized by free-flowing movements since there is no longer a need for right-turning vehicles to stop at the intersection. The high observation of rear-end crashes is likely due to right-turn drivers who do unexpectedly stop. The D2 scenario does require drivers to slow or stop when necessary due to cross street conditions (Yield sign). This treatment also experienced a high proportion of rear-end crashes.

Scenario E2 does not include an exclusive right-turn lane. For the eight turn movements studied, no sideswipe crashes occurred during the two-year period. Similar to scenarios D1 and D2, the rear-end crash was prevalent for this scenario.

CONCLUSIONS

The preliminary observations reported in this paper indicate that further information is necessary before transportation engineers can fully understand the impact of the application of various right-turn treatments. In general, the use of additional lanes, islands, and traffic control devices at a signalized intersection independently offers operational enhancements to facilitate the right-turn movement. The combined use of these features, however, requires additional understanding.

The general findings in this paper imply several hypotheses that merit future analysis. These include:

- The use of a traffic island appears to reduce the number of right angle crashes;
- The addition of an exclusive turn lane appears to correspond to elevated sideswipe accidents;
- The addition of an exclusive lane on the cross street for right-turning vehicles, though perhaps operationally justified, does not appear to reduce the number of rear-end crashes when no additional control is implemented.

Future research should evaluate specific treatments in depth using traffic volumes and conflicts, road type, and limited right-turn treatments. Specifically, the evaluation of scenario D1 (cross street lane added with no additional control) and scenario D2 (merge with cross street traffic and yield control) warrants an in-depth comparative analysis.

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