Right-In Right-Out Channelization

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by

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General Goal

This and other discussion papers were prepared to provide background, enhance understanding and stimulate discussion among individuals representing a variety of groups, agencies, and interests who have concern in Oregon highways.

Specific Objectives

The specific objectives of this discussion paper are to:

1. Summarize the literature and technical knowledge regarding the design and use of right-in right-out channelization.
2. Determine current traffic engineering practice and safety experience at channelized intersections using right-in right-out channelizations.
3. Conduct and analyze field studies of the operational and safety potential of right-in right-out channelization.
4. Prepare guidelines and recommended design standards for right-in right-out channelization.

Acknowledgements and Credits

Mr. Del Huntington is project manager for ODOT. Dr. Robert Layton, Professor of Civil Engineering at Oregon State University, is project director for Transportation Research Institute, OSU. Dr. Vergil Stover is consultant to TRI on this project.

The background research and report on this topic was prepared by Ahmet Aksan, graduate research assistant, TRI, OSU. Ahmet Aksan and Dr. Robert Layton co-authored this discussion paper.

OVERVIEW

Content

This paper summarizes the literature, issues, criteria, standards and experience with right-in right-out channelization. It also recommends guidelines and standards for the use of right-in right-out channelization. The primary focus in establishing these guidelines and design standards is on the operational and safety impacts that result.

Issues

Right-in right-out channelization is used to control left-turn movements into and out of road approaches. The effective operation of this strategy depends on the size of island, presence of wing islands, presence of median islands, and the magnitude of design standards.

BACKGROUND

Intersections at grade are unique elements of the highway. Low volume approach roads and driveways to local activities also create intersections with major facility. By definition, intersections represent points of potential conflict and are thus susceptible to accidents. Intersections require drivers to make decisions about turning or crossing, and present conflicting traffic flows and changing roadway geometrics, which increase driver workload. In urban areas, intersections are of such importance that they control the capacity of a street network.

Two prime objectives of intersection design and control are operational quality and safety. The design layout and features, and traffic control scheme must be developed jointly to provide acceptable quality of operations and to reduce accident potential and severity.

Right-In Right-Out Definition

Right-in right-out channelization has been used to improve operations and safety by placing islands or devices that force drivers to enter or exit a location with a right turn movement, eliminating left turns. However, at some locations, such islands have been found to be ineffective in eliminating the number of left turns. Generally, such islands impose an inconvenience on drivers, and some drivers violate the traffic laws by making a left turn where it is prohibited by a channelizing island. At some locations, drivers are not even aware that they are violating traffic laws by making a left hand turn into the right turn channelization due to the small size of the islands and lack of proper traffic control devices.

BACKGROUND (continued)

Channelization Defined

AASHTO Policy on Geometric Design (1990) defines channelization in the following way:

"Channelization is the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement markings to facilitate the safe and orderly movements of both vehicles and pedestrians. Proper channelization increases capacity, improves safety, provides maximum convenience, and instills driver confidence. In some cases a simple channelization improvement can result in a dramatic reduction in accidents. Improper channelization has the opposite effect and may be worse than none at all."

Right-In Right-Out Applications

Right-in right-out channelization is applicable on all highways where left turn-in and left–out maneuvers create operational or safety problems. The left turn maneuvers are restricted by a channelizing island in the driveway throat. The important design elements for this technique are the triangular island and its location. The island should be large enough to command the driver's attention and should be offset from the through traffic lanes. Figure 1 shows a typical right-in right-out channelization island. The triangular island may be supplemented by "wing" separating islands that extend out from the triangular island, parallel to the major highway.

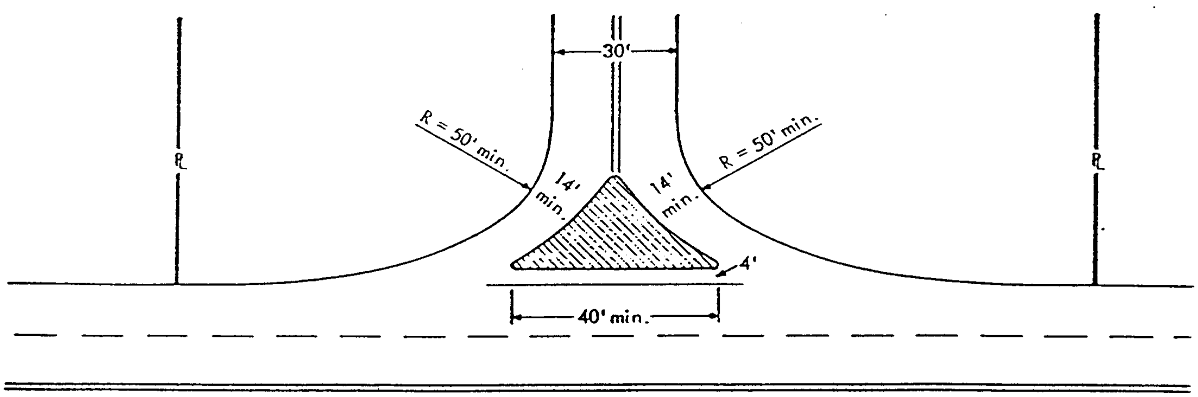


Figure 1. Driveway Channelizing Island to Prevent Left-In and Left-Out Turns (7)

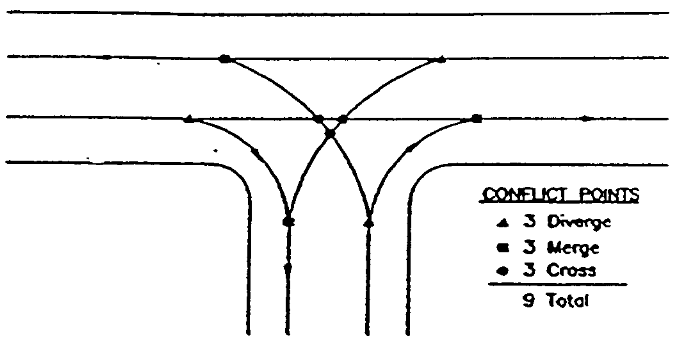
BACKGROUND (continued)

Right-In Right-Out Conflicts

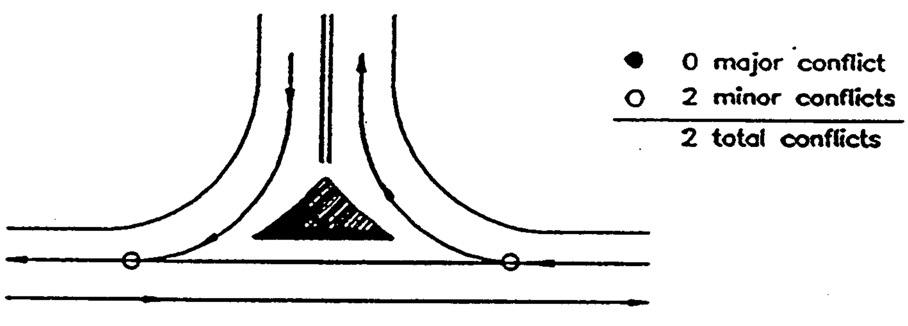
The right-in right-out channelization reduces the frequency and severity of conflicts by reducing the basic conflict points from nine to two at a driveway or an approach road, as shown in Figure 2. This measure is intended to eliminate the crossing conflicts that accompany left turn ingress and egress maneuvers completely. However, the reduction in the number and severity of conflicts is moderated by the possible increase in right and inappropriate indirect left turn maneuvers. A travel time increase may be incurred by vehicles that cannot make left turns.

Sight Distance and Right-In Right Out Channelization

The intersection sight distance is a major control for the safe operation of intersecting roadways. It is a particular concern for access management with the numerous driveways and approach roads that must be safely accommodated. All intersecting driveways and roadways must have adequate intersection sight distance. At some locations, right-in right-out channelization can be used to eliminate crossing conflicts that are created by poor sight distance.



Before Channelization



After Channelization

Figure 2. Number of Conflicts Before and After Channelization (TRI-1, 1995)

BACKGROUND (continued)

Left Turn Accident Experience

The left turn movements at an intersection have a major impact on operations, capacity, and safety. The left turn movements generally generate a large share of total accidents. The left turns also are major contributors to other accident types. According to the literature, 74% of driveway accidents involve left turn maneuvers (18). Of these accidents, 47% are left turn-in maneuvers, as shown in Figure 3. Because the application of this technique is limited to driveways where left turn maneuvers constitute a small percentage of the ADT, the elimination of left turn maneuvers may cause less reduction in total accidents than the percentages stated above. In earlier research, the elimination of both left turn maneuvers was estimated to result in a 50% reduction in total accidents at the driveway, according to a 1975 FHWA study. Eliminating left turn egress maneuvers is expected to result in a 30% reduction in total accidents (7).

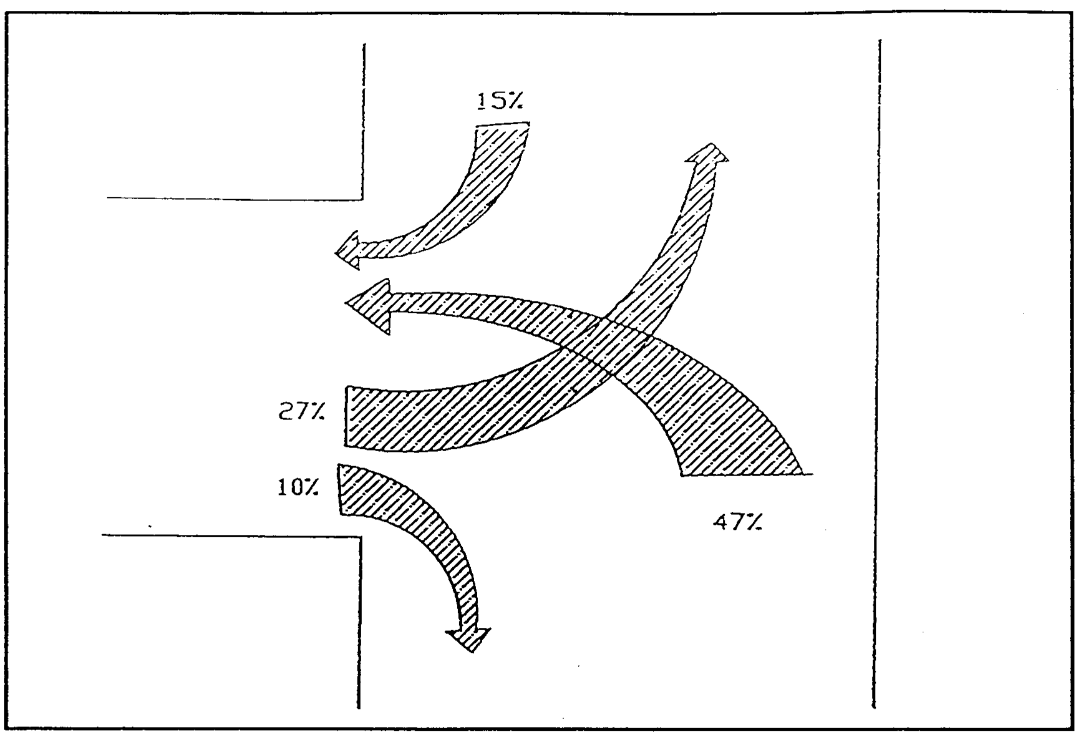


Figure 3. Percentage of Driveway Crashes by Movement (18)

Table 1 shows annual accident reductions per driveway for restricting both left turn-in and -out maneuvers.

Table 1. Annual Accident Reductions per Driveway for Restricting Both Left-Turn-In and Out Maneuvers (7)

	HIGHWAY ADT (vpd)		
	Low <5,000	Medium 5000-15,000	High > 15,000
Low <500	0.13	0.23	0.31
Medium 500-1,500	0.31	0.55	0.75
High >1,599	0.49	0.85	1.15

Typical Right-In Right-Out Warrant

A typical right-in right-out channelization warrant on undivided highways with speeds of 30-45 mph, ADT's greater than 5,000 vpd, and driveway volumes of at least 1,000 vpd requires the prohibited turns to number less than 100 vpd.

BACKGROUND (continued)

Functional Warrant

Right in right-out channelization is also used on arterials where medial and marginal access to arterials may jeopardize the primary function of the arterial. Figure 4 shows the region along the property frontage where right turn only access might be permitted on the basis of the AASHTO policy that a driveway should not be situated within the functional boundary of an intersection (24).

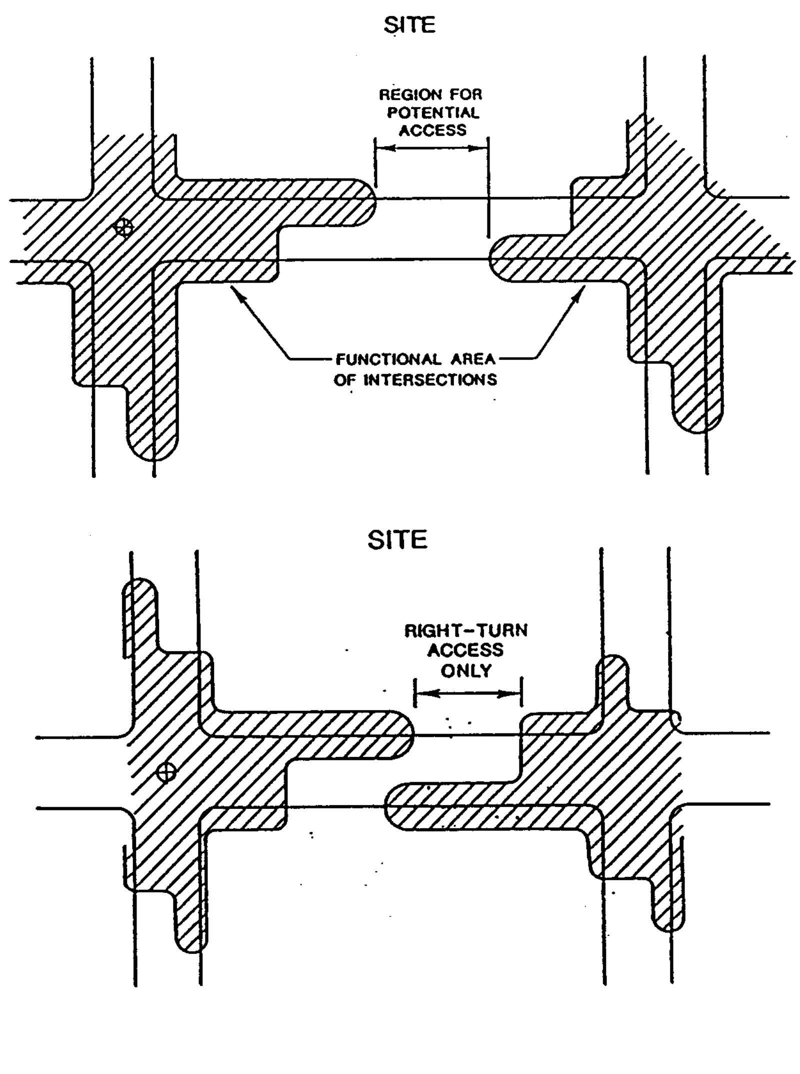


Figure 4. Condition Where Right-Turn Only Access Should Be Permitted (24)

FUNDAMENTAL CONCEPTS

Objectives of Channelization

Potential conflicts between vehicles and pedestrians are reduced through channelization of traffic movements. The traffic channels may be designed to separate and direct traffic movements into specific and clearly defined vehicle paths. Good channelization design should meet the following objectives (22):

1. Separate conflicting movements – usually on intersection approaches.
2. Control angles of conflicting movements.
3. Reduce excessively large paved areas – large paved intersection areas invite unpredictable vehicle and pedestrian movements.
4. Regulate traffic flow and indicate proper use of intersection.
5. Favor predominant turning movements.
6. Protect pedestrians.
7. Protect turning and crossing vehicles.
8. Provide proper and safe location for traffic control devices.
9. Provide "reference" points.
10. Discourage prohibited movements.
11. Control speed.
12. Protect bicyclists and pedestrians.
13. Control or restrict access.
14. Restrict through traffic."

Design of a channelized intersection at an approach road usually involves the following significant design controls: the type of design vehicle, the cross section on the major roadway, the projected traffic volumes in the relation to capacity, the number of pedestrians, the speed of vehicles, the location of any required bus stop, and the type and location of local traffic control devices. Furthermore, the physical controls such as right-of-way

FUNDAMENTAL CONCEPTS (continued)

Objectives of Channelization (continued)

and terrain have an effect on the extent of channelization that is economically feasible (1).

Channelization Design Principles

In order to achieve the purposes of channelization, certain design principles or rules should be followed. The type of intersection control used, that is stop, yield, or traffic signal, has a large impact on many of the design rules. Neuman describes nine design principles (19). The portion of those principles appropriate for right-in right-out channelization are given below.

1. “Undesirable or wrong way movements should be discouraged or prohibited. Channelization – traffic island, raised medians and corner radii – should be used to restrict or prevent undesirable or wrong way movements. Where such movements can not be completely blocked, the channelization scheme should discourage their completion.” (19)
2. “Desirable vehicular paths should be clearly defined. The design of an intersection – including its approach alignment, traffic islands, pavement markings, and geometry – should clearly define proper or desirable paths for vehicles. Exclusive turning lanes should be clearly delineated to encourage their use by turning drivers. . . Traffic islands should not cause confusion about the proper direction of travel around them.” (19)
3. “Desirable or safe vehicle speeds should be encouraged. Channelization should promote desirable vehicle speeds wherever possible. . . In other cases, channelization may be used to limit vehicle speeds in order to mitigate serious high-speed conflicts.” (19)

FUNDAMENTAL CONCEPTS (continued)

Channelization Design Principles (continued)

4. "Points of conflict should be separated where possible. Separation of points of conflict eases the driving task. Channelization techniques, such as development of turning lanes, design of islands, and control of access points, all serve to separate points of conflict. This enables the driver to perceive and react to conflicts in an orderly manner." (19)
5. "Traffic streams should cross at right hand angles and merge at flat angles. When traffic streams cross without traffic signal control, the crossing should be made at or near right angles in order to reduce the potential impact areas, to reduce the time of crossing a conflicting traffic stream, and to provide the most favorable sight lines for drivers to judge relative positions and relative speeds of other vehicles. When they merge, they should merge at small angles. Merging at angles of 10° to 15° permits traffic streams to flow together with minimum speed differentials. Drivers entering the major traffic flow may use relatively short gaps (Homburger, Hall, Loutzenheiser, and Reilley, 1996)." (19)
6. "High priority traffic movements should be facilitated. The operating characteristics and appearance of intersections should reflect and facilitate the intended high priority traffic movements. Selection of high priority movements can be based on relative traffic volumes, functional classification of the intersecting highways, or route designations." (19)
7. "Desired traffic control scheme should be facilitated. The channelization employed should facilitate and enhance the traffic control scheme selected for intersection operation. Location and design of exclusive lanes should be consistent with signalization or stop-control requirements. Location of traffic islands, medians and

FUNDAMENTAL CONCEPTS (continued)

Channelization Design Principles (continued)

curb returns should reflect consideration of the need to place signals and signs in locations visible to drivers." (19)

8. "Decelerating, stopped, or slow vehicles should be removed from high-speed through-traffic streams. Wherever possible, intersection design should produce separation between traffic streams with large traffic speed differentials. Vehicles that must decelerate or stop because of traffic control or to complete a turn should be separated from through traffic proceeding at higher speeds. This practice facilitates safe completion of all movements by reducing rear-end conflicts." (19)
9. "Provide safe refuge for pedestrians and other non-motor vehicle users. Channelization can shield or protect pedestrians, bicycles, and the handicapped within the intersection area. Proper use of channelization will minimize exposure of these vulnerable users to vehicle conflicts, without hindering vehicular movements." (19)

Virtually, all of these design principles are appropriately applied at right-in right-out channelized locations.

Common Errors in Right-In Right-Out Channelization

Given below are some of the common design errors that may occur in right-in right-out channelization (19).

1. "Channelizing where it is not warranted by traffic conditions
2. Use of more islands than are necessary to accomplish purpose.
3. Channelizing in areas too small to permit islands of adequate size. An island should have a surface area of at least 75 square feet.
4. Use of channelization where approach sight distances are inadequate.

FUNDAMENTAL CONCEPTS (continued)

Common Errors in Right-In Right-Out Channelization (continued)

5. Failure to eliminate conflicts of acute angles.
6. Inadequate design of approach end of channelizing islands. Design approach end to give desired natural vehicle path such that island does not create an obstruction in roadway.
7. Geometric design inadequate to accommodate the size and operating characteristics of vehicles.
8. Inadequate design in speed change areas.
9. Inadequate illumination and reflectorization.
10. Planting in islands too small to permit adequate maintenance. Small islands should be paved or gravel.
11. Not recognizing access requirements to properties adjacent to the channelized area.
12. Bicycle and pedestrian movements not properly recognized in the design." (19)

Traffic Islands

An island is a defined area between traffic lanes for control of vehicle movements. Within an intersection, a median or an outer separation is considered an island. Islands vary widely in characteristics and design features. It may be an area delineated by a curb or a pavement area marked by paint. Islands may provide an area for pedestrian refuge and traffic control devices. Design of traffic islands must consider their intended site specific functions. According to Newman, application of design guidelines and standards to reflect these functions involves the following considerations (19):

1. "Selection of an appropriate island type (raised or barrier type, mountable, painted or flush).
2. Determination of the proper size and shape of the islands.

FUNDAMENTAL CONCEPTS (continued)

Traffic Islands (continued)

3. Location of the island relative to adjacent traffic lanes or crosswalks.
4. Design of individual elements of the island itself."

As with other channelization elements, the above considerations are affected by traffic characteristics, such as volume, speed, and environmental factors.

Island Types

Selection of an appropriate type of traffic island should be based on traffic characteristics, cost considerations, and maintenance needs. Flush channelization is not effective in prohibiting or preventing traffic movements, nor is it appropriate for islands intended to serve as locations of pedestrian refuge. Painted (thermoplastic) or flush channelizations are usually not appropriate for right-in right-out channelizations unless accompanied by devices that prohibit vehicles from driving through the area, such as batons, jiggle bars, or delineators.

Raised traffic islands are typically required for right-in right-out channelization (19):

1. Where the island is intended to prohibit or prevent traffic movements.
2. Where the primary function of the island is to shield pedestrians from traffic.
3. Where a primary or secondary island function is the location of traffic signals, signs, or other fixed objects.
4. On low to moderate speed highways where the primary function is to separate high volume from opposing traffic flows.

FUNDAMENTAL CONCEPTS (continued)

Island Types (continued)

5. At locations requiring more positive delineation of vehicle paths, such as at major route turns or intersections with unusual geometry (19).

Island Geometrics

Island sizes and shapes vary significantly from one intersection to another. Islands should be of sufficient size to command attention. The smallest curbed island that normally should be considered is one that has an area of approximately 50 ft^2 for urban streets, and 75 ft^2 for rural intersections. However, 100 ft^2 is preferable for both. Accordingly, triangular islands should not be less than about 40 ft on a side after the rounding of corners.

Islands should be delineated or outlined by a variety of treatments, depending on their size, location, and function. The type of area in which the intersection is located, rural versus urban, also governs the design. In a physical sense, islands can be divided into three groups:

1. Raised islands outlined by curbs.
2. Islands delineated by pavement markings, buttons, or raised (jiggle) bars placed on all-paved areas.
3. Non-paved areas formed by the pavement edges, possibly supplemented by delineators on posts or other guideposts, or a mound-earth treatment beyond and adjacent to the pavement edges.

FUNDAMENTAL CONCEPTS (continued)

Raised Island Design

The edge of through traffic lanes and turning roadways are used to outline a curbed island. For visibility and construction simplicity, the points at the intersections of the curbed island are rounded or beveled. A curbed island may be offset from the through traffic lane, depending on the type of edge treatment and other factors such as island contrast, length of taper or auxiliary pavement in advance of the curbed island, and traffic speed. Island curbs that are introduced abruptly should be offset from the edge of through traffic lanes, even if they are mountable. A mountable curb on an island can be located at the edge of a turning roadway, unless it cannot withstand traffic. Barrier curbs should be offset from edges of through and turning roadway pavements.

Details of triangular curbed island design are shown in Figures 5 and 6, based on the 1990 AASHTO Greenbook (1). The lower right corner of each curbed island is designed as the approach end. Figure 5 shows curbed islands adjacent to through traffic lanes, without shoulders. Where there are no curbs on the approach, the minimum offset of the edge of the curbed island should be 2-3 ft. With a mountable curb on the approach, a similar curb on the curbed island can be located at the edge of the through lane where there is sufficient length of curbed island to effect a gradual taper from the nose offset. Barrier curbs should be offset from the through pavement edge, regardless of the size of the curbed island, to avoid a lateral restriction and shy effect on drivers. When an approach shoulder is used, the curbed island should be offset from the through travel lane by an amount equal to the shoulder width, as shown in Figure 6 (1). Where speeds are intermediate or high and the curbed island is preceded by a deceleration lane or a gradual widening auxiliary pavement, it may be desirable to offset the nose of the large curbed islands an additional 2-4 ft, according to AASHTO (1).

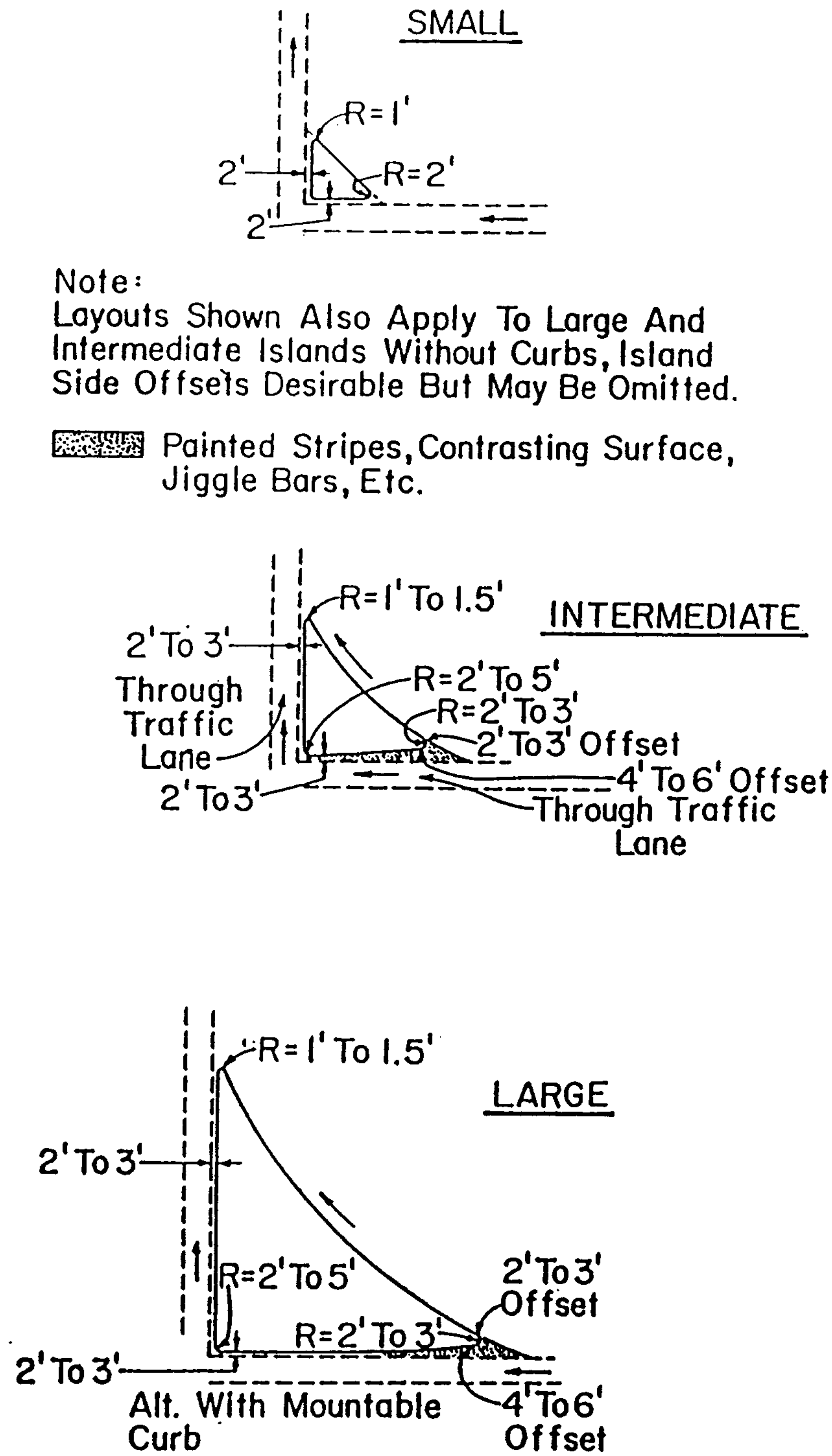


Figure 5. Details of Triangular Island Design (curbed islands, no shoulders) (1)

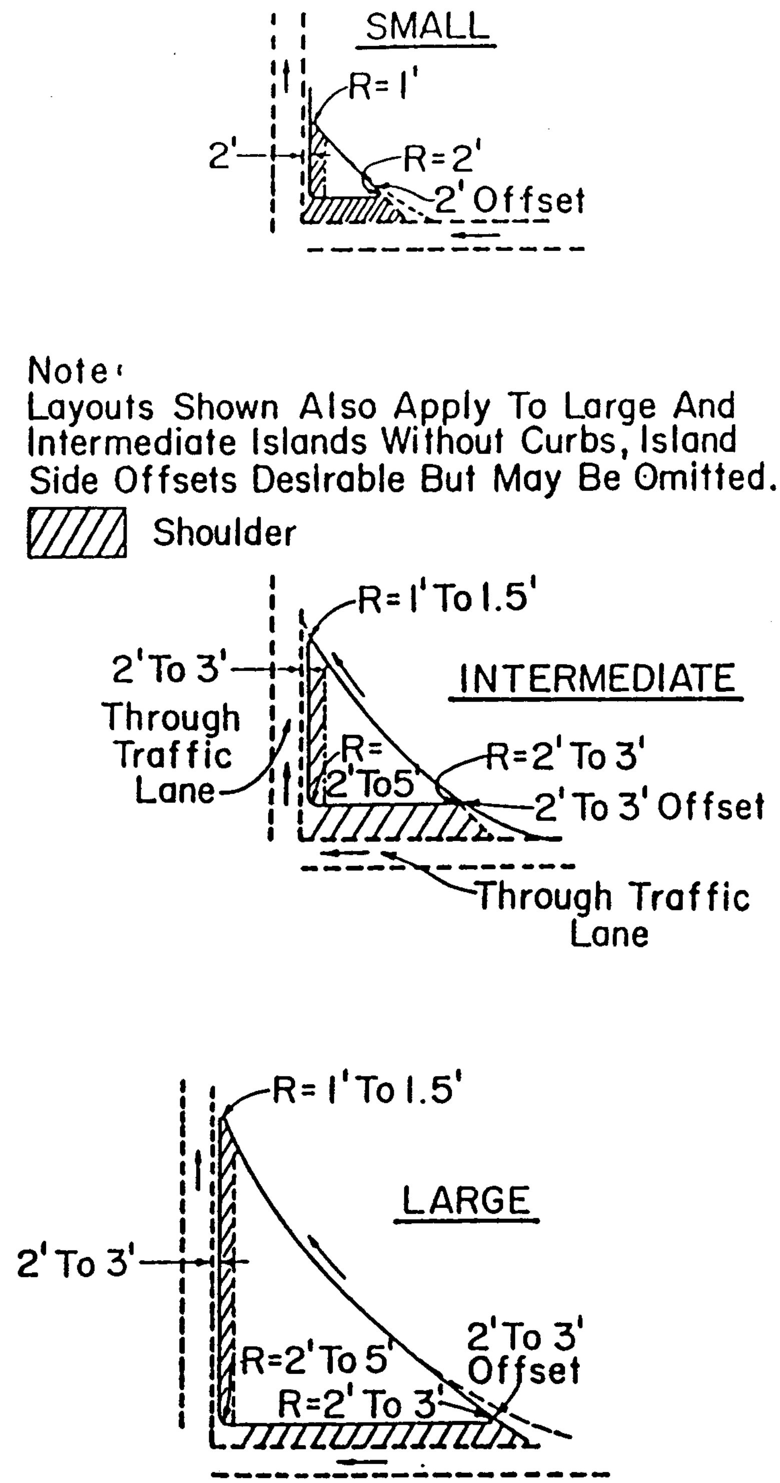


Figure 6. Details of Triangular Island Design (curbed islands, with shoulders) (1)

FUNDAMENTAL CONCEPTS (continued)

Approach End Treatment

Various methods of approach end treatment have been found to be effective: contrasting pavement colors or textures, raised bars, buttons, and median blocks. Various types of illumination, signing and marking may be needed to supplement the pavement surface treatments to provide adequate visibility, warning, and delineation.

The ends of islands first approached by traffic should be preceded by a gradually diverging marking on the roadway surface to guide vehicles into desired paths of travel along the island edge. These markings may contain slightly raised (usually less than 1 inch high) sections of coarse aggregate or other suitable material that may be crossed readily even at considerable speeds. These rumble sections provide increased visibility of the marked areas and produce an audible warning to vehicles inadvertently traveling across them (1).

Small curbed islands are delineated primarily by curbs. Large curbed islands may be delineated by several methods, including color and texture contrasts of vegetative cover, mounded earth, shrubs, delineators, signs, or any combination of these. In rural areas mountable type island curbs should be used, except a barrier is needed to preclude vehicles and protect structures or pedestrians. In those cases, barrier curbs are suitable. Both barrier and mountable curbs are appropriate in urban areas, depending on conditions. High visibility curbs are advantageous at hazardous locations or on islands and roadway forks approached by high-speed traffic (16).

FUNDAMENTAL CONCEPTS (continued)

Approach End Treatment (continued)

Raised bars or buttons may be used in advance of islands having barrier curbs, but they should not create an unexpected hazard. These devices should not project more than 1 to 3 inches above the pavement surface, to provide visibility without loss of control of the vehicle if impacted. Where practical, rumble strips of pavement may be provided in advance of the bars or buttons, or their height should be gradually increased as approached by traffic. Pavement markings may be used with raised bars or buttons to better designate the island area (1).

Island Visibility

Adequate reflectorization and/or illumination should be used to make all islands clearly visible at night. The general layout of the island and immediate vehicular travel paths should be adequately illuminated by overhead lighting or auto headlights, with the greatest illumination at potential hazardous points, as at barrier curbs or other structures (1).

According to the 1988 Manual on Uniform Traffic Control Devices all approach noses of islands in the line of traffic should have an appropriate sign and/or marker (16). The signs used on islands must be reflectorized or illuminated. They should be located where the island has sufficient width, at least 1 foot wider than the sign. These signs should be located back from the approach nose of the island to reduce the likelihood of being struck by a vehicle. In rural areas this set back can be up to 50-75 ft since they are viewed at a distance, and still provide a proper perspective. The posts shall be designed to break away or yield when struck by a vehicle. Where delineators are used the island installations, they shall be the same color as the respective edge lines except that, when facing wrong-way traffic, they shall be red (16).

FUNDAMENTAL CONCEPTS (continued)

Turning Radii

The corner radii are important design elements in that they influence the operational characteristics, construction cost, and maintenance of the intersection. Design of the right corner radii entails more than consideration of turning and tracking requirements for right turning vehicles. Additional factors include the presence of pedestrians and bicyclists, other intersection geometry such as grades and curvature, or traffic islands, desired traffic control, and available right of way (19).

The dimensions for fifteen design vehicles representing vehicles that make up a normal traffic stream are given in Table 2 (1). In the design of any highway facility the largest design vehicle likely to use the facility with considerable frequency or a design vehicle with special characteristics must be taken into account in dimensioning the facility. This design vehicle determines the design of such critical features as radii at intersections and radii of turning roadways (1). Figures 7 and 8 present the minimum turning paths for P (passenger car) and SU (single unit truck) design vehicles. The principal dimensions affecting design are the minimum turning radius, the tread width, the wheelbase, and the path of the inner rear tire. The paths indicated, which are slightly greater than the minimum paths of nearly all vehicles in each class, are the minimums attainable at speeds less than 10 mph, and consequently offer some leeway in driver behavior.

Table 2. Design Vehicle Dimensions (1)

Design Vehicle Type	Symbol	Dimension (ft)										
		Overall			Overhang							
		Height	Width	Length	Front	REAR	WB_1	WB_2	S	T	$WB_3$3	WB_4
Passenger car	P	4.25	7	19	3	5	11					
Single unit truck	SU	13.5	8.5	30	4	6	20					
Single unit bus	BUS	13.5	8.5	40	7	8	25					
Articulated bus	A-BUS	10.5	8.5	60	8.5	9.5	18		4[a]	20[a]		
Combination trucks												
Intermediate semitrailer	WB-40	13.5	8.5	50	4	6	13	27				
Large semitrailer	WB-50	13.5	8.5	55	3	2	20	30				
"Double Bottom" semi-trailer—full-trailer	WB-60	13.5	8.5	65	2	3	9.7	20	4[b]	5.4[b]	20.9	
Interstate Semitrailer	WB-62*	13.5	8.5	69	3	3	20	40–42				
Interstate Semitrailer	WB-67**	13.5	8.5	74	3	3	20	45–47				
Triple Semitrailer	WB-96	13.5	8.5	102	2.5	3.3	13.5	20.7	3.3[d]	6[d]	21.7	21.7
Turnpike Double Semitrailer	WB-114	13.5	8.5	118	2	2	22	40	2[c]	6[c]	44	
Recreation vehicle												
Motor home	MH		8	30	4	6	20					
Car and camper trailer	P/T		8	49	3	10	11	18	5			
Car and boat trailer	P/B		8	42	3	8	11	15	5			
Motor Home and Boat Trailer	MH/B		8	53	4	8	20	21	6			

* = Design vehicle with 48′ trailer as adopted in 19872 STAA (Surface Transportation Assistance Act)

** = Design vehicle with 53′ trailer as grandfathered in 1982 STAA (Surface Transportation Assistance Act)

a = Combined dimesion 24, split is estimated.

b = Combined dimesion 9.4, split is estimated.

c = Combined dimension 8, split is estimated.

d = Combined dimension 9.3, split is estimated.

WB_1, WB_2, WB_3, WB_4 are effective vehicle wheelbases.

S is the distance from the rear effective axle to the hitch point.

T is the distance from the hitch point to the lead effective axle of the following unit.

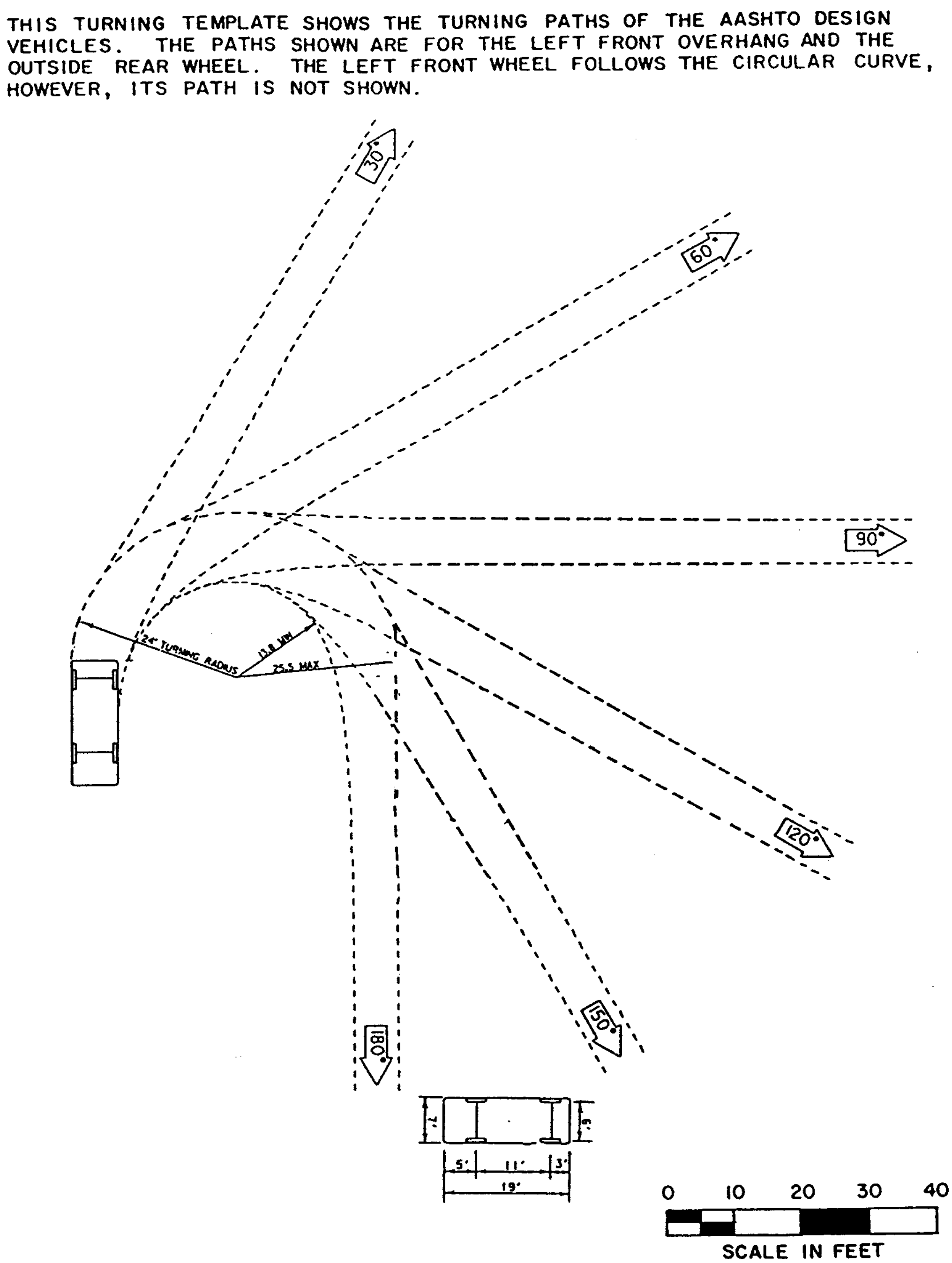


Figure 7. Minimum Turning Path for P Design Vehicle (1)

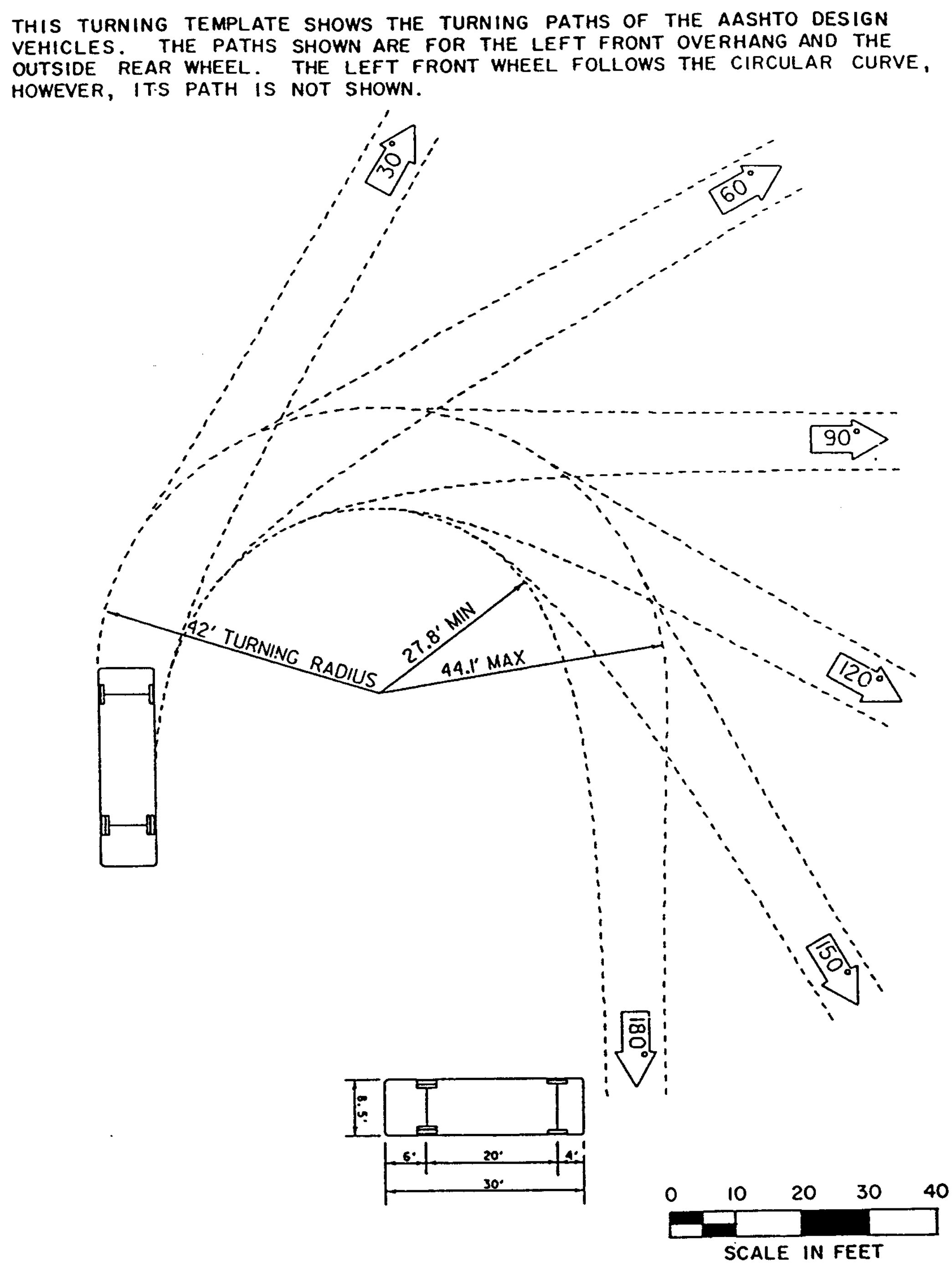


Figure 8. Minimum Turning Path for SU Design Vehicle (1)

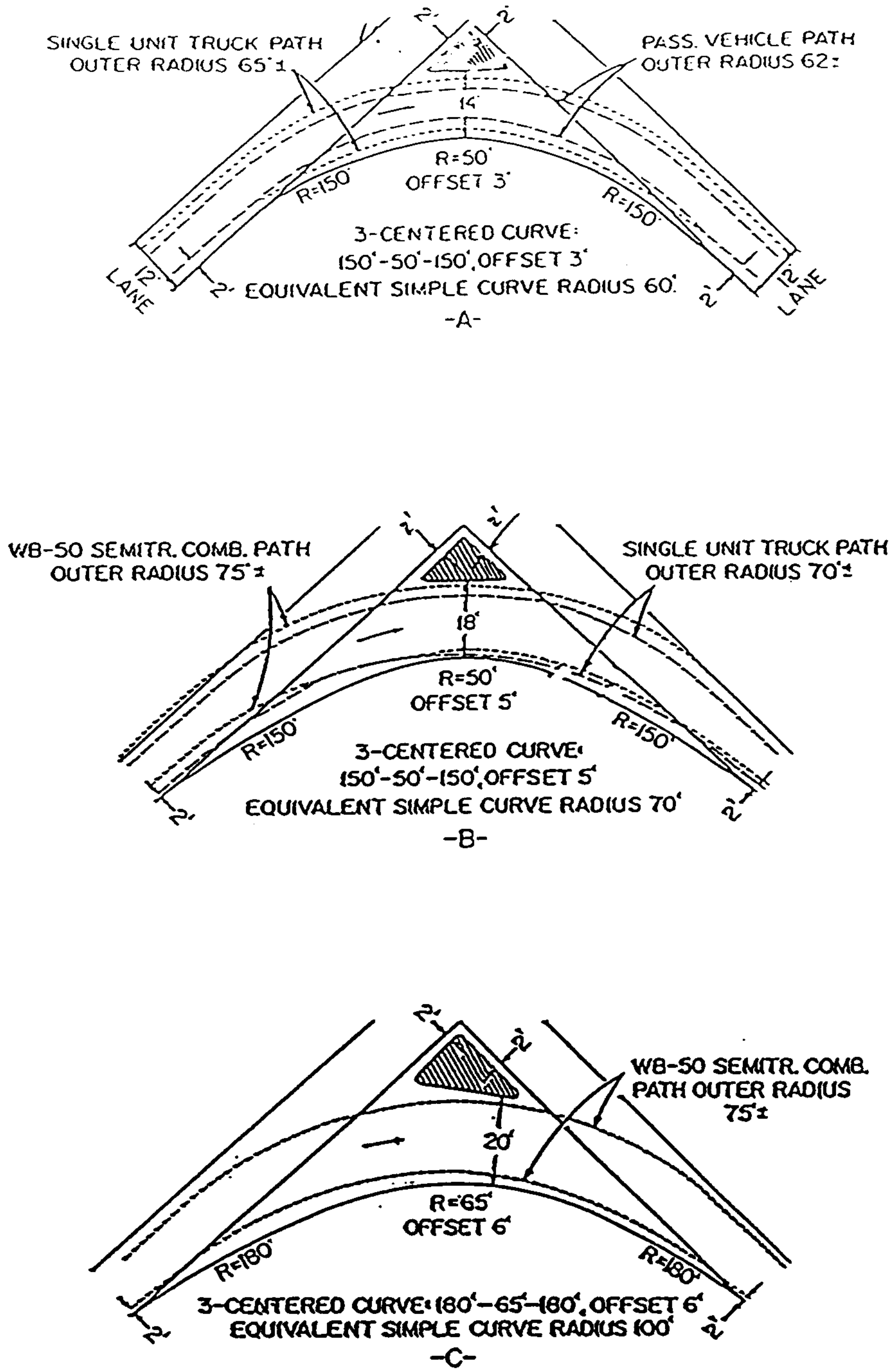


Figure 9. Design for Turning Roadways with Minimum Corner Islands (1)

Turning Roadway Design

In order to accommodate the design vehicle when making a turn at a speed consistent with the operation of the intersection, the alignment of the inner pavement edge and the pavement width are the principle controls for the design of turning roadways. With radii greater than minimum, these controls result in an area large enough for an island, generally triangular in shape, between the inner edge of the turning roadway and the pavement edges of the through highway. The inner edge of pavement on the turning roadway should be designed to provide at least the minimum size island and the minimum width of the turning roadway pavement. The turning roadway pavement should be wide enough to permit the outer and inner wheel track of a selected vehicle to clear the edges of the pavement by about 2 ft on each side. Although the turning roadway pavement width should not be less than 14 ft, pavement widths designed for larger vehicles may be reduced with paint or color contrasting treatments to channelize passenger cars and discourage the appearance of two turning lanes.

Figure 6 shows minimum designs for turning roadways for a 90° right turn to fit these controls. A design based on a minimum size island and a minimum width of channel of 14 ft results in a circular arc of 60 ft radius on the inner pavement edge of the turning roadway or in a three centered curve with radii of 150, 50, 150 ft with the middle curve offset 3 ft from the tangent edges extended. This design not only permits passenger vehicles to turn at a speed of 15 mph, but also enables SU design vehicles to turn on a radius of approximately 65 ft and still clear the pavement edges of the channel by about 1 ft on each side.

Turning Roadway Design for Trucks

By increasing the pavement width to 18 ft and using the same combination of curves, i.e., 150-50-150 ft, but with the middle curve offset 5 ft from the tangent edges extended, SU and WB 50 design vehicles can use a 70 ft turning radius with adequate clearances (1). At locations where a significant number of semi-trailer combinations will be turning, the design with a minimum curve of 65 ft radius, offset of 6 ft, and terminal curves of 180 ft radii should be used. It will provide for a WB 50 design vehicle passing through a 20 ft turning roadway pavement and will benefit the operation of smaller vehicles. For each minimum design, a three centered symmetric, compound curve is recommended; however, asymmetric compound curves could also be used, particularly where the design provides for the turning of trucks (1).

Minimum design dimensions for oblique angle turns are given in Table 3 (1). Curve design for the inner edge of pavement, turning roadway pavement width, and the approximate island size are indicated for the three chosen design classifications described at the bottom of the table.

Exclusive Right Turn Lanes

Drivers leaving a highway at an intersection are usually required to reduce speed before turning. Drivers entering a highway from a turning roadway accelerate until the desired open road speed is reached. Right turn lanes remove the decelerating right turning vehicles from the through traffic lanes and thereby eliminate the need for through traffic to slow down or change lanes behind them. Consequently, right turn lanes improve the operational efficiency of the roadway by eliminating the through vehicle delay and operating cost associated with speed-change cycle (7). The delay experienced by the through vehicle can range from a few seconds to over 20 sec per right turn, depending on the speed and the volume of traffic. When undue deceleration or acceleration by leaving or entering traffic takes place directly on the highway traveled way, it disrupts the flow of through traffic and often is hazardous. To preclude or minimize these undesirable aspects of operation at intersections, speed change lanes are accepted practice and are frequently used on main highway intersections. They often are effective with right-in right-out channelized designs.

Accident Potential of Exclusive Right Turn Lanes

The relative accident involvement rates in Table 4 indicate that a vehicle traveling on an at-grade arterial at a speed of 35 mph slower than the speed of the normal traffic speed is 180 times more likely to be involved in an accident than a vehicle traveling at the same speed as the other vehicles in the traffic stream. A vehicle traveling 35 mph slower than the traffic stream has 90 times the chance of being involved in an accident as a vehicle traveling 10 mph slower (25). Stover and Koepke (23) indicate that, although the relative ranges may be in considerable error, for any specific section of street or freeway, they clearly show that increased accident potential.

Table 3. Minimum Design for Turning Roadways (1)

Angle of Turn (degrees)	Design Classification	Three-Centered Compound Curve Radii (ft)	Three-Centered Compound Curve Offset (ft)	Width of Lane (ft)	Approx. Island Size (sq ft)
75	A	150-75-150	3.5	14	60
	B	150-75-150	5.0	18	50
	C	180-90-180	3.5	20	50
90[a]	A	150-50-150	3.0	14	50
	B	150-50-150	5.0	18	80
	C	180-65-180	6.0	20	125
105	A	120-40-120	2.0	15	70
	B	100-35-100	5.0	22	50
	C	180-45-180	8.0	30	60
120	A	100-30-100	2.5	16	120
	B	100-30-100	5.0	24	90
	C	180-40-180	8.5	34	220
135	A	100-30-100	2.5	16	460
	B	100-30-100	5.0	26	370
	C	160-35-160	9.0	35	640
150	A	100-30-100	2.5	16	1400
	B	100-30-100	6.0	30	1170
	C	160-35-160	7.1	38	1720

[a] Illustrated in Figure IX-29.

NOTES: Asymmetric three-centered compound curves and straight tapers with a simple curve can also be used without significantly altering the width of pavement or corner island size.

Painted island delineation is recommended for islands less than 75 ft^2 in size.

Design classification:

A—Primarily passenger vehicles; permits occasional design single-unit truck to turn with restricted clearances.

B—Provides adequately for SU; permits occasional WB-50 to turn with slight encroachment on adjacent traffic lanes.

C—Provides fully for WB-50.

Therefore, designs which produce small speed differentials of less than 10 or 15 mph are the desirable functional design of arterials.

Table 4. Relative Accident Involvement Rates (23)

	Speed Differential (mph)				
	0	-10	-20	-30	-35
Accident Rate	110	220	720	5,000	20,000
Ratio, 0 mph differential	1	2	6.5	45	180
10 mph differential		1	3.3	23	90

Exclusive Right Turn Lane Width

A speed change lane should be of sufficient width and length to enable a driver to maneuver a vehicle into it properly, and once in it, make the necessary change between the speed of operation on the highway or the street and the lower speed on the turning roadway (1). They should be at least 10 ft wide and preferable 12 ft wide. Desirably, the lane width should be in addition to that of the gutter pan.

Exclusive Right Turn Lane Warrants

The right turn deceleration lane is applicable on all highway types. According to Glennon et al. (7), highway ADTs should exceed 10,000 vpd and highway speeds should be at least 35 mph. Driveway volume should exceed 1,000 vpd with at least 40 right turn ingress movements during peak periods. This technique should not be applied on frontages less than 150 ft in width or where the deceleration lane will restrict access to upstream properties.

Exclusive Right Turn Deceleration Lane Lengths

The recommended lengths for right turn deceleration lanes, according to Glennon et al., are listed in Table 5 (7). However, the effort underway in this project under Discussion Paper No. 11, and the resulting standards should be applied.

Table 5. Recommended Lengths for Right-Turn Deceleration Lanes (7)

Highway Speed (mph)	Deceleration Lane Length (ft)
55	380
50	310
45	250
40	210
35	170
30	150

Exclusive Right Turn Lane Accident Reduction

The literature revealed that 15% of all driveway accidents involve right turn ingress movements. The deceleration lane is expected to eliminate 50% of these accidents. Thus, an overall annual accident reduction of 7.5% is expected by implementation of this technique (7).

Exclusive Right Turn Acceleration Lane Lengths

Installation of a right turn acceleration lane reduces through lane deceleration requirements by facilitating higher speed driveway merge maneuvers. The merge maneuver is facilitated by the availability of the right turn acceleration lane for use by right turn egress driveway vehicles. The speed difference of the driveway-to-highway merge is reduced by allowing driveway vehicles the necessary length to accelerate. The merge maneuver can be accomplished more safely when the speed is more compatible with highway running speeds. The recommended lengths for right turn acceleration lanes, according to Glennon et al., are listed in Table 6. Again, the effort underway with the ODOT Technical Design committee will set these requirements.

Exclusive Right Turn Acceleration Lane Warrants

A right turn acceleration lane may be warranted on all highway types. Highway volumes should exceed 10,000 vpd and speeds should be greater than 35 mph. The technique should be implemented only at driveways that have at least 75 right turn egress movements during peak demand periods. These warrants must be made compatible with those resulting from the efforts of the ODOT Technical Design committee.

Table 6. Recommended Lengths for Right-Turn Acceleration Lanes (7)

Highway Speed (mph)	Deceleration Lane Length (ft)
55	850
50	680
45	450
40	310
35	210
30	150

Use of a Channelizing Island with the Exclusive Right Turn Lane

The application of a channelizing island, or wing, prevents right turn deceleration lane vehicles from returning to the through lanes, as shown in Figure 10. It also eliminates some of the left ingress movements from the opposing lanes. A reduction in the encroachment conflict, basically sideswipe, occurs. However, an increase in the number of single vehicle mishaps may occur due to vehicles striking the island. This median should possess the following dimensions and characteristics:

- 2 ft width, minimum
- 2 ft separation from through traffic lanes, minimum
- Minimum of 6 ft extension into intersection
- Reflectorization for night time driving
- Extend far enough to prohibit reentry into through lanes
- Consist of sufficient lane width to accommodate traffic safely.

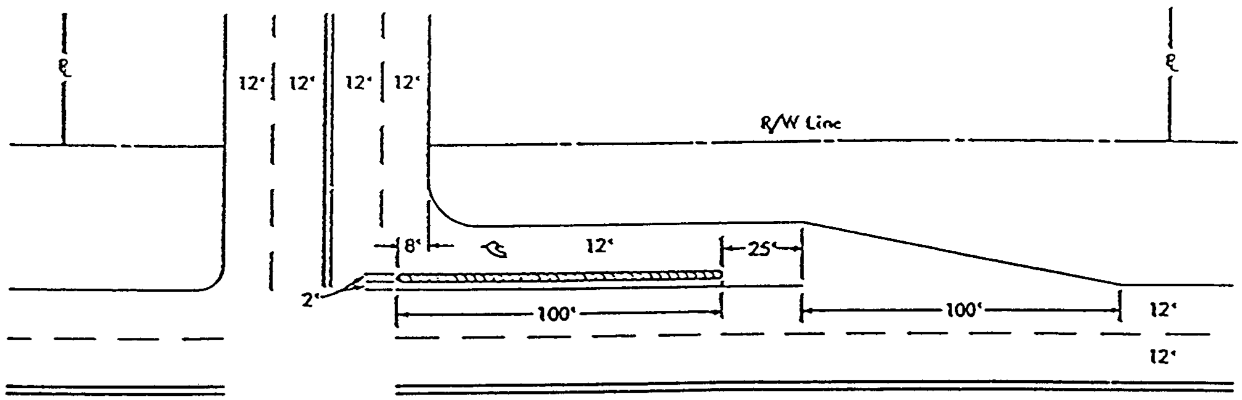


Figure 10. Right-Turn Lane Channelization (7)

Medians

A nontraversible raised median on the major facility can improve the operations of a right-in right-out design by precluding the left turning movements. The safety benefits of medians are discussed in Discussion Paper 4, TRI, OSU for the ODOT Access Management Project.

RESEARCH RESULTS

Research Study

The research results and recommendations in this report are based on a study of 20 different locations in Oregon and Washington. The intersections were selected to investigate the effects of the following factors on performance of right-in right-out channelization:

- Location setting
- Island size
- Island shape
- Median type
- Use of traffic control devices
- Existence of acceleration and deceleration lanes

Seventeen of the islands are located on arterials as a secondary entrance to an activity center, such as a shopping mall or warehouse. Although sufficient access is available from a signalized intersection, the existence of this access reduces the turning volume along the other roads. The other three islands are located at the crossing of an arterial and local street. Table 7 provides information about the locations. A comprehensive discussion of this research effort and the results are given in the unpublished Masters of Science research project report, "Right-In Right-Out Channelization," Ahmet Aksan, TRI, OSU, 1997.

Left-In and Left-Out Violations

There are three types of violations at right-in right-out channelized sites:

- Left-in violations
- Left-out violations
- Wrong way operation

The violations at the study locations are given in Table 8. The left-in and left-out turn percentages given in Table 8 are found by dividing the total number of left-in or left-out violations by the total number of right-in right-out movements, respectively. Wrong way movements are not included in left turns.

In general, there were less left-out violations than left-in violations at the intersections studied. The left turn from the approach is the most difficult maneuver to execute at an unsignalized intersection. First, it faces the most complex set of conflicting flows, such as major street flows, in addition to the opposing right turn and through movement on the minor roadway. Secondly, a "Right Turn Only" sign warns the drivers who enter the major street from an approach that a left-out turn is prohibited. Few locations have "No Left Turn" signs for left-in turning vehicles. At some locations, where another driveway is located across from the right-in right-out channelized island, some drivers make the left turn by crossing the street into the approach on the other side, making a U-turn, and then making a right turn from that approach.

Table 7. Site Information

Location Number	Location Setting	Traffic Signal	Setting	Median Type for In	Median Type for out	Right turn decel lane	Right turn accel lane	Left lane vol per hour	Right lane vol per hour	Highway Vol per hour	Volume phpl
#1	C	DU-400ft	C	TWLTL	TWLTL	Yes	No	578	488	1066	533
#2	A	DU-300ft	A	No	No	Yes	No	812	396	1208	604
#3	A	D-300 ft	A	TWLTL	TWLTL	No	No	687	548	1234	617
#4	C	D-70ft	C	No	No	Yes	No	829	309	1138	569
#5	B	U-300ft	B	Short-Raised	Long Raised	Yes	No	1119	893	2012	1006
#6	B	U-120ft	B	No (LTL for thru traf)	No (LTL for thru traf)	Yes	No	599	804	1402	701
#7	B	U - 70 ft	B	No (LTL for thru traf)	No (LTL for thru traf)	Yes	No	436	310	746	373
#8	B	U- 300ft	B	TWLTL	TWLTL	No	No	745	613	1358	679
#9	B	U-600 ft	B	Flush	Flush	No	No	810	709	1519	760
#10	A	D-250ft	A	TWLTL	TWLTL	Yes (10 ft shoulder)	No	581	556	1137	568
#11	A	D-400ft	A	No	No	Yes (15 ft Shoulder)	Yes (15ft Shoulder)	616	0	616	308
#12	A	U-400 ft	A	No	No	Yes (10 ft Shoulder)	Yes (10 ft Shoulder	606	0	606	606
#13	A	D-600 ft	A	No	No	Yes (15 ft shoulder)	Yes (15ft Shoulder)	616	0	616	616
#14	C	D-300ft	C	No	Short Raised	No	No	497	506	1002	501
#15	B	U-200 ft	B	No	Short Raised	Yes	Yes	643	434	1077	539
#16	B	U-600ft	B	Long Raised	Short Raised	Yes	No	625	424	1049	525
#17	B	U-300ft	B	TWLTL	TWLTL	Yes (15ft Shoulder)	Yes (15ft Shoulder)	738	849	1587	793
#18	D	U-100ft	D	No	No	No	No	465	716	1181	590
#19	D	D-400ft	D	Raised	Raised	No	No	900	880	2677	892
#20	D	No	D	Raised	Raised	No	No	1085	1103	3291	1097

Table 8. Violation Rates of Locations

Location Number	Location Setting	Right-in per hour	Left-in per hour	Left-in percentage	Wrong way per hour	Wrong way percentage	Right-out per hour	Left-out per hour	Left-out percentage
#2	A	167	0	0.00	0	0.00	56	4	0.06
#11	A	35	1	0.01	0	0.00	48	0	0.00
#13	A	44	4	0.09	0	0.00	40	2	0.05
#12	A	70	7	0.10	2	0.02	48	2	0.03
#3	A	74	9	0.12	0	0.00	8	1	0.07
#10	A	178	70	0.39	1	0.00	97	3	0.03
#16	B	31	1	0.03	0	0.00	57	1	0.01
#15	B	26	1	0.04	1	0.02	22	0	0.00
#9	B	34	4	0.10	0	0.00	63	1	0.01
#7	B	113	12	0.11	0	0.00	137	0	0.00
#8	B	16	4	0.22	0	0.00	33	0	0.00
#17	B	57	14	0.25	0	0.00	52	0	0.00
#6	B	29	17	0.60	2	0.07	37	1	0.01
#5	B	44	32	0.73	0	0.00	266	0	0.00
#1	C	59	1	0.01	0	0.00	12	1	0.09
#4	C	22	1	0.05	0	0.00	38	1	0.01
#14	C	31	3	0.08	0	0.00	128	1	0.00
#19	D	228	0	0.00	0	0.00	31	0	0.00
#20	D	236	0	0.00	0	0.00	333	0	0.00
#18	D	39	8	0.19	2	0.04	32	3	0.10

There were different types of left-in violations. At locations without raised medians, drivers usually make a direct left-in turn and enter the approach road. A long-raised or short-raised median forces the drivers with the intention of a left-turn to make a U-turn after passing the island to enter the approach.

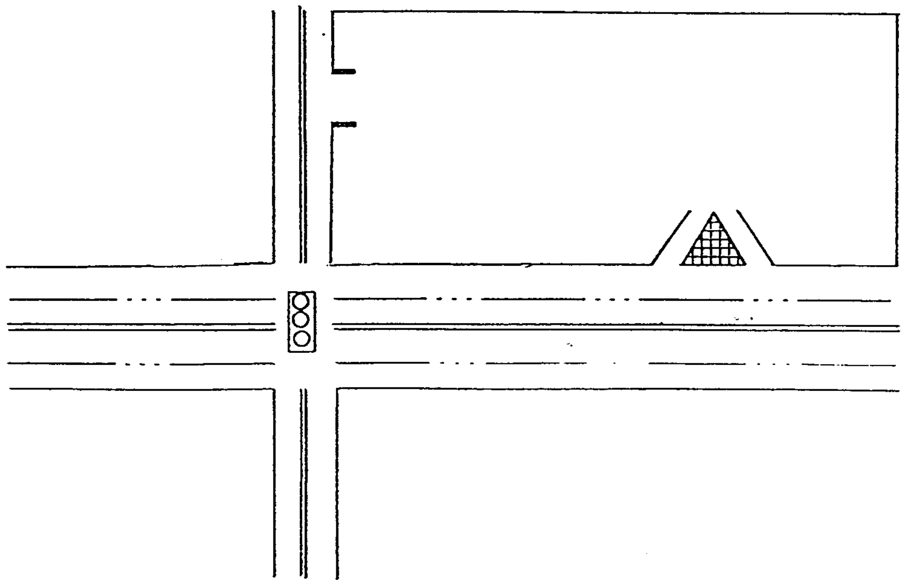
Location Settings

After carefully reviewing the research data, four common settings for channelized island locations were found that help define the performance of right-in right-out locations. The location setting reflects the location of the channelizing island with respect to the best directional desire line to the major activity at the site for drivers approaching the site. Drivers try to take the most direct route to their desired destination. Data also indicated that there is a strong correlation between the channelized island settings and violation rate. At locations where the only means to decrease the travel time to or from an activity center is through a violation, the violation rate is found to be high. The location settings are developed based on how the right-in right-out channelized intersection is placed relative to other access and primary activities.

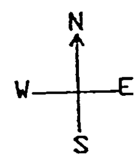
At some locations drivers have to pass by the channelized entrance on the arterial to enter the activity center because a left-in turn is not permitted. They enter the activity center through the signalized intersection which is located farther along the arterial. At these locations, where the driver can save some time by taking a left-in turn, the violation rate is found to be high. However, if the drivers arrive at the signalized intersection with a crossing roadway that has an entrance to the activity center right-in right-out before the right-in right-out island on the arterial, the violation rate is found to be low.

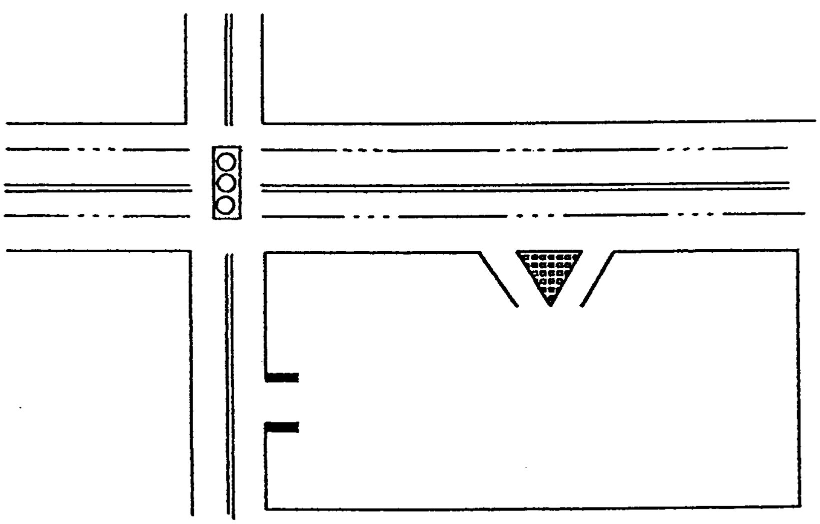
<u>Setting A</u> (Figure 11a)

In this setting the activity center has two entrances. The main entrance is onto the crossing roadway connected by a signalized intersection. The second entrance has a channelization island which is located on the arterial. For drivers coming from the west (W), the entrance on the arterial is the best option to enter the activity center. Drivers coming from the north (N) and the east (E) have to pass the signalized intersection and use the main entrance conveniently.



a) Setting A





b) Setting B

Figure 11. Setting A and B

However, if the main traffic generator in the mall area is located close to the island and far from the main entrance, the shortest way to that location is through the entrance on the arterial where the island is located. This also applies for drivers who do not want to interfere with the pedestrian and vehicle traffic at the entrance and at the parking of the activity center. Basically, by making a left-in turn, drivers can avoid delays and therefore decrease their travel time.

For drivers leaving the activity center, there are several options. Drivers going E can either use the main entrance or the channelized entrance on the arterial without any problem. It is the same for drivers going N or S. However, for a driver going W, the shortest way out of the activity center is through the entrance on the arterial and a left-out turn.

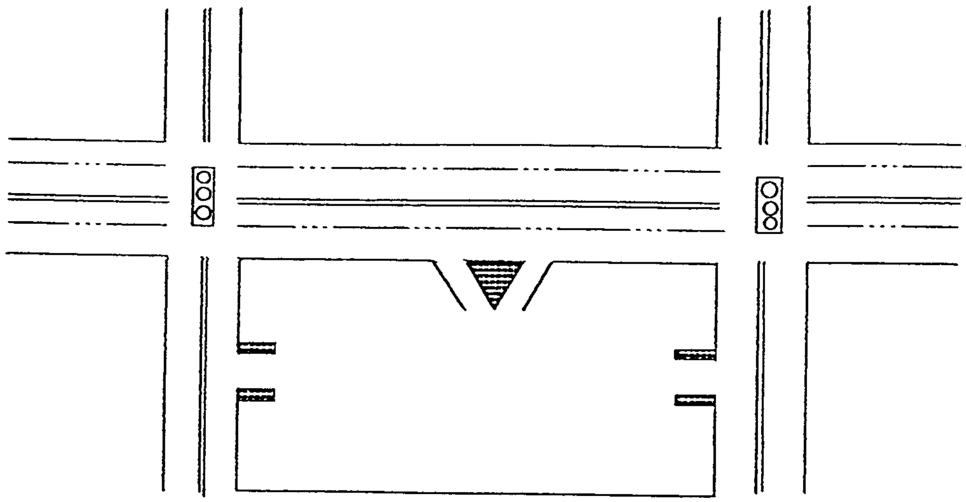
Setting B (Figure 11b)

There are two entrances for the activity center. The main entrance is onto a crossing roadway connected by a signalized intersection, and the second one is through a channelized intersection on the arterial. Drives come from W and N would usually go through the intersection and enter the area either through the main entrance or through the channelized intersection without any difficulties. However, drivers coming from E have to take a longer path. They have to drive to the intersection, wait for the left turn signal, and after passing through the intersection, enter the activity center. For these drivers, making a left-in turn on the arterial saves them from the delay and additional distance that they would have to drive at their destination.

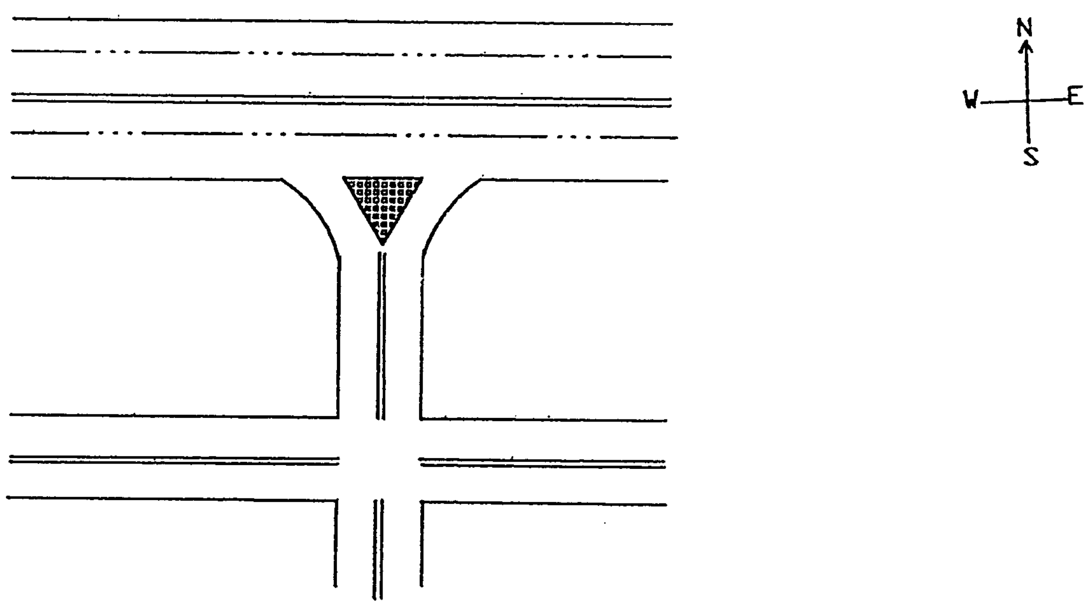
In leaving the shopping area, none of the drivers can make their trip shorter by taking the left-out turn. The left-out turn is a better option only for drivers who want to avoid the traffic inside the activity center. However, this type of movement has seldom been observed.

Setting C (Figure 12a)

The activity center is provided with three entrances. The channelized entrance is located at the arterial between the other two entrances, which usually are signalized. None of the drivers would save any time, nor would they take the shortest path by making a left-out turn at the channelized island.



a) Setting C



b) Setting D

Figure 12. Setting C and D

<u>Setting D</u> (Figure 12b)

The island is located at the crossing of an arterial and a local street. In most cases, the drivers who feel the need for a left turn can go to their destination with the help of a parallel street without much delay. It is believed that most of the violations are by drivers who are not familiar with the location. It is observed that some drivers stop after seeing the "Right Turn Only" sign. They back up, make a turn and drive into the opposite direction.

Location Settings vs. Violation Rates

Information on the violation rates relative to location settings are given in Table 8. Figures 13a and 13b show the percentages of the left-in and left-out violations sorted by the settings. Setting B for left-in turns results in more violations than the other three settings. For left-out turns, however, locations with Setting A have more violations than any other setting. Location #18 has a very high violation rate among the islands with the same setting. This location has a painted island, and painted islands are not very effective in preventing traffic movements.

Locations 3 and 10 show high violation rates for left-in turns compared to other locations with the same setting. However, in both cases, drivers have easier access to the main traffic generators through the channelized island, as shown in Figure 14.

Violations by Median Type

In this analysis there are seven different types of median: flush median, TWLTL, left turn lane (LTL) for the opposing traffic, no median, short raised median, long raised median, and continuous raised median. Each location is analyzed separately for left-in and left-out turns because at some locations the length of the median had an influence only on one turn and not on both. Table 9 provides information on the violation rates relative to the median types of each location.

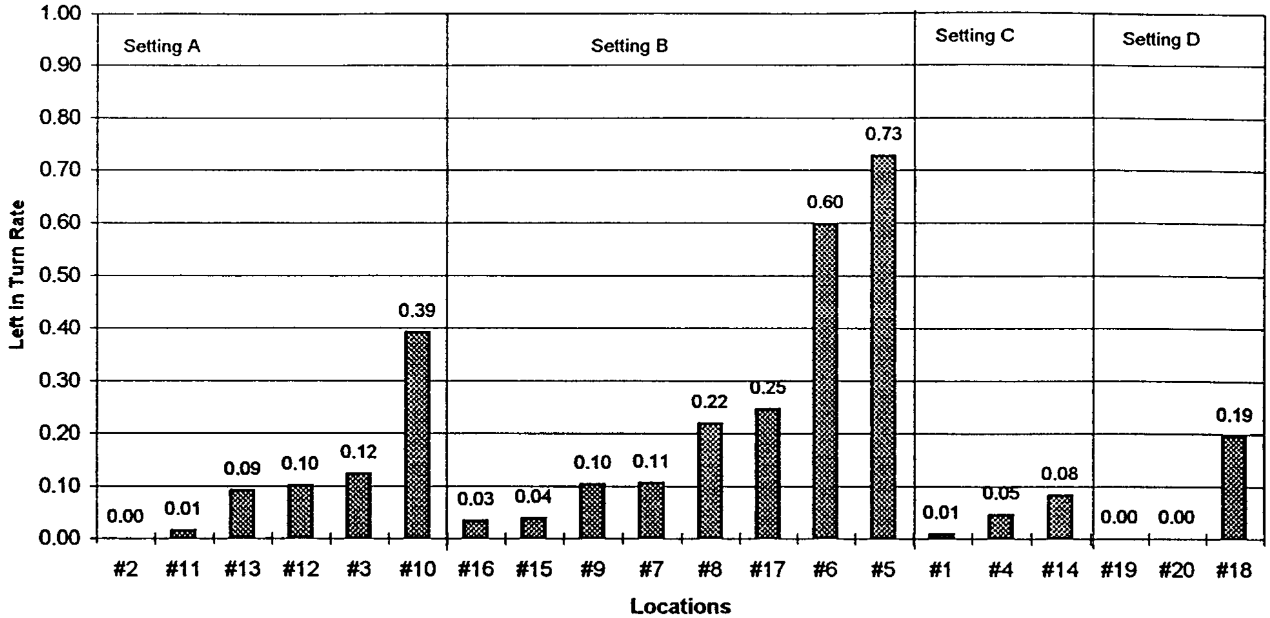


Figure 13a. Violation Rates for Left-In Turns

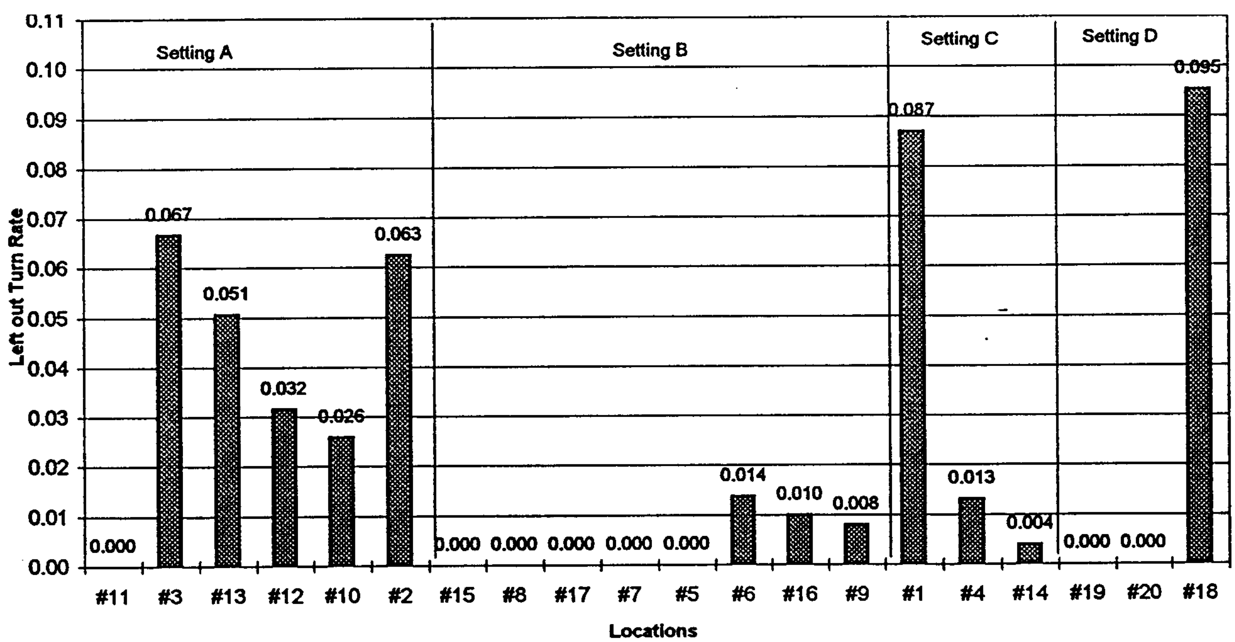


Figure 13b. Violation Rates for Left-Out Turns

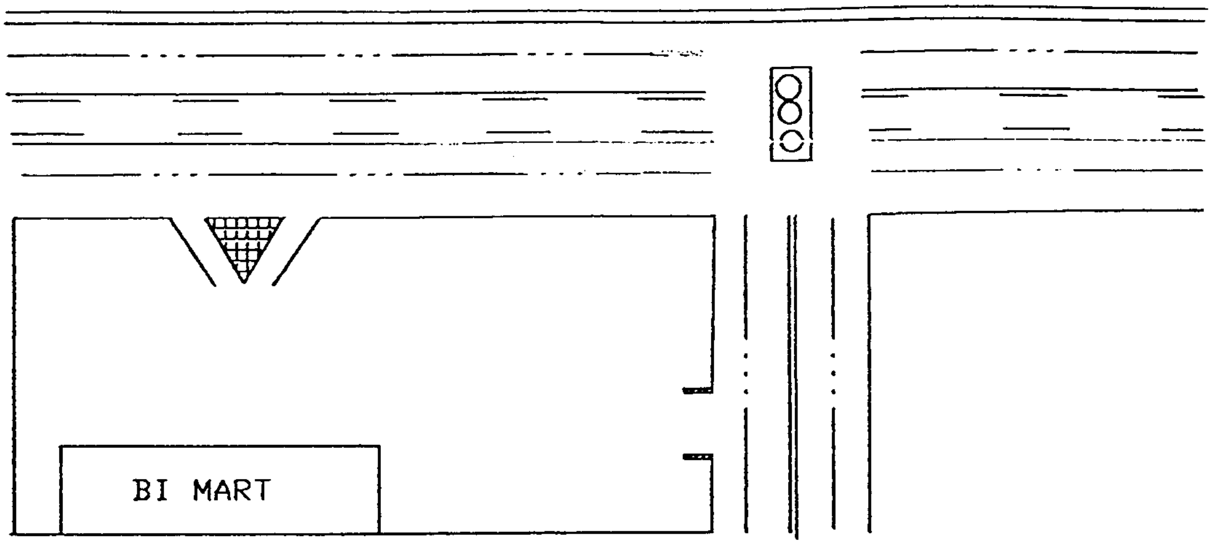


Figure 14a. Setting for Location #3

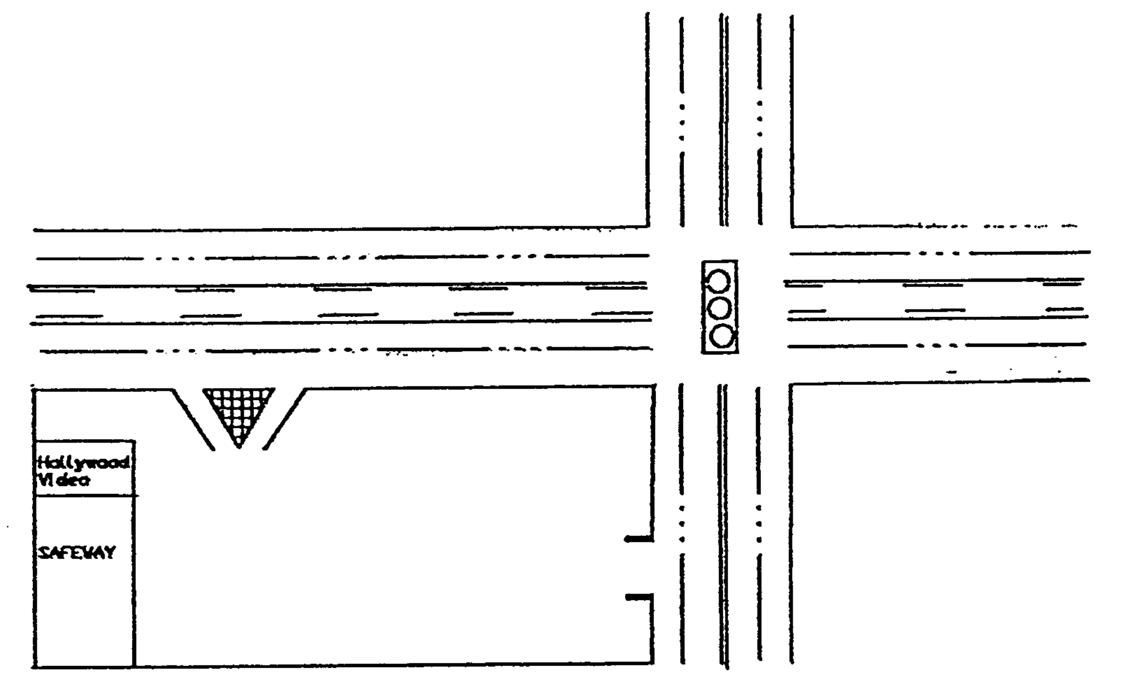


Figure 14b. Setting for Location #10

Table 9. Median Type and Violation Rates of Locations

Location Number	Location Setting	Median Type for Left-in	Median Type for Left-out	Left-in percentage	Left-out percentage
#3	A	TWLTL	TWLTL	0.12	0.07
#10	A	TWLTL	TWLTL	0.39	0.03
#2	A	No	No	0.00	0.06
#11	A	No	No	0.01	0.00
#13	A	No	No	0.09	0.05
#12	A	No	No	0.10	0.03
#8	B	TWLTL	TWLTL	0.22	0.00
#17	B	TWLTL	TWLTL	0.25	0.00
#9	B	Flush	Flush	0.10	0.01
#7	B	No (LTL for thru traf)	No (LTL for thru traf)	0.11	0.00
#6	B	No (LTL for thru traf)	No (LTL for thru traf)	0.60	0.01
#15	B	No	Short Raised	0.04	0.00
#16	B	Long Raised	Short Raised	0.03	0.01
#5	B	Short-Raised	Long Raised	0.73	0.00
#1	C	TWLTL	TWLTL	0.01	0.09
#4	C	No	No	0.05	0.01
#14	C	No	Short Raised	0.08	0.00
#18	D	No	No	0.19	0.10
#19	D	Raised	Raised	0.00	0.00
#20	D	Raised	Raised	0.00	0.00

It is observed that for Setting B, a signalized intersection near the island has a significant influence on the left-in violation rate. When the traffic light is red for the traffic from W, drivers with the intention of a left-in turn can easily find the gap they need to make the turn. If the island is within the functional limits of the intersection, the drivers coming from E, with the intention of a left turn at the intersection, are backed up past the island. In this case, drivers who want to make a left-in turn don't create problems for the drivers behind them. Since the volume from the cross streets into the arterial is usually not that high, the drivers find the gap they need and make the left-in turn.

The locations with TWLTL or LTL for opposing traffic have higher violation rates than the others (Figure 15). In both cases, the drivers who want to make the left-in turn can protect themselves from the through traffic by pulling into the TWLTL or into the LTL. When the traffic light is red for the through traffic, they find the gap they need and complete their turn. For Setting B, Location #8 and #17 have high left-in violation rates. For Setting A, Locations #3 and #10 experience the highest violation rates. All of these locations have TWLTLs. Locations #6 and #7 have LTLs and also high violation rates.

At the locations with continuous raised medians, no violations were found (Locations #19 and #20). Long raised medians manage to keep the violation rate low but do not eliminate them completely. Short raised medians help to keep the violation rate low at certain locations but also create other problems. It is observed that drivers enter the lanes of the opposing traffic, drive in the wrong direction until they pass the island and finally cross the street. There are not many problems at undivided streets with no median. This may be because drivers on the through lanes would feel pressure from the cars behind and not attempt to make the turn at all.

The analysis of left-out turns and median type indicate very low correlation (Figure 15). Continuous raised medians showed no violations. Long raised medians showed very low violation rates.

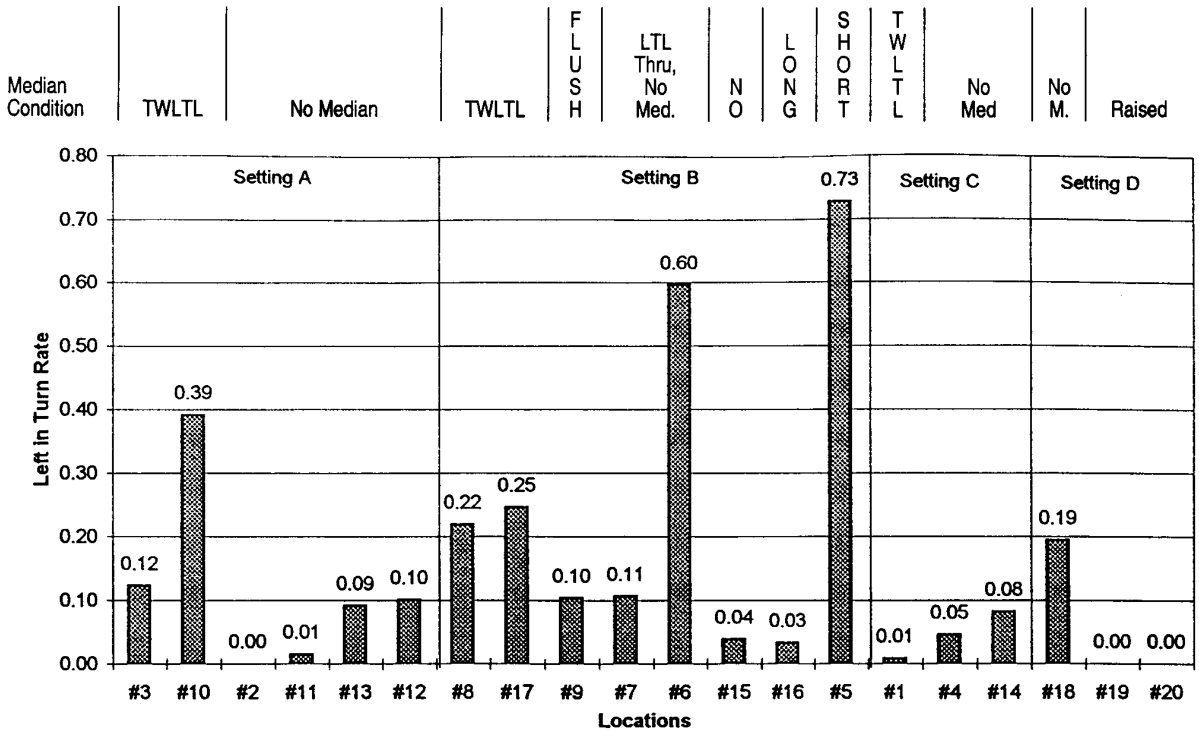


Figure 15a. Left-In Violation Rates Sorted by Setting and Median Type

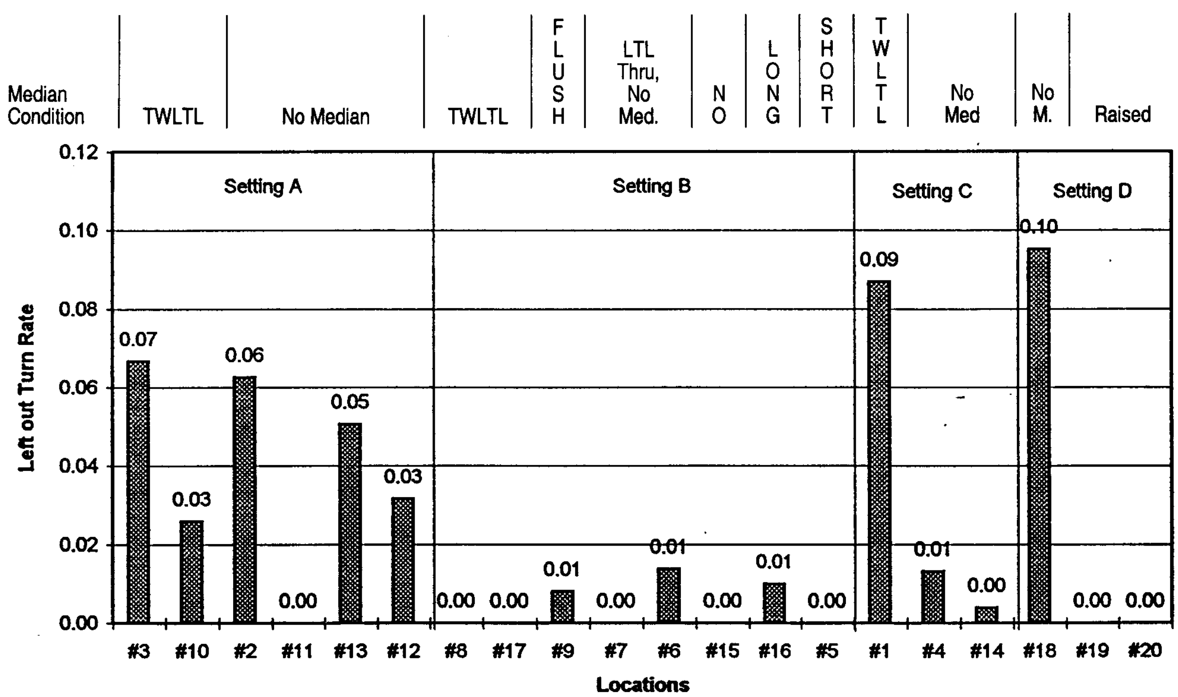


Figure 15b. Left-Out Violation Rates Sorted by Setting and Median Type

Island Length

The analysis of a location for violations requires the consideration of the setting, median type, distance to the closest intersection, and the size of the island. The data collection effort was limited to 20 locations which is not sufficient for a good comparison. However, the locations observed provided some insight on the effect of island length.

In this project three different terms were used to identify island dimensions. Upstream length (Lu), meaning the island length on the upstream side of the island, downstream length (Ld), meaning the length of the island on the downstream side of the island, and depth, meaning the length of the island from the arterial into the side street. (Figure 16)

Downstream length and upstream length are analyzed separately because many of the islands are not symmetrical (Table 10). It is believed that, although the island size plays an important role in reducing the number of violations, other factors such as setting and median type are more important factors.

Right-turn lanes are desirable at arterials to accommodate speed changes. However, for left turning vehicles from the arterial into the activity center, they provide some additional space to complete the turn. The vehicles can easily manage turning angles up to 135° within the extra width provided by the right-turn lane. Unless the upstream side of the island is large and the width of the deceleration lane is narrow, they can have a very comfortable turn at locations with a traversable median.

For Setting A in Figure 17, the smallest islands have the most violations. Locations #3 and #10 both have TWLTLs. It is believed that when a location has a small size island and a TWLTL, it creates a good setting for violations. Locations #2 and #11 have large island sizes and also very low violation rates.

Table 10. Island Sizes and Right-Turn Lanes

Location Number	Location Setting	Right turn decel lane	Right turn accel lane	Island Depth	Upstream Length (ft)	Downstream Length (ft)
#10	A	Yes (10 ft shoulder)	No	17.4	10.7	4.0
#3	A	No	No	64.2	15	12.8
#12	A	Yes (10 ft Shoulder)	Yes (10 ft Shoulder)	39.9	15.7	14.1
#13	A	Yes (15 ft shoulder)	Yes (15 ft shoulder)	53.0	27.4	25.5
#11	A	Yes (15 ft shoulder)	Yes (15 ft shoulder)	45.4	41.4	33.8
#2	A	Yes	No	39.4	44.1	11.3
#17	B	Yes (15 ft shoulder)	Yes (15 ft shoulder)	14.7	8	6.2
#8	B	No	No	20.7	9	8.6
#9	B	No	No	23.7	11	11.0
#16	B	Yes	No	17.2	15.8	7.3
#7	B	Yes	No	64.0	30	35.8
#6	B	Yes	No	57.0	31	26.8
#5	B	Yes	No	107.7	36.3	14.1
#15	B	Yes	Yes	30.5	76	50.4
#4	C	Yes	No	38.5	11.4	18.5
#14	C	No	No	28.7	20.4	15.7
#1	C	Yes	No	47.6	112.6	24.8
#20	D	No	No	32.5	7	33.3
#19	D	No	No	28.7	13.5	15.7
#18	D	No	No	NA	NA	NA

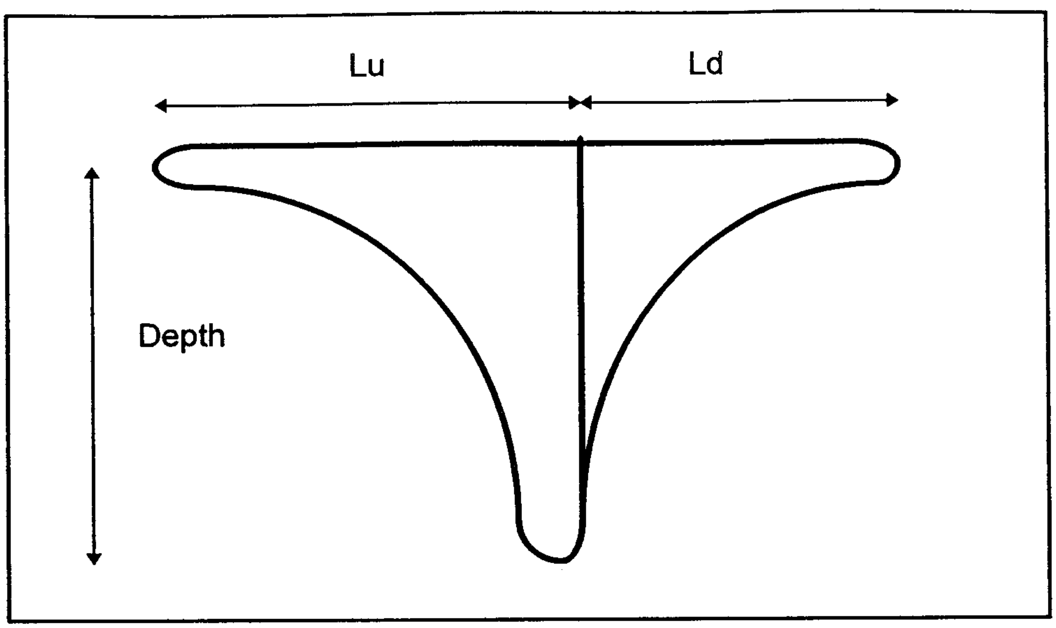


Figure 16. Island Terminology

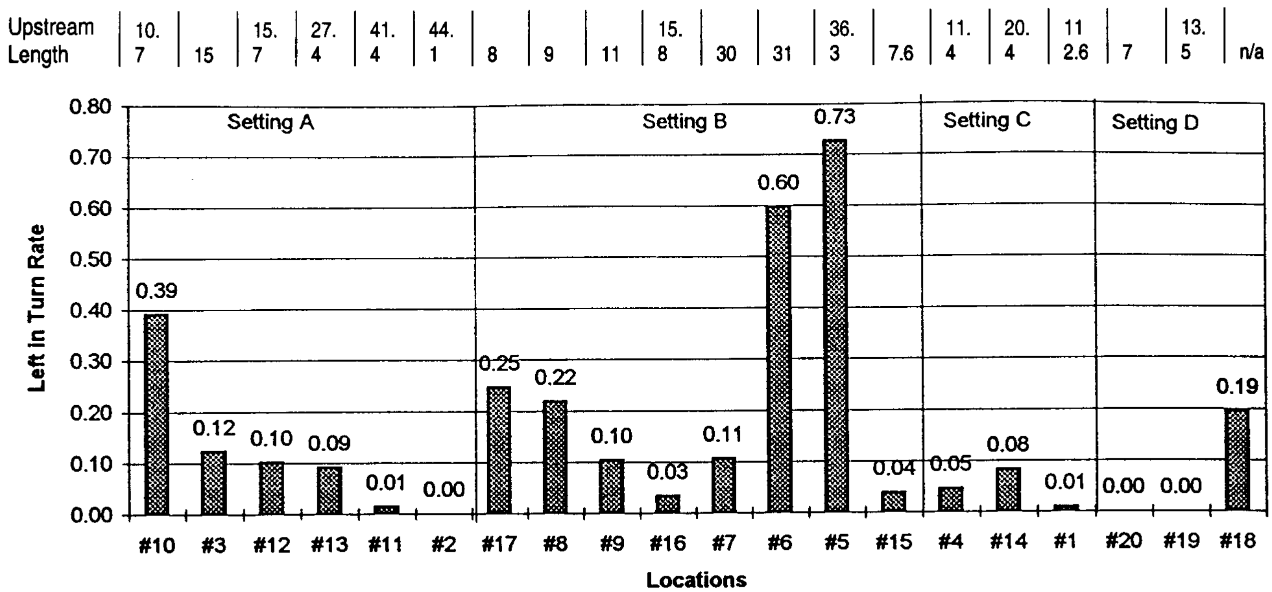


Figure 17a. Left-In Violation Rates Sorted by Setting and Upstream Length

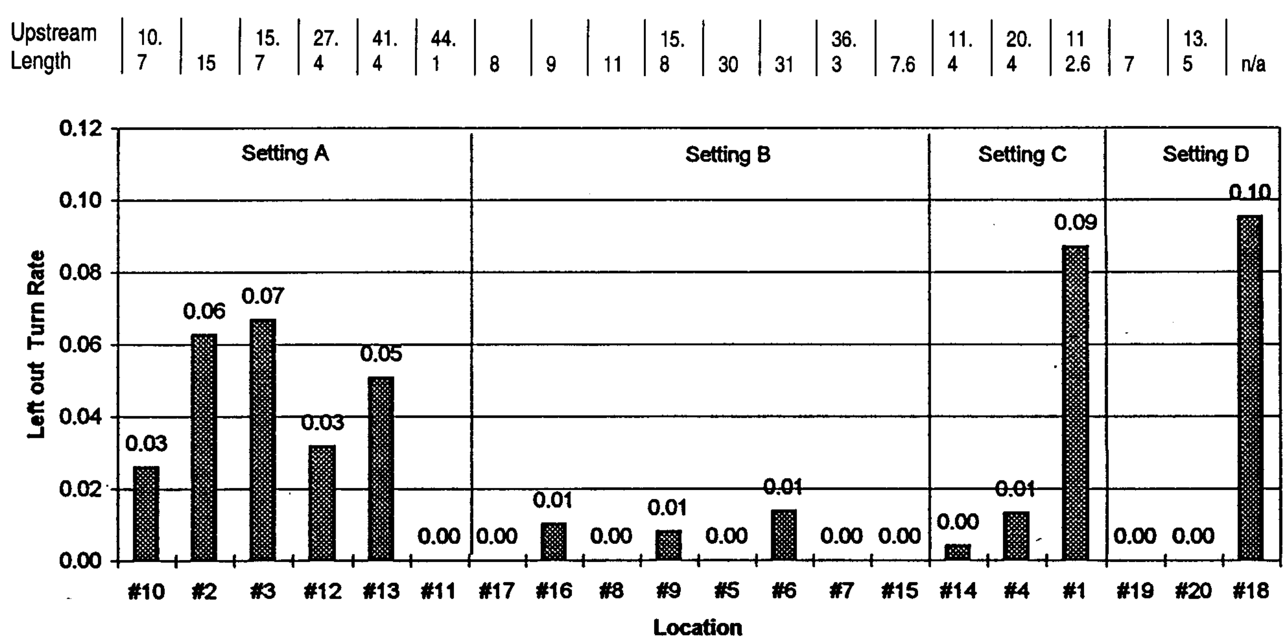


Figure 17b. Left-Out Violation Rates Sorted by Setting and Upstream Length

When analyzing the data for Setting B, an obvious pattern between the length and the left-in violation rate could not be found. The islands with the most violations are also the largest ones. However, at Locations #5 and #6 the islands are within the functional area of the intersection and the drivers can easily find the gap they need to make a left-in turn. The size of the island can not help keep the violation rate down. Locations #8 and #17 also have high violation rates. The reason for this is believed to be the small island sizes and TWLTLs. Location #16 has the lowest violation rate. At this location the long raised median prevents all of the left-in turns. Location #15 has the longest upstream length and also one of the lowest violation rates. At this location the island size is believed to be the most important factor in keeping the violation rate low.

For left-out turns, Setting A has the highest violation rate. There is no obvious correlation between the island size and violation rate among these islands. Location #11 has zero violations and also the biggest island size. However, other locations with similar setting and island size experience high violation rates.

Wrong Way Movements

Four locations experienced wrong way movements. The data do not indicate any obvious reason for these locations to have wrong way violations. Locations #6, #12 and #18 have already had high left-in rate when compared with other islands in the same setting. However, it is observed that at Locations #6 and #12 the drivers did not have any difficulty in entering the wrong way. Location #18 has a painted island that has been run over by many drivers as well. The driver who committed the violation at Location #15 had to drive almost 150 ft in the wrong way to enter the activity center from the wrong way. At other locations where drivers could easily make a violation no violations were observed.

Right-In Speeds

A speed change lane helps the driver make the necessary change between the speed of the operation on the highway and on the turning roadway. In a more complete analysis of the right-in maneuver, speed and conflict data were collected.

Figure 18a indicates that there is not much difference between the right-in speeds at locations with a deceleration lane (12.38 mph) or without a deceleration lane (12.24 mph) (Locations #18 and #19 were excluded). However, conflict data (Table 11) indicate that right turn same direction conflicts are substantially lower at locations with a deceleration lane.

No correlation could be found between the size of the island and right-in speed. Therefore, data were organized based on the site specifications (Figure 18b). Some locations have crowded entrances due to vehicle and pedestrian traffic. At some other locations drivers had to drive downgrade or upgrade after leaving through traffic lanes. The rest of the locations were not crowded and were level.

At locations with crowded entrances (11.5 mph) or where the drivers had to go upgrade (11.75 mph), the average entrance speed is low. However, drivers coming to a location with a downgrade entrance can enter at higher speeds (13.70 mph). Locations #18 and #19 were excluded from the calculations because these islands are located at the crossing of an arterial and a local street and also merge with an angle that provides a higher entrance speed for the vehicles. Locations without any special conditions average an entrance speed of 12.31 mph. Locations #3 and #20 have lower right-in speed than the others with the same conditions because of poor sight distances.

Conflict data indicate that there are not many conflicts created by violations (Table 12). It was observed that drivers who violate usually take their time and wait for a convenient moment to complete their turn. They are much more careful than if they were making a regular left turn. The reason for this may be that the drivers already know that they are in violation, so they take extra caution and do not put themselves into jeopardy.

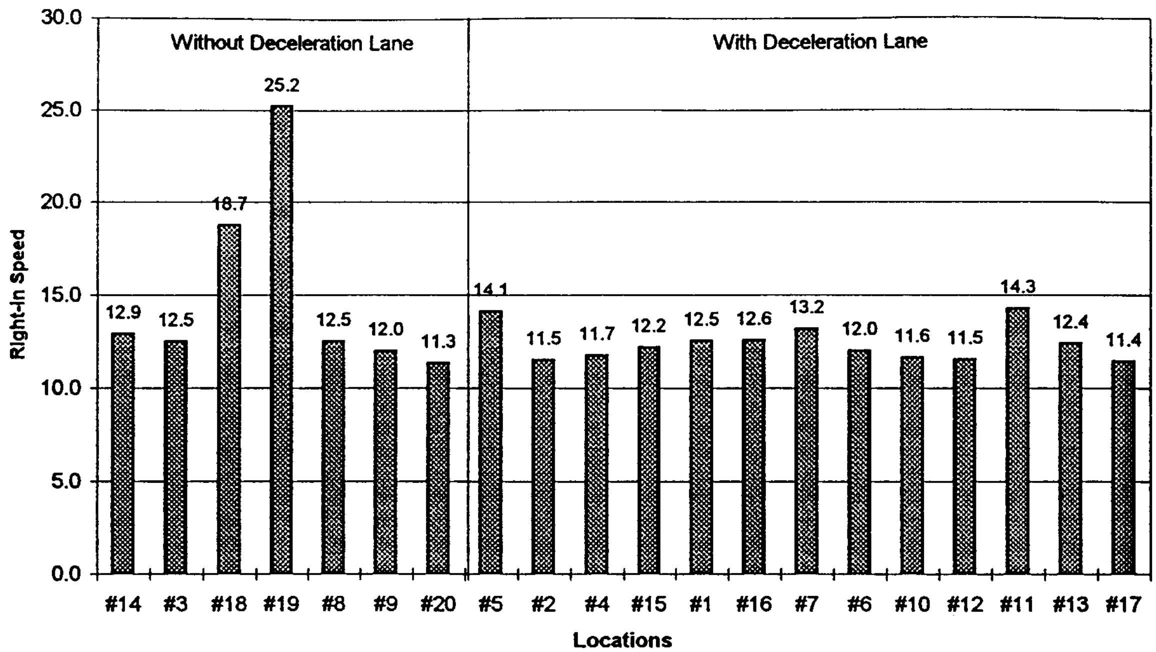


Figure 18a. Right-In Speeds Sorted by Right-Turn Lane

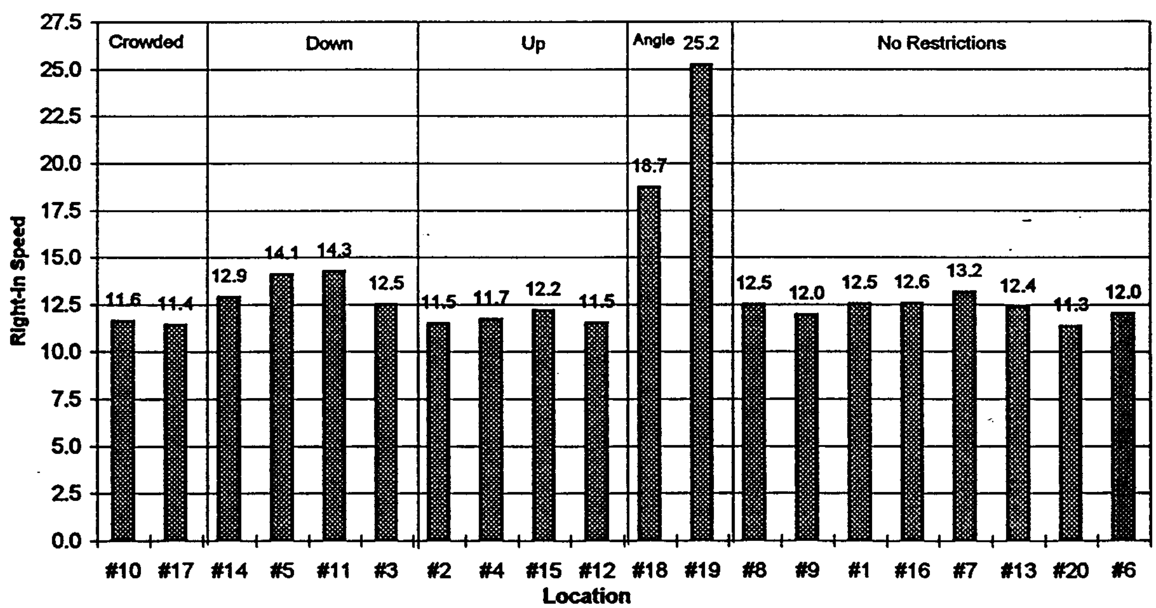


Figure 18b. Right-In Speeds Sorted by Speed Reason

Table 11. Speed Information of Locations

Location Number	Setting	Right turn decel lane	Right turn accel lane	85 th % Speed	Average Speed	Right in speed	Speed Differance	Speed Reason
#10	A	Yes (10 ft shoulder)	No	37.5	32.4	11.6	20.73	C
#17	B	Yes (15ft Shoulder)	Yes (15 ft shoulder)	35.5	29.8	11.4	18.20	C
#14	C	No	No	30.3	26.1	12.9	13.22	D
#5	B	Yes	No	29.4	26.3	14.1	12.19	D
#11	A	Yes (15 ft Shoulder)	Yes (15 ft shoulder)	38.2	34.6	14.3	20.32	D
#3	A	No	No	24.8	21.6	12.5	9.06	D
#2	A	Yes	No	29.7	25.9	11.5	14.40	U
#4	C	Yes	No	29.7	25.9	11.7	14.15	U
#15	B	Yes	Yes	42.7	37.9	12.2	25.70	U
#12	A	Yes (10 ft Shoulder)	Yes (10 ft Shoulder)	34.4	29.7	11.5	18.19	U
#18	D	No	No	30.2	27.4	18.7	8.71	A
#19	D	No	No	39.5	35.5	25.2	10.25	A
#8	B	No	No	33.9	30.1	12.5	17.56	NR
#9	B	No	No	33.9	30.1	12.0	18.08	NR
#1	C	Yes	No	40.7	37.0	12.5	24.49	NR
#16	B	Yes	No	54	46.2	12.6	33.61	NR
#7	B	Yes	No	25.4	20.6	13.2	7.47	NR
#13	A	Yes (15 ft shoulder)	Yes (15 ft shoulder)	38.2	34.6	12.4	22.90	NR
#20	D	No	No	42.3	37.9	11.3	26.60	NR
#6	B	Yes	No	26.2	23.0	12.0	11.02	NR

C= Crowded D= Downgrade U= Upgrade NR= No Restrictions

Table 12. Total Conflicts for 2 hours Period

Location Number	Right turn same directio	Slow vehicle same direction	Lane change from left to right	Lane change from right to left	Opposing left	Right turn cross from right	Left turn cross from right
# 1	1	0	1	0	0	1	0
# 2	4	1	1	2	0	4	1
# 3	53	25	4	8	6	5	0
# 4	2	0	0	0	1	38	0
# 5	4	3	0	0	6	15	0
# 6	7	3	0	0	8	9	0
# 7	7	2	3	2	1	7	0
# 8	9	5	0	1	1	3	0
# 9	11	5	0	1	1	10	0
# 10	11	6	0	0	8	3	2
# 11	2	0	0	0	0	2	0
# 12	2	1	0	1	2	0	0
# 13	2	1	0	0	2	0	0
# 14	8	3	0	0	0	12	0
# 15	1	0	0	0	0	2	0
# 16	0	0	0	0	0	4	0
# 17	7	2	1	3	2	9	0
# 18	21	10	0	4	2	3	3
# 19	52	21	0	5	0	12	0
# 20	75	39	0	3	0	69	0

Accident Rates

Traffic accidents often follow certain patterns that can be identified. Accidents reflect a shortcoming in one or more components of the driver-vehicle-roadway system. Table 13 shows the accident rates for the locations. The analysis shows that 10 of the locations did not experience any accidents. Only five locations had some accidents; however, the accident rate at these locations is very low. Location #20 has the highest violation rate. The majority of the accidents at this location are rear-end accidents. The reason for that is believed to be the high average running speed (37.9 mph) and the lack of right turn lanes. Location #17 also has a high accident rate compared to other locations with right turn channelization. However, it is believed that the accidents are related to the intersection traffic and not to the island itself.

DISCUSSION OF RESULTS

Location Setting Most Important Consideration

Specific guidelines are not available to evaluate the violation rates fully at right turn only channelization. The results of the research show that the setting of the island is the most important element in analyzing the violation rates. The median type and the size of the island are believed to be other critical factors in decreasing the rate of violations.

Continuous Raised Median Eliminates Violations

For left-in turns, it is believed that the size of the upstream length of the island plays a big role in keeping the violation rate down. Other sites with continuous raised median prevents all left-in or left-out turns. Locations that are very to close to an intersection may experience high rates of violation if they can use the left turn bay and turn when the signal blocks approaching traffic. Locations with continuous raised median had zero violations.

For left-out turns, sites with a large downstream length had zero violations. A site with a painted island had the highest rate among all islands. As it was with left-in turns, sites with continuous raised medians had zero violations. Sites with short raised medians had violation rates that are very low. However, they still experience some violations.

Table 13. Accident Rates for Locations

Location Number	ADT	Fixed Object	Rate	Rear End	Rate	Opposite Direction	Rate	Entering at Angle	Rate	Overturn	Rate	Total Rate
#2	17300	0	0.00	1	0.05	0	0.00	0	0.00	0	0.00	0.05
#11	15700	0	0.00	2	0.35	0	0.00	0	0.00	0	0.00	0.35
#13	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#12	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#3	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#10	34800	0	0.00	1	0.04	0	0.00	0	0.00	0	0.00	0.04
#16	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#15	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#9	No data available	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
#7	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#8	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#17	28800	2	0.06	29	0.92	0	0.00	3	0.10	0	0.00	1.08
#6	30100	0	0.00	0	0.00	0	0.00	1	0.03	0	0.00	0.03
#5	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#1	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#4	No accidents found	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00
#14	No data available	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
#19	32100	1	0.03	2	0.06	1	0.03	4	0.11	0	0.00	0.23
#20	46500	0	0.00	54	1.06	0	0.00	2	0.04	1	0.02	1.12
#18	No data available	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

There is no pattern for wrong way violations. However, at most of the locations where wrong way violations occurred, the drivers had good sight distance and could see whether somebody was exiting or not. Also at locations with very low volumes, some wrong way violations occurred even though sight distance was poor.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

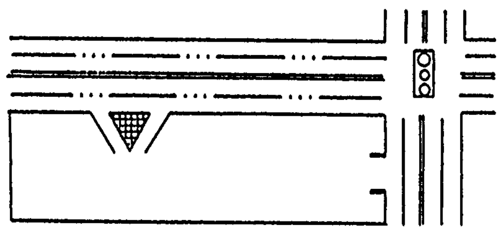
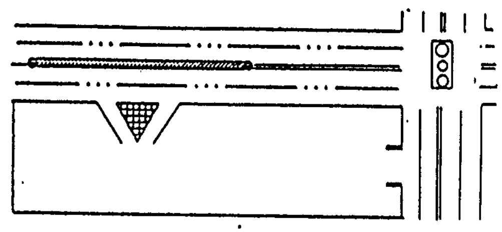
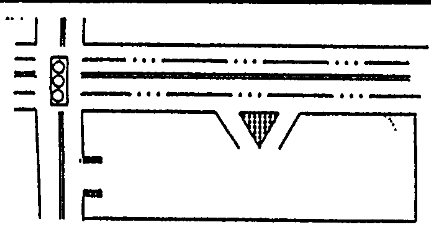
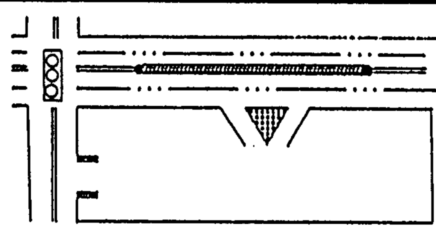
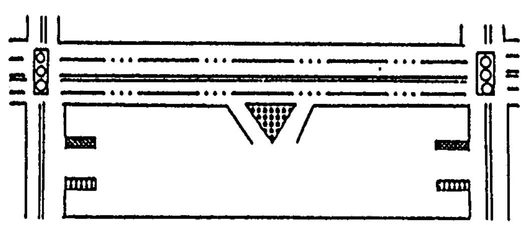
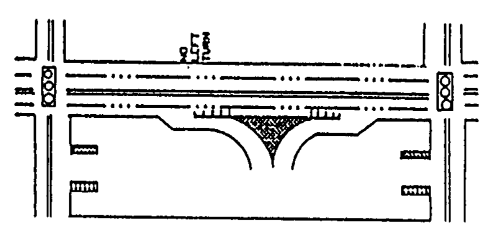
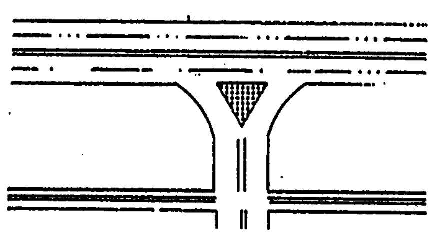
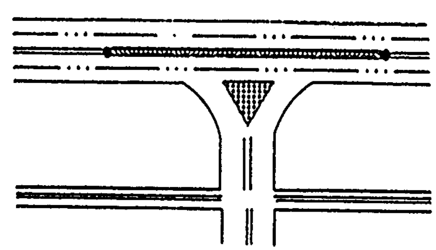
On the basis of the findings of this study the following conclusions are made:

1. The rate of violation depends on the setting of the island. At locations where a left turn could decrease the travel time, a high rate of violations is found.
2. A continuous raised median is the only solution for preventing left turns to and from a right-in right-out island. Long raised medians, short raised medians, and bigger island sizes have been found helpful but are not sufficient to prevent violations.
3. At arterials with a middle lane (TWLTL or LTL) between through traffic lanes, the violation rate is high.
4. Right-in speed can be increased slightly by increasing the radius. However, the most important element in right-in speed is the site specifications such as the grade or vehicle and pedestrian traffic at the entrance.
5. Right-in right-out channelization reduces the accident rate significantly. However, no correlation between the accident rate and the violation rate could be found.

Recommendations

Table 14 summarizes the recommended improvements for different settings.

Table 14. Recommended Improvements for Different Settings

SETTING	RECOMMENDED IMPROVEMENT	NOTES
 Setting A	 Setting A	1. Left-out violations are the main problem. 2. If the main traffic generator is located close to the island and far from the entrance, the number of left-in turns increase. 3. If there is an acceleration or deceleration lane, the length of the raised median should exceed the length of these lanes. 4. The ends of the island should be marked with flexible reflectorized vertical tubular posts or other vertical delineation, in accordance with MUTCD.
 Setting B	 Setting B	1. Left-in violations are the main problem. 2. Undivided highways without a median experience less violations than highways with TWLTL and LTL. 3. If the island is located close to an intersection, the raised median should begin at the intersection. 4. If there is an acceleration or deceleration lane, the length of the raised median should exceed the length of these lanes.
 Setting C	 Setting C	1. There are not any major violations. 2. Undivided highways without a median experience less violations than the highways with TWLTL and LTL. 3. A raised median is the best alternative to keep the violation rates down. However, large island sizes are also effective. 4. The extensions of the island should be marked with reflectorized vertical tubular posts.
 Setting D	 Setting D	1. Violation rates vary from location to location. Turning traffic is not going to a specific destination. Unfamiliar drivers may be confused by the operation with the island present. There are not enough data available to make a good analysis.

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