

Discussion Paper No. 11

RIGHT-TURN LANES

prepared for the

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Salem, Oregon**

by the

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Discussion Paper No. 11

RIGHT-TURN LANES

DISCLAIMER

This discussion paper represents the viewpoints of the authors. Although prepared for the Oregon Department of Transportation (ODOT), they do not represent ODOT policies, practices nor procedures.

GENERAL OBJECTIVE

This and other discussion papers were prepared for the purpose of stimulating discussion among interested individuals representing a variety of agencies having an interest in Oregon's highways.

SPECIFIC OBJECTIVES

The specific objectives of this discussion paper are:

1. Provide information for discussion leading to the adoption of warrants for right-turn lanes on Oregon highways, and
2. Provide information for discussion leading to standards for queue storage and the design of right-turn lanes.

ACKNOWLEDGMENTS AND CREDITS

Mr. Del Huntington is project manager for ODOT. Dr. Robert Layton, Professor of Civil Engineering at OSU is project director for the TRI. This discussion paper was prepared by Dr. Vergil G. Stover, consultant to the TRI. The content of this discussion paper is an elaboration on information which Dr. Stover has published elsewhere.

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INTRODUCTION

Discussion Items

As with left-turn bays, dealing with right-turns has two elements. Firstly, where should they be provided? And secondly, if warranted, how long should they be?

This discussion paper first deals with the issue of warrants and then with the topic of their length -- including storage.

The following topics are the subjects of this discussion paper.

1. Should right-turn deceleration lanes be provided? On Oregon highways? If so, what warrants are to be used? When, if provided, how should the length be determined?
 2. Should right-turn acceleration lanes be provided? If so: where/when? How long should they be?
-

Questions to be Answered

The specific questions to be addressed in consideration of this discussion paper are:

1. Should warrants for right-turn lanes be adopted by ODOT?
2. If adopted: What should be the basis for the warrants (turn volume, through volume, speed, functional class, urban/rural, combination(s) of the above)?
3. If the warrants are based on turn volume, though volume and speed, should the same warrants apply to all highway classifications? If not, what warrants should be adopted for each of the different functional classes?
4. What criteria (speed differential between turning and through traffic, deceleration rate and queue storage) are to be used? Are the criteria the same for all classes of roadways? IF not, how do they differ by roadway class?
5. What bay taper should be used?
6. Can more than one access drive be served by a single right-turn deceleration bay? When? Under what conditions?

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INTRODUCTION (Continued)

**Questions
to be
Answered
(Continued)**

7. Are there applications for continuous right-turn deceleration lanes (a lane of substantial length serving several access drives)? Where/when? Under what conditions?
 8. Are warrants for right-turn acceleration lanes needed? If so, what should they be? And, how long should they be?
-

**AASHTO
Guidelines
for Use of
Auxiliary
Lanes**

AASHTO (1) makes the following statement which are applicable to right-turn lanes (pp. 749-751, 1994 edition; pp. 797-799, 1990 edition).

"Drivers leaving a highway at an intersection are usually require to reduce before turning. Drivers entering a highway from a turning roadway accelerate until the desired open-road speed is reached. 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. To preclude or minimize these undesirable aspects of operation at intersections, speed-change lanes are standard practice on highways having expressway characteristics and are frequently used on other main highway intersections."

"A speed-change lane is an auxiliary lane, including tapered areas, primarily for the acceleration or deceleration of vehicles entering or leaving the through-traffic lanes. The terms "speed-change lane," "deceleration lane," or "acceleration lane," as used here, apply broadly to the added pavement joining the traveled way of the highway or street with that of the turning roadway and do not necessarily imply a definite lane of uniform 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 into it, to make the necessary change between the speed of operation on the highway or street and the lower speed on the turning roadway. Deceleration and acceleration lanes may be designed in conjunction with each other, the relationship depending on the arrangement of the intersection and traffic requirements. They may be designed as parts of at-grade intersections but are especially important at ramp junctions where turning roadways meet high-speed traffic lanes."

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INTRODUCTION (Continued)

Speed Differential and Relative Crash Rates

The relative crash rates in Table 1 indicate that a vehicle traveling on an at-grade arterial at a speed 15 km/h (10 mph) slower than the speed of the normal traffic stream is 180 times (20,000/110) 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 25 km/h (15 mph) slower than the traffic stream has 90 times (20,000/220) the chance of being involved in an accident as a vehicle traveling 15 km/h (10 mph) slower. While the relative ranges may be in considerable error, for any specific section of street or freeway, they clearly show that increased accident potential. Thus, designs which produce small speed differentials 15 km/h or 25 km/h (less than 10 or 15 mph) should be major criteria for the functional design of arterials.

Table 1 - Relative Accident Involvement Rates

	Speed Differential (mph)				
	0	-10	-20	-30	-35
At-grade arterials:					
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

Source: Reference (2)

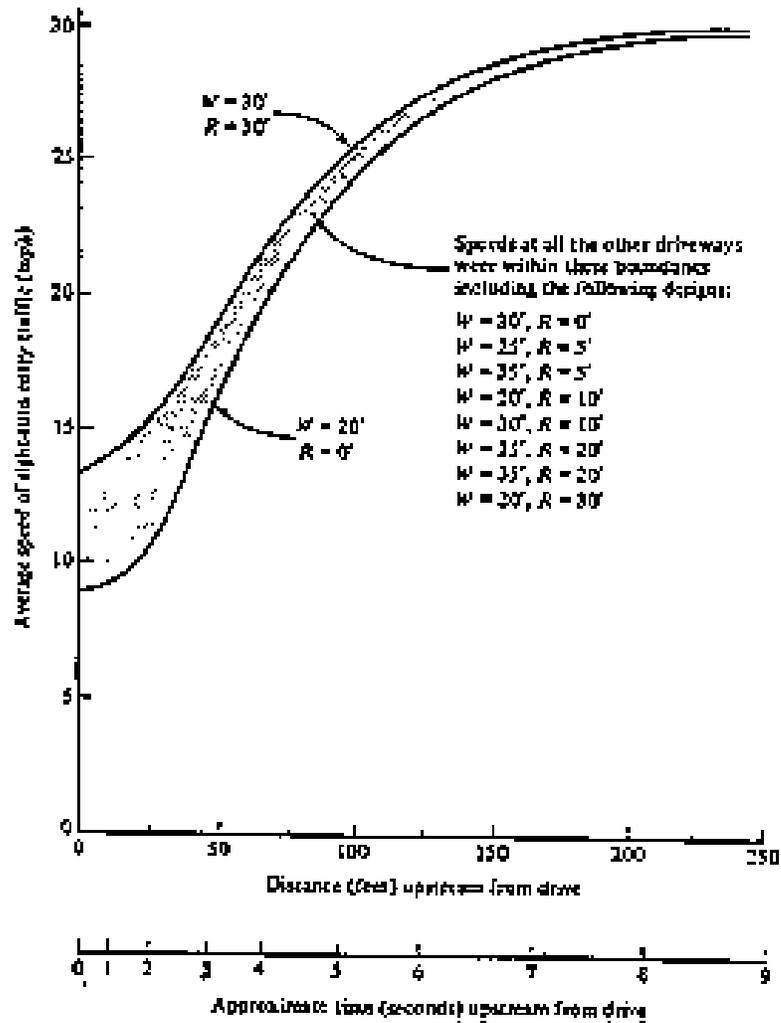
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INTRODUCTION (Continued)

Right-Turning Speeds

The speed of a vehicle making a turn at an intersection is very slow from all reasonable combinations of throat width and curb return radii as illustrated in Figure 1. The forward speeds of the vehicle (as measured by fifth wheel) are between 10 and 21 km/h (6 and 13 mph); however, the speed vector parallel to the through traffic lanes is only 2.4 to 4.0 km/h (1.5 to 2.5 mph).



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**Figure 1 - Between Speed of Vehicles
Relationship Entering the Driveway and Different Combinations of Throat
Width and Curb Return Radii**

INTRODUCTION (Continued)

**Right-Turning
Speeds
(Continued)**

A speed differential of 15km/h (10 mph) or more occurs at least 75 metres (250 feet) and at least 9 seconds upstream from the driveway for off-peak arterial street speeds. The fact that excessive speed differentials are created a considerable distance upstream from the point at which the driveway maneuver is made probably results in an under-reporting of driveway related accidents on accident reports. It also shows that turn lanes are needed in order to achieve acceptable speed differentials between driveway traffic and through vehicles on arterial streets.

Use of a taper on the upstream side of the driveway does not significantly influence the speed of the vehicle making the driveway maneuver. However, the taper results in a reduction in exposure time (the time which the turning vehicle is blocking the through traffic lane).

Also, the use of long curb radii does not decrease the speed differential. However, long curb return radii on the approach side reduces the dispersion of the vehicle trajectories which drivers steer when entering a driveway and facilitates a "smoother" entry maneuver.

Conclusion

All reasonable combinations of curb return radii and throat width produce high speed differentials. And, accident potential increases exponentially speed differential increases. Thus, auxiliary lanes (left-turn and right-turn bays) must be used if acceptable (safe) speed differentials are to be achieved on major urban streets.

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WARRANTS FOR RIGHT-TURN LANES

AASHTO Guidelines for the Use of Right-Turn Lanes

"Warrants for the use of speed-change lanes cannot be stated definitely. Many factors must be considered, such as speeds, traffic volumes, percentage of trucks, capacity, type of highway, service provided, the arrangement and frequency of intersections, and accident experience. Observations and considerable experience with speed-change lanes have led to the following general conclusions:

1. Speed-change lanes are warranted on high-speed and on high-volume highways where a change in speed is necessary for vehicles entering or leaving the through-traffic lanes.
2. All drivers do not use speed-change lanes in the same manner; some use little of the available facility. As a whole, however, these lanes are used sufficiently to improve the overall safety and operation of the highway.
3. Use of speed-change lanes varies with volume, the majority of drivers using them at high volumes.
4. The directional type of speed-change lane consisting of a long taper fits the behavior of most drivers and does not require maneuvering on a reverse-curve path.
5. Deceleration lanes on the approaches to at-grade intersections that also function as storage lanes for turning traffic are particularly advantageous, and experience with them generally has been favorable. Such lanes improve safety and increase capacity.

"Deceleration lanes always are advantageous, particularly on high speed roads, because the driver of a vehicle leaving the highway has no choice but to slow down on the through-traffic lane if a deceleration lane is not provided. The failure to brake by the following drivers because of a lack of alertness causes many rear-end collisions. Acceleration lanes are not always desirable at stop-controlled intersections where entering drivers can wait for an opportunity to merge without disrupting through traffic. Acceleration lanes are advantageous on roads without stop control and on all high-volume roads even with stop control where openings between vehicles in the peak-hour traffic streams are infrequent and short."

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WARRANTS FOR RIGHT-TURN LANES (Continued)

Colorado DOT Warrants

The right-turn deceleration warrants adopted by the Colorado DOT are shown in Figure 1. They have also been adopted by local governments administering access to state highways in their jurisdiction and by some states (New Mexico and Kansas for example).

4.7.2 Deceleration Lanes for Right Turning vehicles

a. A speed Change lane for right turning deceleration movements is required for any access according to the graph 4.7.2 when the DHV values of the highway single lane and the DHV of right turns intersect at a point on or above the curve for the posted speed.

b. Where the DHV of the right turn into the access is less than five DHV and the Highway's outside lane volume exceeds 250 DHV on a 45 to 55 mph highway, or a 450 DHV on a 35 to 45 mph highway, or 600 DHV on a 25 to 30 mph highway, then a right turn lane may be required due to high traffic volumes or other unique site specific safety considerations.

c. When the right turn access volume meets or exceeds 25 DHV with a highway posted speed of 25 to 40 mph or 20 DHV above 40 mph, a right turn deceleration lane is required.

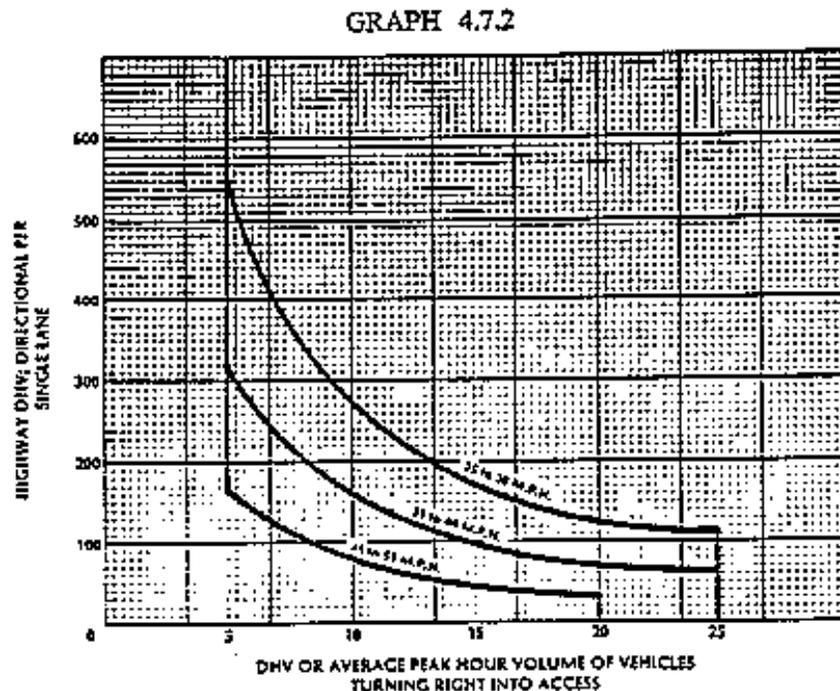


Figure 1 - Colorado DOT Warrants for Right-Turn Lanes

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WARRANTS FOR RIGHT-TURN LANES (Continued)

**Colorado
DOT
Warrants
(Continued)**

The Colorado warrants are based upon turn volume, through volume, and speed. These speed warrants apply to all highway classifications in both urban and rural areas.

In urban areas through volumes on major streets in peak periods commonly exceed 400 vph per lane and often exceed 600 vph per lane.

And where marginal access is provided, right-turn volumes are characteristically high. Thus, the application of these warrants mean that right-turn deceleration lanes are required at most, if not all, accesses on all major urban streets.

Right-turn deceleration bays will also be required at many access points to minor arterials and perhaps major collectors under these warrants. Consequently, these warrants essentially apply to rural and fringe suburban areas where traffic volumes (both through and right-turn) are low.

**Direct
Taper**

Some have proposed that use of a direct taper (a taper only without any full width turn lane) may be sufficient where through traffic and/or left-turns are of intermediate volumes. The Virginia DOT uses such an approach, see Figures 2 and 3.

Research has shown that a direct taper will not measurably decrease the speed differential. It will however, reduce the exposure time for which following vehicles will be exposed to the high speed differential.

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WARRANTS FOR RIGHT-TURN LANES (Continued)

Direct
Taper
(Continued)

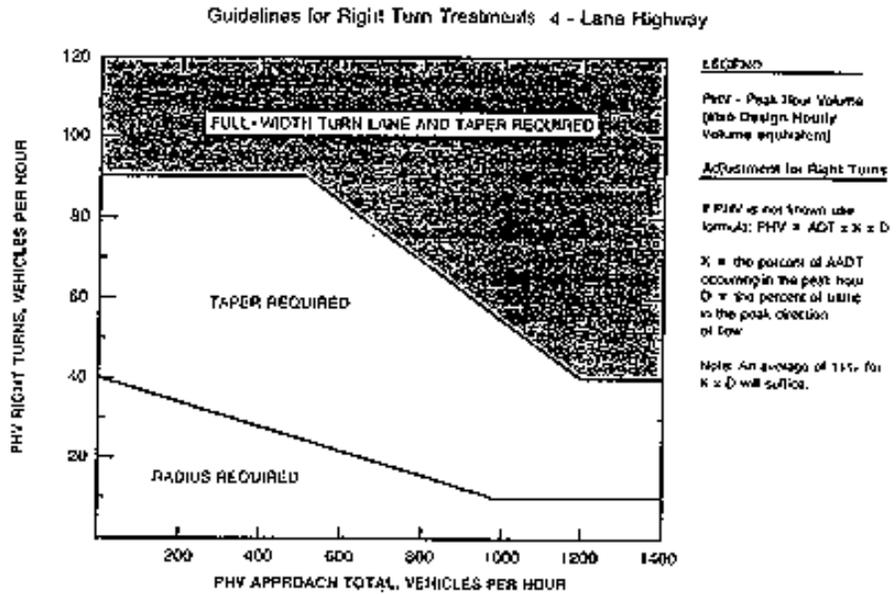


Figure 2 - Virginia DOT Warrants for Right-Turn Lanes on 4-Lane Highways

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WARRANTS FOR RIGHT-TURN LANES (Continued)

Direct
Taper
(Continued)

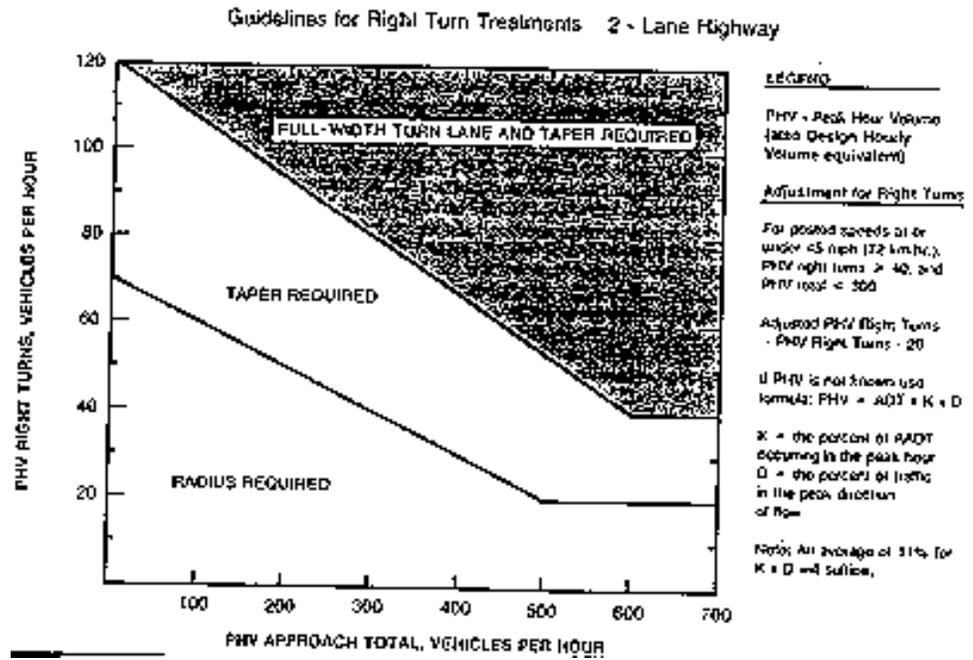


Figure 3 - Virginia DOT Warrants for Right-Turn Lanes on 2-Lane Highways

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WARRANTS FOR RIGHT-TURN LANES (Continued)

**Colorado
Warrants
Acceleration
Lanes**

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The Colorado DOT has also adopted specific warrants for right-turn acceleration lanes (see Figure 4). Obviously very long spacings between areas points are necessary if both right-turn deceleration and right-turn acceleration lanes are to be provided. At the spacings often encountered in urbanized areas, a choice of one or the other must be made. In the vast majority of cases the option is for the deceleration lane.

4.7.3 Acceleration Lane for Right Turning Vehicles

- a. A speed change lane for right turning acceleration movements is required for any access according to the graph 4.7.3 when the DHV values of the highway single lane and the DHV of right turns intersect at a point on or above the curve for the posted speed.
- b. A right turn acceleration lane may be required for any access where a high traffic volume on the highway and lack of gaps in traffic make use of an acceleration lane necessary for vehicles to enter the highway traffic flow through the use of merging techniques. A right turn acceleration lane may be required when the posted speed is 40 mph or greater. An acceleration lane may be required where necessary for public safety and traffic operations based upon site specific conditions.
- c. Where the DHV of the right turn movement out of the access is less than 15 DHV for speeds of 45 mph and above, or less than 30 DHV for a speed of 40 mph, no acceleration lane is required unless determined by the Department or issuing authority to be specifically necessary due to safety considerations.

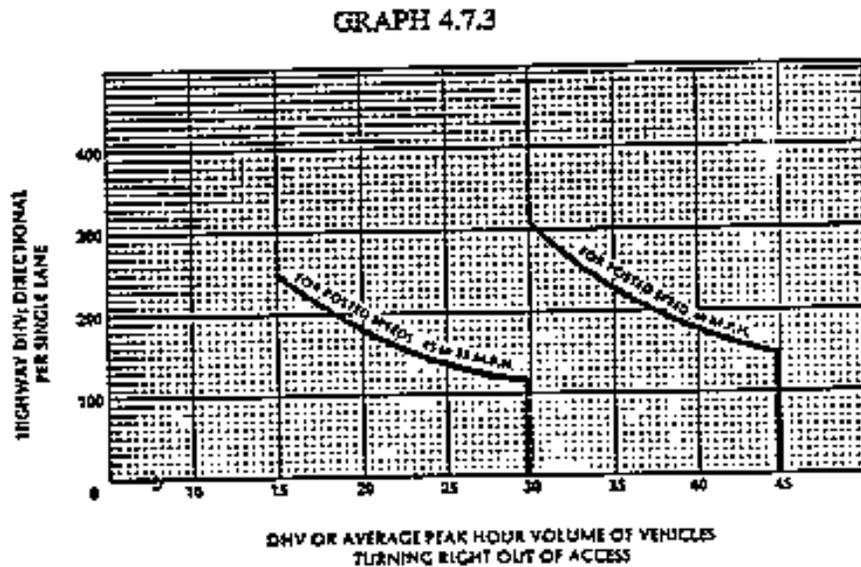


Figure 4 - Colorado DOT Warrants for Right-Turn Acceleration Lanes

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RIGHT-TURN LANE LENGTH

AASHTO Guidelines for Length of Right-Turn Lanes

AASHTO (1, p. 828, 1990 edition; p. 780, 1994 edition) indicates that the length of a right-turn bay (and a left-turn bay) is the sum of the following three components:

1. deceleration distance
2. queue storage length
3. taper

Ideally, all deceleration would occur after turning vehicle has cleared the through traffic lane. However, as AASHTO indicates common practice is to accept some acceleration in the through traffic lane. As addressed later in this discussion paper it is suggested that this should be no more than 15 km/h (10 mph) on major roadways. More deceleration while the turning vehicle still occupies part of the through lane may be quite acceptable on minor roadways.

Where access points are closely spaced the length of a turn bay may be limited to storage plus taper. It may be recalled that an old definition of turn bay consisted of only storage plus taper. While this will require all or at least much of the deceleration will need to occur in the through traffic lane, some length of auxiliary lane is better than none.

AASHTO Guidelines for Deceleration Length

The following is the discussion of deceleration distance from the 1990 (pp. 828-829) of the AASHTO "Greenbook". The same statement with distances in metres is contained on p. 780 of the 1994 edition.

“ Provision for deceleration clear of the through-traffic lanes is a desirable objective on arterial roads and streets and should be incorporated into design whenever feasible. The total length required is that needed for a safe and comfortable stop from the design speed of the highway. Minimum deceleration lengths for auxiliary lanes on grades of 2 percent or less, with an accompanying stop condition, for design speeds of 30, 40, and 50 mph are 235, 315, and 435 ft respectively.

“These lengths exclude the length of taper which should be approximately 8 to 15 ft longitudinally to 1 ft transversely. Long tapers indicate the path drivers to follow and reduce the unused portion of the pavement. However, long tapers tend to entice some through drivers into the deceleration lane. On the other hand, shorter tapers produce better “targets” for approaching drivers and give positive visibility of the added auxiliary lane.

“On many urban facilities it will not be feasible to provide full length for deceleration. In such cases at least a part of the deceleration must be accomplished before entering the auxiliary lane. However, the lengths given should be accepted as a desirable goal and should be provided where practical and feasible. deceleration lengths shown are applicable to both left and right-turning lanes, but speed is usually lower in the right lane than in the left.”

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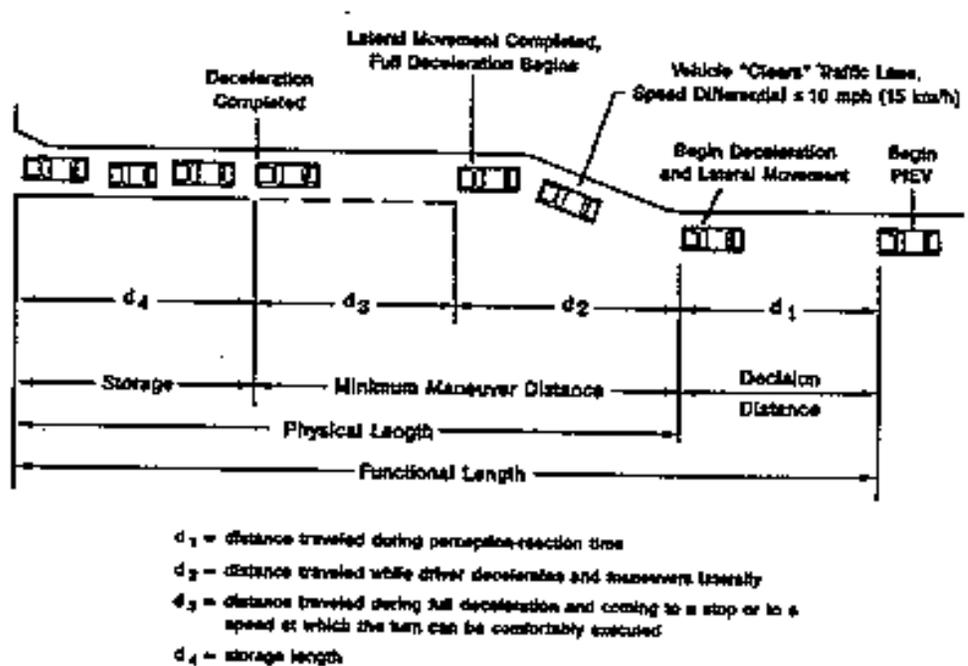
RIGHT-TURN LANE LENGTH (Continued)

Intersection Area

The functional intersection area is composed of the following four elements:

- d_1 = distance traveled during perception-reaction time
- d_2 = distance traveled while driver decelerates and maneuvers laterally
- d_3 = distance traveled during full deceleration and coming to a stop or to a speed at which the turn can be comfortably executed
- d_4 = storage length

As illustrated in Figure 5, the functional intersection area is larger than the physical length.



Source: Reference (2, 3, 4)

Figure 5 - Elements of the Functional Area of an Intersection

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RIGHT-TURN LANE LENGTH (Continued)

Maneuver Plus Queue Storage

As illustrated in Figure 5, the physical length of a right-turn lane should be sufficient to allow a driver to maneuver laterally into the turn bay and come to a stop (distances d_2 and d_3) plus providing for queue storage (d_4). The distance d_2 plus d_3 will depend upon assumptions regarding the following:

1. The average deceleration rate. Should it allow for "comfortable" deceleration or can the design assume "sever" deceleration? Should it be a rate acceptable to most drivers (85%) or the average driver (50%), or
 2. The speed differential between the turning vehicle and through traffic when the turning vehicle clears the through traffic lane. A 15 km/h (10 mph) speed differential is commonly considered to be acceptable on major roadways. A higher speed differential might be acceptable on roadways of lower functional classification.
-

Upstream Intersection Area

Table 2 presents maneuver distances and total distances (maneuver plus PIEV distance) for the selected conditions indicated with the table. These distances represent the minimum functional length of an approach to an intersection as they exclude storage.

As indicated in the footnotes to Table 2, 1.8 metres per second (6 fps)² was used in as the full deceleration rate (distance d_2 in Figure 5). This is somewhat less than the 2.1 mps² (7.0 fps²) used in previous guidelines such as in Transportation Land Development. The change is due to the research results which indicated that most (85% of drives will use an average deceleration rate of at least 1.8 mps² (6 fps²). Only 50% of drives were observed to utilize an average deceleration rate of 2.7 mps² (9 fps²) or more used in calculating the limiting maneuver distance.

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RIGHT-TURN LANE LENGTH (Continued)

**Upstream
Maneuver
Area**

Table 2 - Calculated Upstream Maneuver Distance

		Maximum Maneuver Distance ⁽¹⁾ in Metres (Feet)							
		Desirable Conditions ⁽²⁾				Limiting Condition ⁽³⁾			
Speed		Deceleration ⁽⁵⁾		Total ⁽⁶⁾		Deceleration		Total ⁽⁶⁾	
		meters ⁽⁴⁾	(feet)	meters ⁽⁴⁾	(feet)	meters ⁽⁴⁾	(feet)	meters ⁽⁴⁾	(feet)
km/h ⁽⁴⁾	(mph)								
50	(30)	70	(225)	100	(325)	50	(170)	65	(215)
55	(35)	90	(295)	130	(425)	65	(220)	80	(270)
65	(40)	115	(375)	160	(525)	85	(275)	70	(335)
70	(45)	140	(465)	190	(630)	105	(340)	125	(405)
80	(50)	170	(565)	230	(750)	125	(410)	145	(480)
90	(55)	205	(675)	265	(875)	150	(495)	170	(565)
95	(60)	240	(785)	305	(1005)	170	(565)	200	(655)

Source: Reference (4)

- (1) All values rounded to nearest 5 metres (5 feet).
- (2) 2.5 second perception-reaction time; 1.1 mps² (3.5 fps²) average deceleration while moving laterally into turn bay and an average 1.8 mps² (6 fps²) deceleration thereafter, 16 kph (10 mph) speed differential.
- (3) 1.0 second perception-reaction time; 4.5 fps² (1.4 mps²) deceleration while moving laterally into turn bay and an average 9.0 fps² (2.7 mps²) deceleration thereafter, 10 mph (16 kph) speed differential.
- (4) Nearest 5 kph for design.
- (5) Distance to decelerate from speed to a stop while maneuvering laterally into a left or right-turn bay.
- (6) Deceleration distance plus distance traveled in perception-reaction time.

Note: Distances in metres were calculated using metric equations; distance in feet were calculated using English equations. Therefore, direct (soft) conversation from feet to metres (or metres to feet) will not yield the metres given in the table.

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RIGHT-TURN LANES

RIGHT-TURN LANE LENGTH (Continued)

AASHTO Guidelines for Queue Storage

"The Greenbook" (p. 829, 1990 edition; pp. 780-781, 1994 edition) provides the following general guidance for the provision of queue storage.

" The auxillary lane should be sufficiently long to store the number of vehicles likely to accumulate during a critical period. The storage length should be sufficient to avoid the possibility of left-turning vehicles stopping in the through lanes. The storage length should be sufficiently long so that the entrance to the auxiliary lane is not blocked by vehicles standing in the through lanes waiting for a signal change of for a gap in the opposing traffic flow.

" At unsignalized intersections the storage length, exclusive of taper, may be based on the number of turning vehicles likely to arrive in an average 2-min period within the peak hour. As a minimum requirement, space for at least two passenger cars should be provided; with over 10 percent truck traffic, provisions should be made for at least one car and one truck. The 2-min waiting time may need to be changed to some other interval that depends largely on the opportunities for completing the left-turn maneuver. These intervals, in turn, depend on the volume of traffic. Where the volume of turning traffic is high, a traffic signal will usually be required.

"At signalized intersections the required storage length depends on the signal cycle length, the signal phasing arrangement, and the rate of arrivals and departures of left-turning vehicles. The storage length is a function of the probability of occurrence of events and should usually be based on one and one-half to two times the average number of vehicles that would store per cycle, which is predicated on the design volume. This length will be sufficient to serve heavy surges that occur from time to time. As in the case of unsignalized intersections, provision should be made for storing at least two vehicles."

RIGHT-TURN LANE LENGTH (Continued)

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Queuing During Peak Traffic Periods

The distance required to maneuver from the through traffic and come to a stop is much longer at high approach speeds (off-peak periods) than at slower speeds (peak periods). This difference results in substantial peak period queue storage.

For example, Table 2 shows that the deceleration distance for desirable conditions is 465 ft. of 45 mph. At 30 mph it is 225 ft. Thus, the difference between the distance needed for off-peak speeds (45 mph) and peak period speeds (30 mph) is 240 ft. (465-225). At 25 ft. per vehicle in the queue (including the space between vehicles), this will provide storage for 10 cars.

Right-Turn Queue Storage at Signalized Locations

The average number of right-turning vehicles arriving on the red interval is:

$$Q_a = q(c-g)/3600$$

Where: Q = average arrivals during red phase (vph)
 q = arrival flow rate (vph)
 c = cycle length (seconds)
 g = green time for right-turns (seconds)

The required queue storage can then be estimated as:

$$Q_s = Q_a \times A \times L$$

Where: Q_s = queue storage (feet)
 Q_a = average number of vehicles arriving during red phase
 A = queuing factor to convert the average number of arrivals, Q_a , to the design queue
 L = the average length occupied by a queued vehicle; 25 ft. per passenger car, measured front bumper-to-bumper, or passenger car equivalents.

Where the right-turn-on-red is prohibited, all vehicles arriving during the red phase must join the queue. For this condition the value of A might range from about 1.8 to 2.0 or more. Where conflicting movements do not seriously interfere with the right-turn-on-red, the value of A might be about 1.1 to 1.5.

RIGHT-TURN LANES

RIGHT-TURN LANE LENGTH (Continued)

Queue Storage on Major Road at Private Drive

The throat length, on-site circulation and on-site traffic control at the intersection of a private drive with a major road should be designed so that queue storage occurs after the right-turn from the major public road has occurred. Thus, only minimal storage should be needed in the right-turn bay. It is also to be noted that the distance from a slow speed (peak periods) than from a high speed (off-peak periods). Consequently, substantial storage as in the right-turn bay will be available during peak traffic periods in urban areas.

The intersection of a major arterial and a collector cross-road should be designed so that "storage occurs after the turning vehicles have completed the right-turn from the major road to the collector. This accomplished by providing adequate downstream corner clearance to that first local street or access drive. As indicated in Figure 6, the corner clearance increases as the curb return radius, and hence turning speed, increases. For this reason it is suggested that the arterial-collector intersections not be channelized. The use of a 25 ft. to 35 ft. radius will accommodate the turning traffic but permit a local street or access drive close to the intersection.

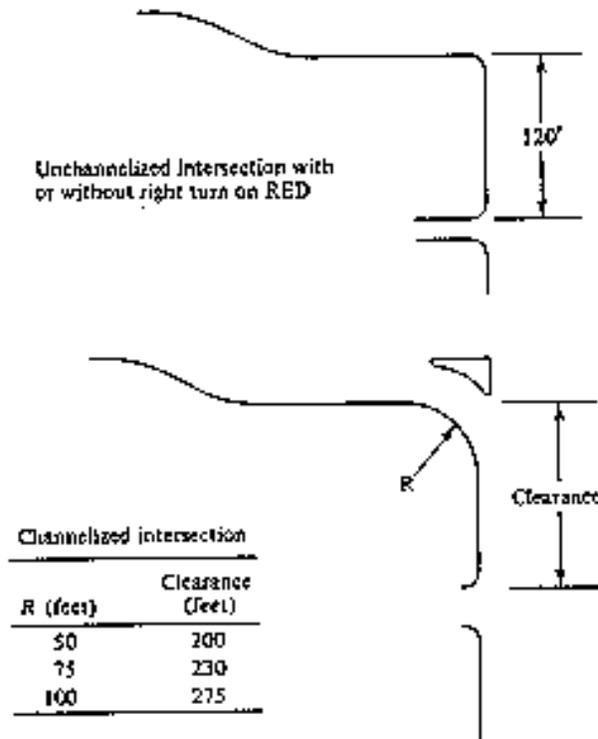


Figure 6 - Minimum Downstream Corner Clearances

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RIGHT-TURN LANES

QUEUE STORAGE

Traffic Characteristics in Rural Areas

The following is typically characteristics of traffic in rural areas:

- Relatively low volume and high speed throughout the day (i.e., there are not peak and off-peak periods).
- Headways between vehicles arriving at a point along a major road are random.
- The number of right-turning vehicles are very low.

Under these conditions, the probability of two or more right-turning vehicles, one or the other, is very small. Consequently, the issue is most commonly a problem of speed differential between a right-turning vehicle and following through traffic.

Rural Right-Turn Bay Length

The traffic characteristics on rural highways are such that queue storage is not a common problem. Therefore, it is suggested that turnbay length be based upon the following: 1) the speed of traffic and 2) an acceptable speed differential. Exceptions where queue storage for right-turning vehicles need to be specifically considered might include truck stops, roads serving recreational areas, an industrial plant, etc.

The issues to be resolved are then:

1. What speed should be used in the design?
 2. What speed differential is acceptable?
 3. Should some minimum storage be used in all cases?
-

Other Determinants of Right-Turn Bay Length

Any of the following criteria may determine length of a right-turn bay.

1. Headway is through traffic stream: Minimum length so that vehicles turning right from a through traffic lane does not leave a gap in the through traffic stream. That is, all through vehicles enter the intersection at uniform minimum headways.
2. Queue in through lanes: Long queues in the through traffic lane may restrict entry into the right-turn bay. This will cause delay to

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QUEUE STORAGE

**Other
Determinants
of Right-Turn
Bay Length
(Continued)**

the right-turning vehicles resulting increased fuel consumption and increased vehicular emissions. Extension of the turn bay so that

the bay, excluding bay taper, is longer than the longest design queue.

3. Vertical alignment: A turn bay which begins in proximity of the crest of a short vertical curve will not be very visible to approaching drivers. The full width of the turn bay on a crest vertical curve should be visible to approaching drivers before the driver is expected to begin the lateral movement from the through traffic lane into the turn bay.

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RIGHT-TURN LANES

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4. "Access Management, Location and Design," Participant Notebook for NHI Course 15255, National Highway Institute, Federal Highway Administration.