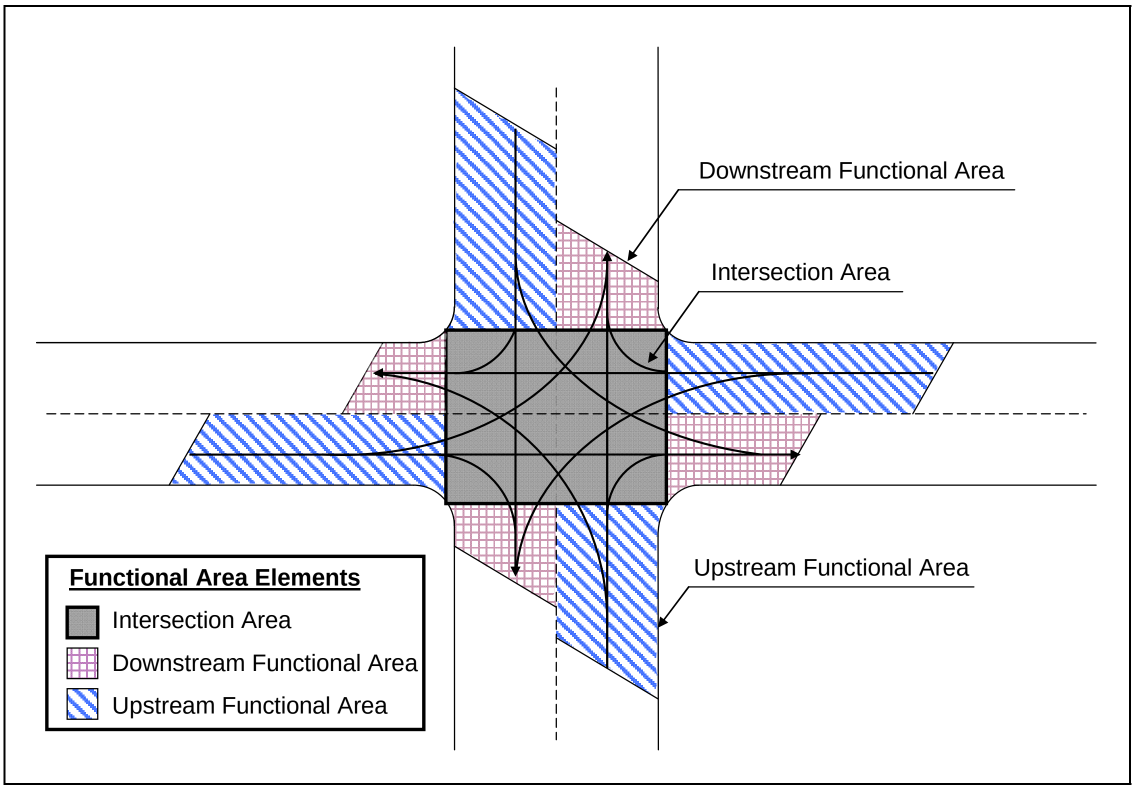
7.3.1 Functional Area of an Intersection[1]

The functional area of an intersection is the area in which an intersection affects vehicle paths. The intersection functional area influences driver decisions, vehicle movements, and vehicle queues. The influence of the intersection extends beyond the actual intersection area, including auxiliary lanes, to incorporate roadway sections immediately upstream and downstream. Exhibit 1 shows the functional area of an intersection.

The intersection area is the physical area where two roads overlap. The sections beyond the intersection area are composed of upstream and downstream functional areas. The upstream functional area for vehicles moving toward the intersection has four maneuvering elements. The downstream functional area for vehicles traveling away from the intersection has one maneuvering element, the stopping sight distance. Each element is unique in its contribution to the functional area.

Exhibit 1: Components of the Functional Area[1]



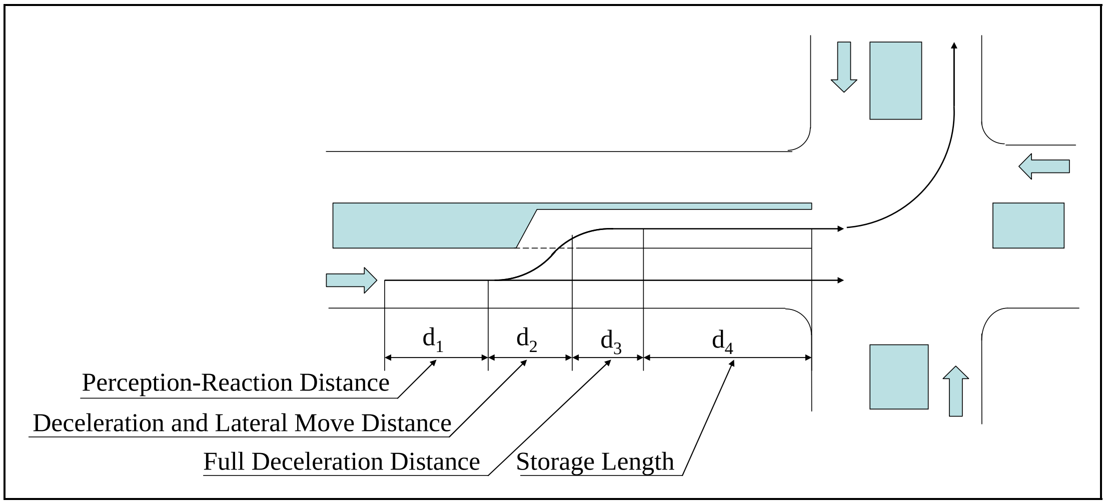
[1] Data referenced through exhibits in this section were obtained from the Discussion Papers presented to the Oregon Department of Transportation by the Transportation Research Institute (TRI) of Oregon State University. The results of the TRI studies were reviewed and summarized for the Access Management Classes.

It is necessary to look at upstream and downstream functional areas for any potential highway improvement or access adjacent to an intersection. Only the upstream functional area needs to be studied if an access is opened upstream of an intersection and only the downstream functional area needs to be studied if an access is opened downstream of an intersection. Both upstream and downstream may need to be studied for an intersection improvement or any project with access in the immediate intersection area. Functional area analysis may determine the placement of an access, the provision of turn movements, or the number of travel lanes.

Upstream Functional Area

There are four elements that make up the distance a vehicle travels as it approaches an intersection: the distance traveled during the perception-reaction time (d_1), the distance traveled while the driver decelerates and moves laterally (d_2), the distance traveled during full deceleration (d_3), and the storage length (d_4). Exhibit 2 depicts the succession of these movements.

Exhibit 2: Upstream Functional Area, d_1, d_2, d_3, and d_4



Turn lanes may be installed at unsignalized intersections to improve safety and at signalized intersections to expand the roadway capacity. The minimum length for a turn bay (including the taper) is the deceleration and lateral move distance and the full deceleration distance, plus the storage length ($d_2 + d_3 + d_4$). The upstream functional area increases/decreases with the number of lanes (related to d_2), the rate of deceleration (related to d_3), and the queue (d_4). Vehicles that change lanes at an intersection expand the influence area of the intersection and the intersection functional area.

The components of functional area are as follows:

- **The upstream intersection functional area includes the distance traveled during the perception–reaction time, d_1**, as the driver approaches the intersection. The perception-reaction time has four phases: perception, intellection, emotion, and volition (PIEV). This section of highway involves the driver seeing the intersection, thinking about his options, making a decision, and initiating his response. The

Discussion Paper No. 7, Functional Intersection Area (January 1996). *Discussion Paper No. 7* was prepared for the Oregon Department of Transportation to support ODOT's policies, practices, and procedures. A table of perception-reaction distances for varying time intervals is shown in Exhibit 3.

Exhibit 3: Perception-Reaction Time, d_1

Distance Traveled During Perception-Reaction					
US Customary Units (Feet)(1)(2)					
Speed (mph)	Perception-Reaction Time (Seconds)(3)				
	1.0	2.0	3.0	4.0	5.0
30	45	90	130	175	220
40	60	115	175	235	295
45	65	130	200	265	330
50	75	145	220	295	370
60	90	175	265	355	440
70	105	310	310	410	515

(1) Rounded to 5 feet

(2) US Customary: distance (feet) = 1.47*(speed in mph)*t

(3) Distance traveled in t-seconds

- **The area d_2 is the distance traveled while braking and moving laterally into a turn bay**. The limiting condition for a vehicle traveling laterally over a 12 foot lane is three seconds in urban areas with an assumed lateral movement at four feet per second (fps). For each 12 foot lane, three seconds of travel time should be added. Four seconds of travel time per 12 foot lane should be assumed for rural conditions, with an assumed lateral movement at three fps.
- **Full deceleration, d_3, is the distance traveled to the end of the storage queue.** The maneuver distances are based on a 6.7 fps^2 deceleration rate accommodating 85% of drivers. The limiting condition accommodates 50% of drivers with a deceleration rate of 9.2 fps^2 or higher. The distances of d_1, d_2, and d_3 are dependent on vehicle speed. Maneuver distances (d_2 + d_3) and PIEV plus maneuver distance (d_1 + d_2 + d_3) are based on the intersection functional area approaches from the Access Management Manual (February 2002). Values for just the maneuver distance and PIEV plus maneuver distance are developed from the uniform acceleration formulas and are listed in the table in Exhibit 4. Note that storage length, d_4, is not included in the values of Exhibit 4. Perception-reaction time may not always be included in an

Exhibit 4: Upstream Functional Intersection Area, $d_1 + d_2 + d_3$

Upstream Functional Intersection Area Excluding Storage, in Feet[1]				
Speed (mph)	Desirable Conditions		Limiting Conditions	
	Maneuver Distance[2] [6] (ft)	PIEV[3] Plus Maneuver Distance (ft)	Maneuver Distance[4] [6] (ft)	PIEV[5] Plus Maneuver Distance (ft)
	$d_2 + d_3$	$d_1 + d_2 + d_3$	$d_2 + d_3$	$d_1 + d_2 + d_3$
20	70	130	70	100
25	110	185	105	140
30	160	250	145	190
35	215	320	190	240
40	275	395	245	305
45	345	475	300	365
50	425	570	365	440
55	510	670	435	515
60	605	780	510	600
65	710	900	590	685

(1) Rounded to 5 feet

(2) 10 mph speed differentials, 5.8 fps^2 deceleration while moving from the through lane into the turn lane; 6.7 fps^2 average deceleration after completing lateral shift into the turn lane

(3) 2.0 second perception-reaction-time

(4) 10 mph speed differential; 5.8 fps^2 deceleration while moving from through lane into the turn lane; 9.2 fps^2 average deceleration after completing lateral shift into the turn lane

(5) 1.0 second perception-reaction time

(6) Assumes turning vehicle has “cleared the through lane” (a following through vehicle can pass without physically encroaching on the adjacent through lane when the turning vehicle has moved laterally 10 ft. Also assumes a 12 ft. lateral movement will be completed in 3.0 seconds

- **The length required to store turning vehicles, d_4**, is calculated by the 95th percentile queue for turning or through traffic, whichever is greater. Turn bays on major roadways are designed for a 95% probability of storing the entire queue during the peak hour. Turn lanes remove turning vehicles from the general flow of traffic allowing through vehicles to proceed without significant slowing or stopping. Research indicates that the crash potential between turning vehicles and through traffic increases exponentially as the speed differential increases. It is desirable to have no more than a 10 mph speed differential between vehicles in the through lanes and vehicles entering turn bays. Providing a turn lane with adequate deceleration distance significantly lowers the speed differential between turning vehicles and through traffic.

  Turn lanes at a signalized intersection serve as capacity expanders and are constructed where demand approaches or exceeds capacity. Turn lanes on the major roadway at unsignalized intersections are generally constructed for safety reasons and serve as safety refuges. The typical urban turn bay is 100 feet unless capacity or speeds require it to be longer, while the typical rural turn bay is 150 feet. The 95th percentile queue is generally calculated by traffic analysis software for signalized intersections. Chapter 7 contains the procedures to consider turn bays for intersections and estimating the length for right turn and left turn vehicle queues.

It is important to determine driver familiarity to the area by the type of development impacting the area. A driver who uses a road often may have a perception-reaction time as little as one second or less, but an unfamiliar driver may require several seconds to make a decision. A familiar driver will choose the appropriate lane in anticipation of a turn and may reduce speed at the intersection approach. An unfamiliar driver may take quick lane changes or may decelerate abruptly. The length of the vehicle paths also depends on whether the development will attract familiar drivers (a grocery store) or unfamiliar drivers (a vacation destination).

An extended perception-reaction time benefits other types of drivers in addition to the unfamiliar driver. The perception-reaction time is used to account for roadway user demographics. Older drivers may have significantly longer perception-reaction times than the typical two seconds because of physical or medical conditions. Younger drivers may have longer perception-reaction times while developing decision making skills. Reviewing type of development and roadway users helps build roads that best serve the community.

A functional area analysis has four possible values: The unfamiliar path under desirable conditions, the unfamiliar path under limiting conditions, the familiar path under desirable conditions, and the familiar path under limiting conditions. Limiting conditions are used for projects that have design constraints. A project using limiting conditions must justify the reason for using limiting conditions and provide appropriate documentation. Anywhere from one to all of these scenarios may need to be checked depending on driver types and roadway conditions.

The Oregon Vehicle Code states that an unlawful or unsignaled turn occurs if “The person fails to give an appropriate signal continuously during not less than the last 100 feet traveled by the vehicle before turning.” The code mandates a minimum 100’ signaling distance for all turn movements and lane changes. This is an addition to the four elements, d_1 through d_4, to determine if driveways and access points are a safe distance from an intersection and accommodate traffic turning at both locations.

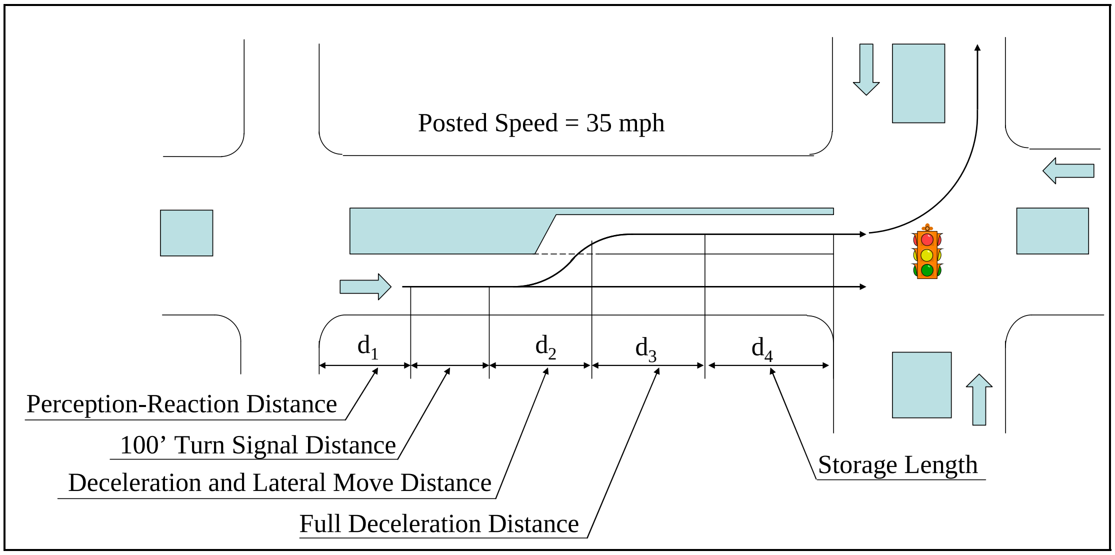
Note that the upstream functional area analysis is a check for adequacy in safety and legality. Further analysis will be necessary to ensure the adequacy of the design.

Example 7-3 Upstream Functional Area

A development proposes to access the roadway upstream of a signalized intersection. The intersection shown has a volume of 100 vph using the left turn lane.
The road has a posted speed of 35 mph. How close to the intersection can a proposed driveway be placed?

Assume the signal has a 120 second cycle length.

Upstream Functional Area Example



Solution:

PIEV Plus Maneuver Distance ($d_1 + d_2 + d_3$)
Check values from Exhibit 4:

Limiting Condition
$d_{L1} = d_1 + d_2 + d_3 = 240$ feet

Desirable Condition
$d_{D1} = d_1 + d_2 + d_3 = 320$ feet

Storage Length (d_4)

For this signalized intersection, the Left Turn Movement Queue Estimate Technique was used.

Assume each cycle is 120 seconds (30 per hour)

Assume the constant, t, is 1.85 to find the 95th percentile queue. (See chapter 7.5.1 for background information)

$$\text{Length} = \frac{\text{volume}}{\#\text{ of cycles/hour}} * t * 25\text{feet}$$

$$\frac{100\text{vph}}{30\text{cycles/hour}} * 1.85 * 25\text{feet} = 154.17\text{feet} = 154 \text{ feet (rounded)}$$

Turn Signal Length

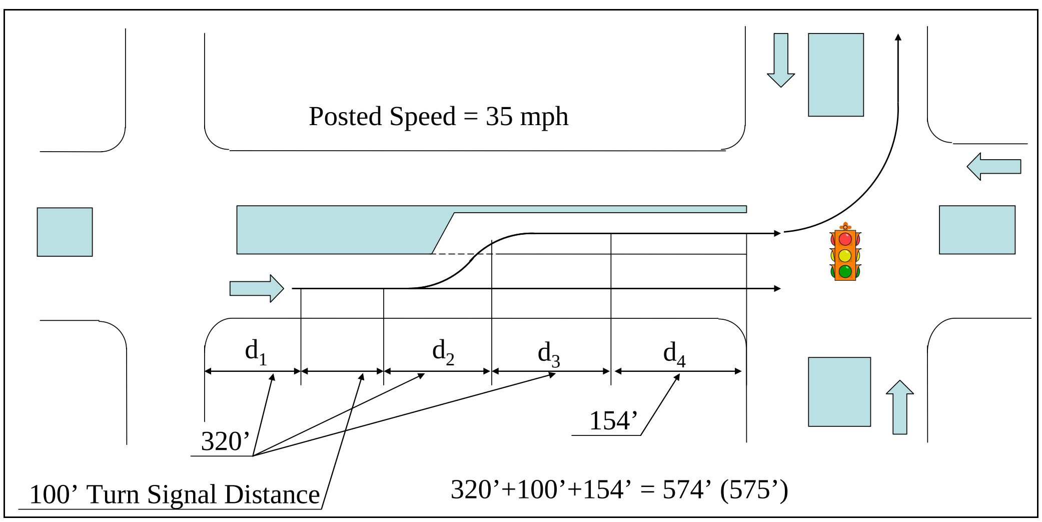
Another 100 feet must be added to provide distance for the turn signal to be used.

Total Functional Area Length

Limiting Condition
$d_{LTotal} = d_1 + d_2 + d_3 + d_4 +$ Signal Distance = 240’ + 154’ + 100’ = 494 feet

Desirable Condition
$d_{DTotal} = d_1 + d_2 + d_3 + d_4 +$ Signal Distance = 320’ + 154’ + 100’ = 574 feet

Upstream Functional Area Desirable Condition



Using the values for a 35 mph speed in Exhibit 4, the desirable conditions path is 575 feet long and the limiting conditions path is 495 feet long. The desirable condition calculated using the value from Exhibit 4 is the greatest distance and is the closest location to access the highway with respect to the intersection. The driveway should be no less than 575 feet from the intersection.

Downstream Functional Area

As a vehicle travels away from an intersection the driver needs a minimum stopping sight distance (d_5) before approaching another intersection or driveway. The stopping sight distance is the distance traveled while braking to avoid an unexpected obstacle. Stopping sight distance is determined by the American Association of State Highway and Transportation Officials (AASHTO) by the speed, brake reaction time, and the deceleration rate. A table developed from the following AASHTO equation is shown in Exhibit 5:

$$d = 1.47 * V * t + 1.075 * \left(\frac{V^2}{a} \right)$$

Where: V –speed, mph
t – brake reaction time, 2.5s
a – deceleration, ft/s^2

If an acceleration lane is present, the stopping sight distance is measured from the end of the taper. The downstream intersection functional area includes the distance traveled during acceleration before merging into the general traffic flow. Acceleration lanes are rarely provided for at grade arterials. Lane drops that have an auxiliary lane longer than the distance traveled during acceleration before merging will not be included in the functional area analysis.

Exhibit 5: Downstream Functional Area

Downstream Intersection Functional Area	
Speed (mph)	**AASHTO Stopping Sight Distance (Feet)**
20	115
25	155
30	200
35	250
40	305
45	360
50	425
55	495
60	570

Note that the downstream functional area analysis is a check for adequacy in safety and legality. Further analysis will be necessary to ensure the adequacy of the design.

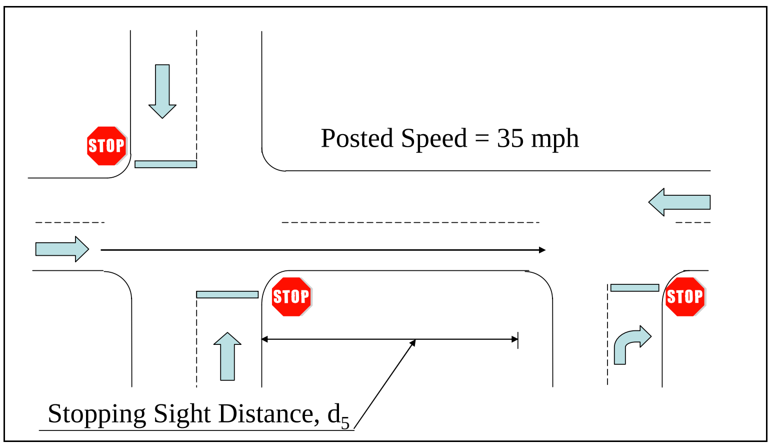
Functional Intersection area is detailed in the Access Management Manual at www.oregon.gov/ODOT/HWY/ACCESSMGT/ and further information is in *Discussion Paper No. 7* prepared by the Transportation Research Institute of Oregon State University: http://www.oregon.gov/ODOT/HWY/ACCESSMGT/docs/FnctlIntArea.pdf.

Example 7-4 Downstream Functional Area

There is a driveway located 350 feet downstream of the intersection shown. The main street has no traffic control and a speed of 35 mph.

Is there adequate spacing between the intersection and the driveway? What is the stopping sight distance (d_5) for this intersection? The following figure shows a general diagram of the intersection area.

Downstream Functional Area Example



Solution:

Stopping Sight Distance, d_5
Check values from Exhibit 5: AASHTO Stopping Sight Distance at 35 mph
d_5 = 250 feet

The driveway must be at least 250 feet from the westbound stop bar to avoid a stopping sight distance conflict. Keep in mind that the downstream functional area analysis is a check for adequacy in safety and legality. Further analysis will be necessary to ensure the adequacy of the design.

Functional Area Application

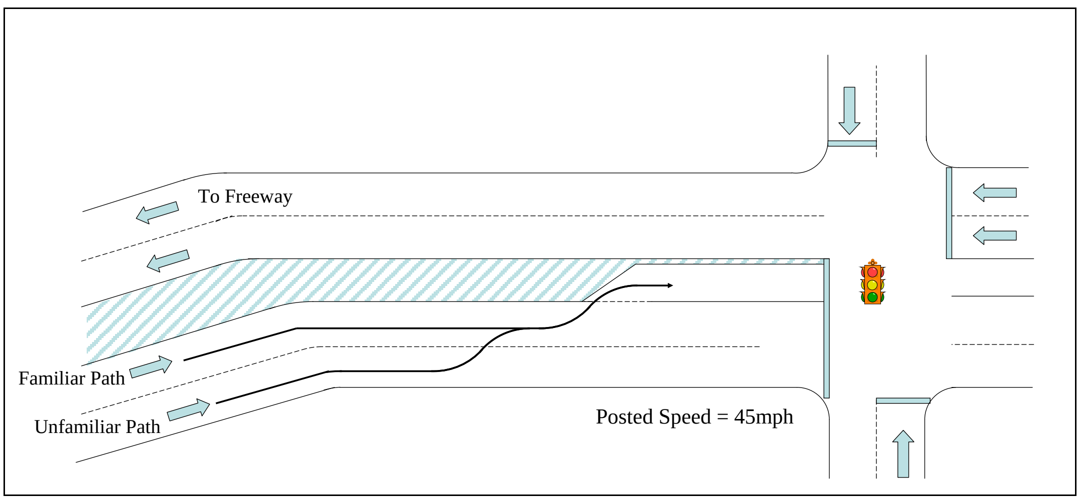
The principles of functional area can be used to test geometric and operational adequacy before detailed analysis starts. The primary objective is to check vehicle paths for adequate length to perform safe and legal maneuvers. For example, a path that connects a right turn onto a roadway to a turn left at the next intersection, or two paths come from two roadways merging together and terminating at a signal, may require lane changes that have safety and legal constraints. Although a functional area analysis may reveal potential conflicts, simulation is used to ensure the adequacy of design in the detailed analysis. Generally, functional area overlaps will appear in simulation results as slowdowns or bottlenecks.

Example 7-5 Functional Area Application – Geometric Adequacy

There is a two lane ramp transitioning from a freeway to an arterial and has geometry similar to an interchange. A development proposes a driveway to intersect the arterial near this ramp as shown in the following figure. The queue at a speed limit of 45 mph is estimated at 400 feet.

Test the adequacy of the design for a driver in either lane of the exit ramp to turn left into the driveway. Can movements from the off ramp to northbound driveway occur safely in this design? Check both the familiar path and the unfamiliar path.

Upstream Functional Area Application Example Paths



Solution:

Familiar drivers will generally use the familiar path, the lane closest to the turn bay, in anticipation of the left turn. Unfamiliar drivers may take the unfamiliar path which starts from the furthest lane or the "wrong lane" and must change lanes into the turn bay. The maneuver distance over one lane is 198 feet when a 3.0 s maneuver time is assumed.

At Speed Maneuver Distance:

$$\left(\frac{45\text{miles}}{\text{hr}}\right)*\left(\frac{1\,\text{hr}}{3600\,\text{s}}\right)*\left(\frac{5280\text{ft}}{1\,\text{mile}}\right)*3\text{s} = 198\text{ft} \quad \text{(200 feet)}$$

Perception-reaction (PIEV) distances are found in Exhibit 3. Assume a two second PIEV (130 feet) for desirable conditions and a one second PIEV (65 feet) for limiting conditions as set by the TRI.

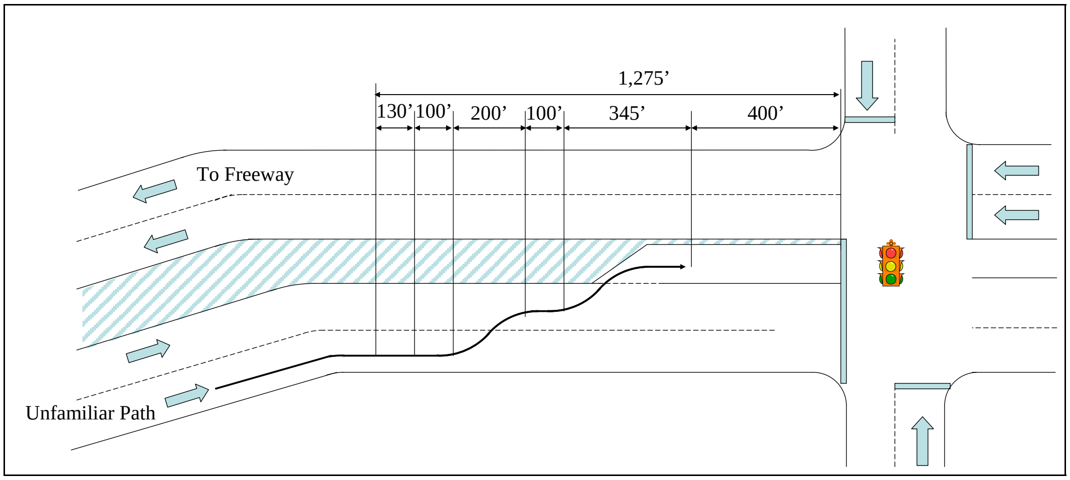
The maneuver distances for the turn bay includes the deceleration and lateral move distance along with the full deceleration distance. The maneuver distances are found in Exhibit 4. For a speed of 45 mph, there should be 300 feet of distance to meet the limiting conditions and 345 feet is desirable.

Lane changes and turn movements should be signaled for 100 feet prior to the action. If an unfamiliar driver follows the unfamiliar path, a lane change must be signaled to move laterally into the near lane and the turn bay separately. The following figures show the components of the unfamiliar path and familiar path for desirable and limiting conditions.

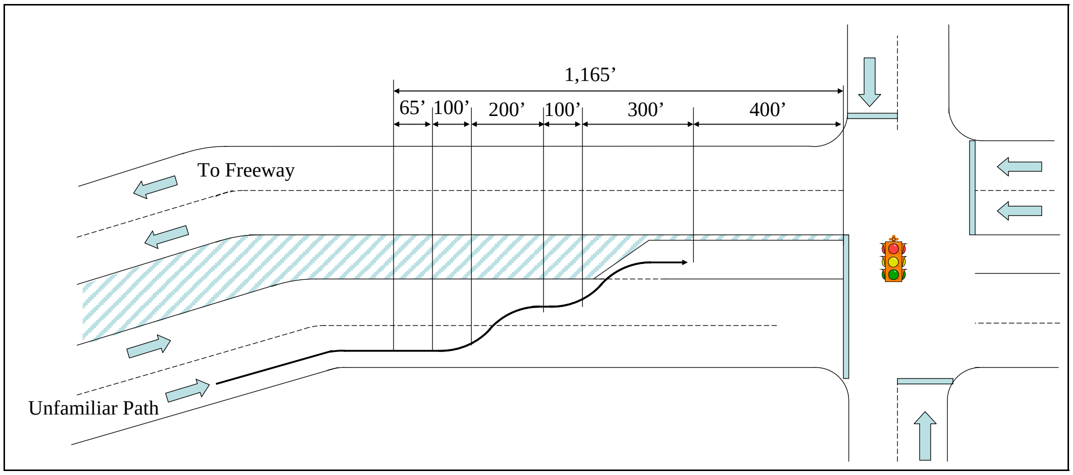
<u>Unfamiliar path (desirable conditions)</u>
d_{UD} = 130' (PIEV) + 100' (turn signal) + 200' (at speed maneuver) + 100' (turn signal) + 345' (desirable distance into the turn bay) + 400' (queue)
d_{UD} = 1,275'

<u>Unfamiliar path (limiting conditions)</u>
d_{UL} = 65' (PIEV) + 100' (turn signal) + 200' (at speed maneuver) + 100' (turn signal) + 300' (limiting distance into the turn bay) + 400' (queue)
d_{UL} = 1,165'

Upstream Functional Area, Unfamiliar Path (Desirable Conditions)



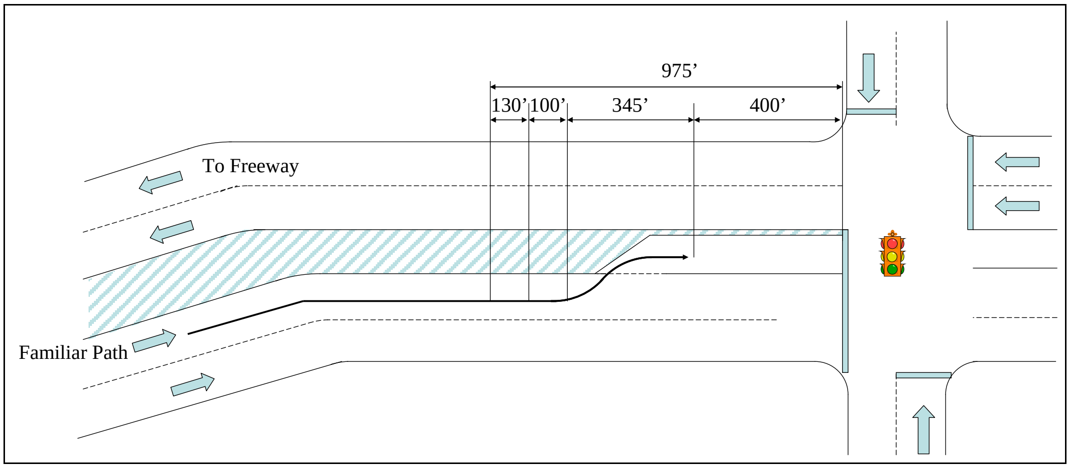
Upstream Functional Area, Unfamiliar Path (Limiting Conditions)



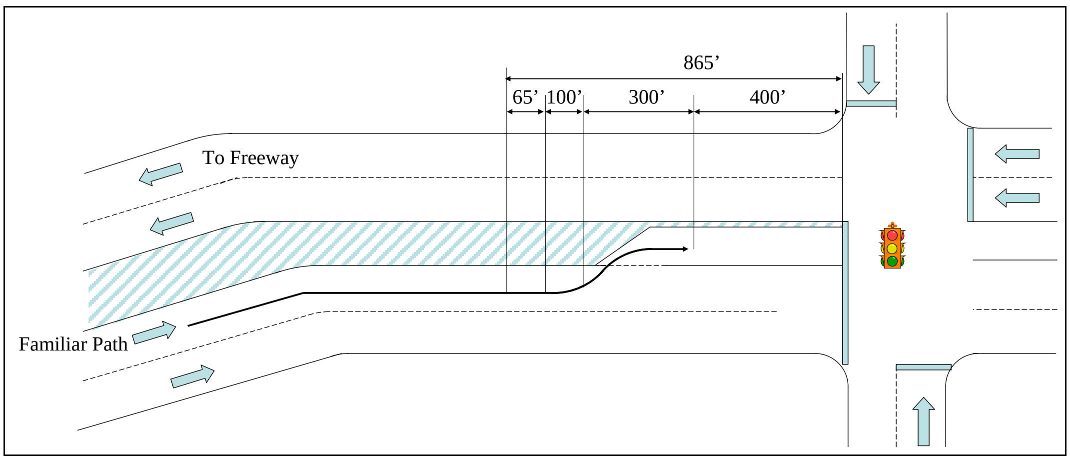
Familiar path (desirable conditions)
d_{FD} = 130' (PIEV) + 100' (turn signal) + 345' (desirable distance into the turn bay) + 400' (queue)
d_{FD} = 975'

Familiar path (limiting conditions)
d_{FL} = 65' (PIEV) + 100' (turn signal) + 300' (limiting distance into the turn bay) + 400' (queue)
d_{FL} = 865'

Upstream Functional Area, Familiar Path (Desirable Condition)



Upstream Functional Area, Familiar Path (Limiting Condition)



Unfamiliar path (desirable conditions): d_{UD} = 1,275’

Unfamiliar path (limiting conditions): d_{UL} = 1,165’

Familiar path (desirable condition): d_{FD} = 975’

Familiar path (limiting condition): d_{FL} = 865’

The design would need to ideally allow 1,185’ feet between the stop bar at the intersection back to the gore point. If the distance available was between 865 and 1,185’ then drivers using the unfamiliar path would be subject to high speed differentials.