Urban Challenge

Technical Evaluation Criteria

March 16, 2006

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Document Change Summary

Section	Description	Date
D.7	Specifications for the emergency braking updated	March 16, 2007

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Urban Challenge
Technical Evaluation Criteria

1. Scope

This document provides additional information regarding the technical evaluation criteria for the Urban Challenge program. This information augments the criteria listed in the Proposers Information Pamphlet (PIP) and the Urban Challenge Rules.

In case of discrepancy, the Urban Challenge Rules document takes precedence over this document.

Nothing in this document may be interpreted as modifying the statement of work or authorizing work outside the terms and conditions of any existing contract or agreement with DARPA.

2. Criteria

The technical evaluation criteria for the Urban Challenge are organized into four sets, each set subsuming the previous leading to vehicle behavior requirements that are progressively more complex. The Basic Navigation and Basic Traffic criteria are applied to vehicle performance at the site visit (Milestone 2), the Advanced Navigation criteria are applied to vehicle performance at the National Qualification Event (NQE) navigation test (Milestone 3) and the Advanced Traffic criteria are applied to vehicle performance at the NQE traffic test (Milestone 4).

The Urban Challenge technical evaluation criteria are consistent with all requirements for the Urban Challenge Final Event.

A. Basic Navigation

The basic navigation criteria apply to all events.

A.1. Preparation for run

Vehicle is in autonomous mode and ready to begin run less than 5 minutes after receipt of the Mission Data File (MDF) from DARPA.

The MDF will be delivered to the team on a USB 2.0 flash drive. The vehicle and software system must be configured to enable automatic pre-processing of data without the need for human inspection of the data. The file may be copied from the flash drive onto a vehicle computer (the flash drive need not stay with the vehicle).

A.2. Mission start

Vehicle follows checkpoints in the DARPA MDF starting at any location in the route network.

The vehicle may start anywhere in the route network. Figure A.2 shows a very simple mission start scenario consisting of two start chutes leading into a road with a checkpoint. The vehicles must proceed to the first checkpoint.

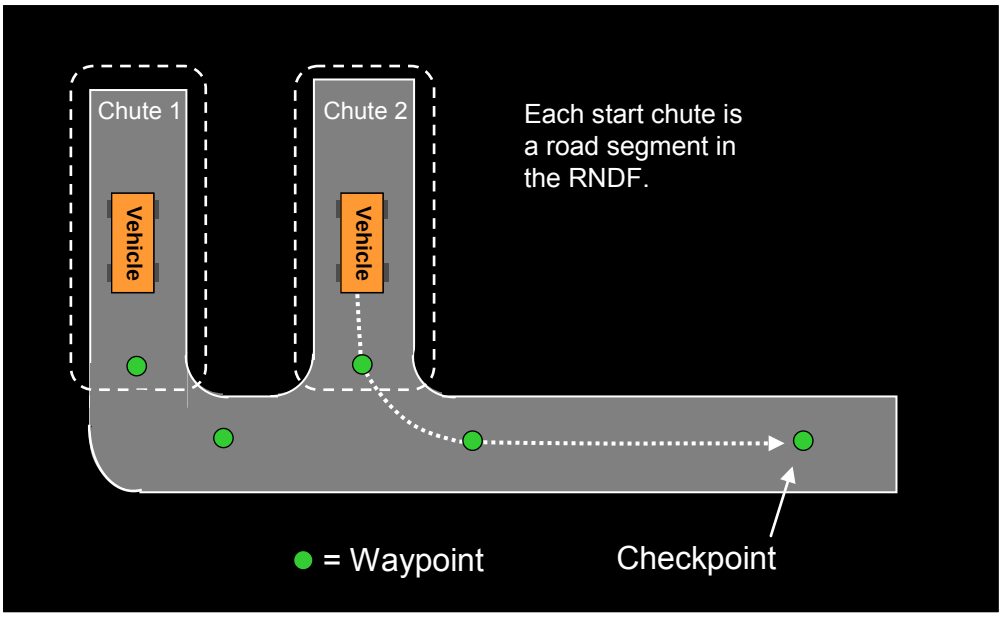

Figure A.2 Mission Start

This criterion requires the vehicle to display the ability to start or re-start a mission from any road segment in the route network. A vehicle in the midst of a mission, for example, might be repositioned after a DARPA intervention and must be able to resume the mission from a new location or orientation.

Note that all accessible portions of a road segment are considered part of the route network. The entire start chute is part of the network, for example, even though the segment is defined by a single waypoint.

A.3. Checkpoints

Vehicle front bumper passes over each checkpoint in the MDF in the correct lane or spot and in the correct sequence.

Checkpoints will generally be in the middle of a travel lane or parking spot. The checkpoint location will be marked on the ground or pavement as a circle of approximately 15 cm in diameter for viewing by the officials. This mark may or may not be visible to the vehicle. To get credit for visiting a waypoint, the vehicle front bumper must pass over the checkpoint as marked. Checkpoints will not be placed next to walls or barriers such that they are difficult to access. Vehicles must be located in the appropriate orientation to visit a checkpoint. This is illustrated in Figure A.3.

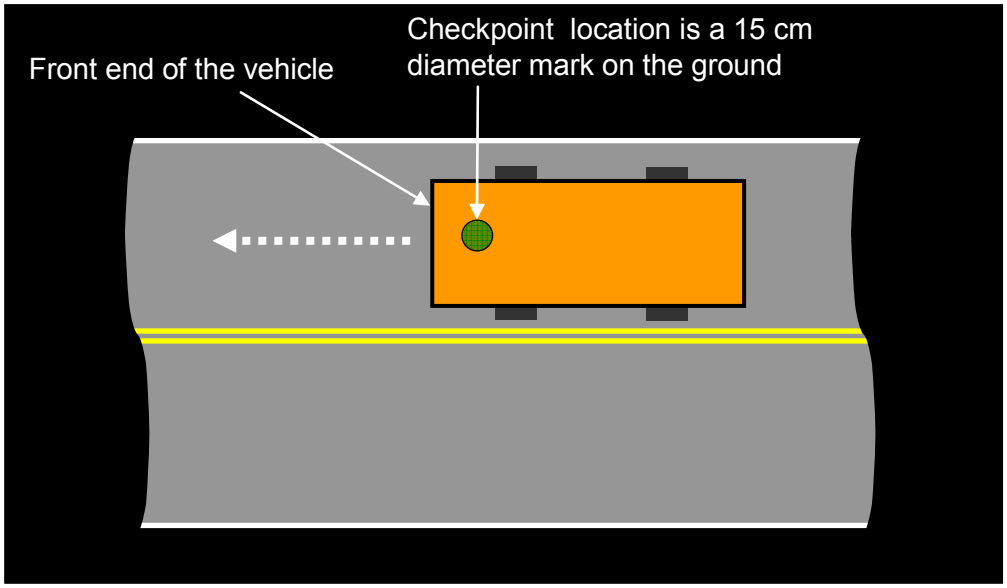

Figure A.3 Vehicle visiting checkpoint

A.4. Stay in lane

Vehicle remains entirely in travel lane at all times except when performing a legal traffic maneuver such as a left turn or maneuvering to avoid an obstacle.

All wheels of vehicle should remain in travel lane, at least one meter from the center line. Although the travel path may not be marked at an intersection, the appropriate vehicle path is understood to be a smooth arc that connects the lane centers (Figure A.4).

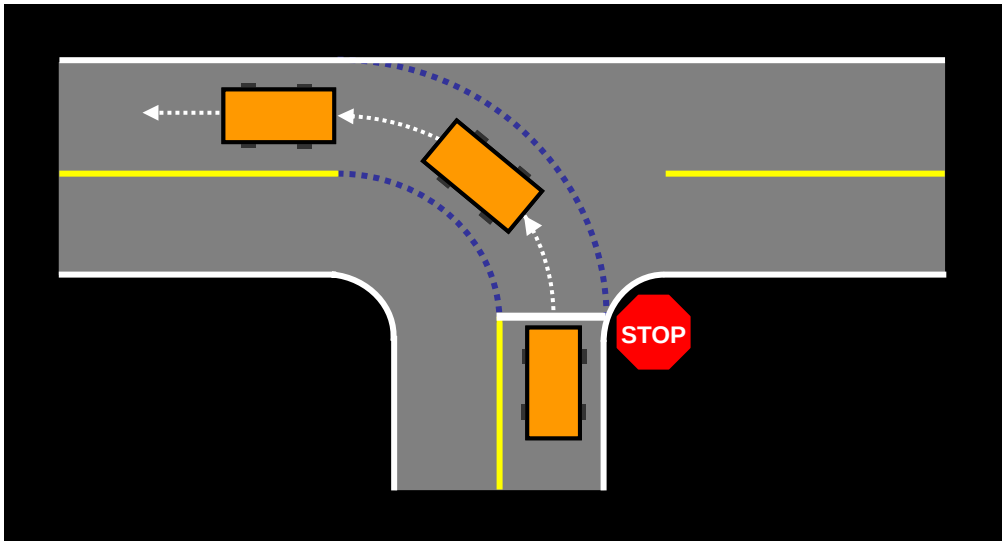

Figure A.4 A vehicle making a left turn at an intersection. White dotted lines depict travel path through an intersection

Vehicles may leave the travel lane under exceptional circumstances, such as passing a static obstacle or vehicle or during maneuvers such as left turns or U-turns.

A.5. Speed limits

Vehicle speed conforms to minimum and maximum limits.

DARPA will use the minimum speed limit to ensure smooth and orderly flow of traffic. Enforcement will be situation-dependent. For example, a vehicle encountering a stopped vehicle or detecting a blocked road should come to a full stop which will not be interpreted as a violation of the minimum speed limit. In contrast, a vehicle that comes to a full stop at every waypoint would likely incur penalties for violation of the minimum speed limit.

Maximum speed limits are absolute and must be adhered to. Vehicles will be able to complete the course under the required time without exceeding the maximum speed limits.

A.6. Excess delay

Vehicle exhibits less than 10 seconds of excess delay on route as judged by DARPA.

Vehicles that exhibit excessive "stop and stare" delays will be penalized. This will deter vehicles from impeding the ability of other vehicles to complete the course, creating a traffic hazard, or disrupting the smooth flow of traffic.

Overly-cautious behavior is always preferred to behavior that leads to a collision or accident.

A.7. Collisions

Vehicle acts to avoid collisions and near-collisions at all times, as judged by DARPA.

Effective navigation while avoiding collisions is the primary guiding principle for the Urban Challenge. This principle encompasses a range of behaviors involving both careful navigation and lane keeping, but also defensive driving. Vehicles must continuously monitor the path ahead for vehicles and obstacles and avoid collisions, and should not assume that other vehicle behavior is entirely predictable.

A.8. Stop line

Vehicle stops so front bumper is within 1 meter of the center of the stop line at intersection.

This is depicted in Figure A.8. Precision driving is a prerequisite for safety in an urban environment, and vehicles must be capable of precise vehicle control.

In all cases, the vehicle should err on the side of caution- a vehicle that stops short of the line and inches forward is preferred to a vehicle that overshoots. Vehicles must never stop in a location that protrudes into or partially blocks an intersection.

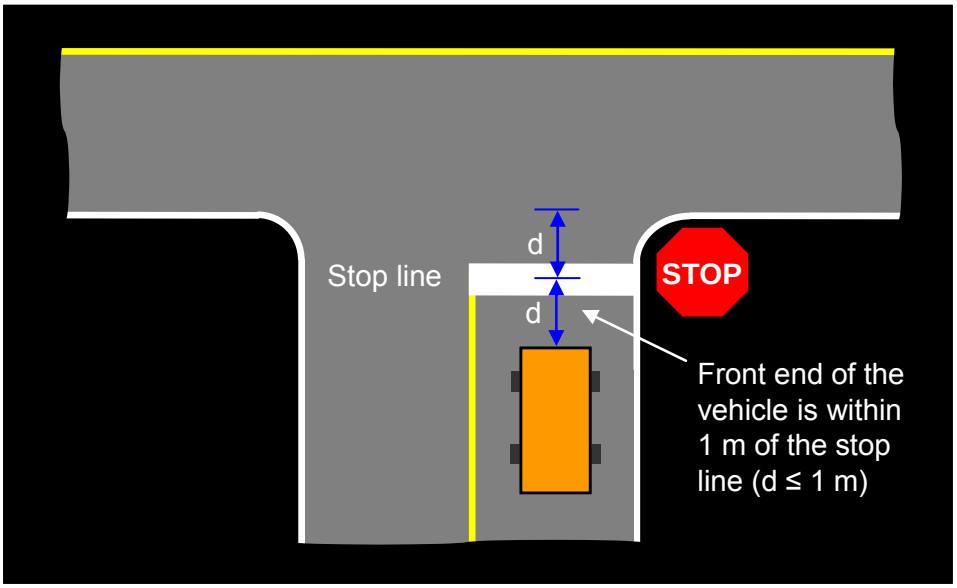

Figure A.8 Stop distance in relation to stop line

A.9. Vehicle Separation

Vehicle maintains a minimum standoff of 1-meter on the sides and rear from all obstacles and vehicles in all areas. In safety areas, vehicle maintains a minimum forward vehicle separation equal to 2-meters. In travel areas, vehicle maintains a minimum forward vehicle separation of one vehicle length for every 10 miles-per-hour of speed, one vehicle length minimum.

Every point of the route network lies in either a safety area or a travel area. Safety areas include:

- The 30 meters of a lane leading up to a stop line (see Figure A.8a).
- The center box of an intersection with three or four stop lines (see Figure A. 8a).
- Road segments in the start and finish areas
- Zones, including parking lots and obstacle fields.

Travel areas include every point of the route network not in a safety area.

The forward vehicle separation distance is measured from the foremost part of the vehicle to the nearest point of an obstacle or vehicle, as shown in Figure A.8b.

Within a safety area, the minimum forward vehicle separation is 2 meters.

Within a travel area, the minimum forward vehicle separation is one (self) vehicle length for each 10-miles-per-hour of (self) vehicle speed, one vehicle length minimum.

The minimum standoff distance of 1 meter on the sides and back of a vehicle is also shown in Figure A.8b. This requirement represents standoff from vehicles and obstacles as well standoff from the lane center and edge.

All of the vehicle separation criteria are absolute minimum values. Teams should consider localization precision and other sources of error to eliminate the possibility of side-swipe damage due to an obstacle or another vehicle.

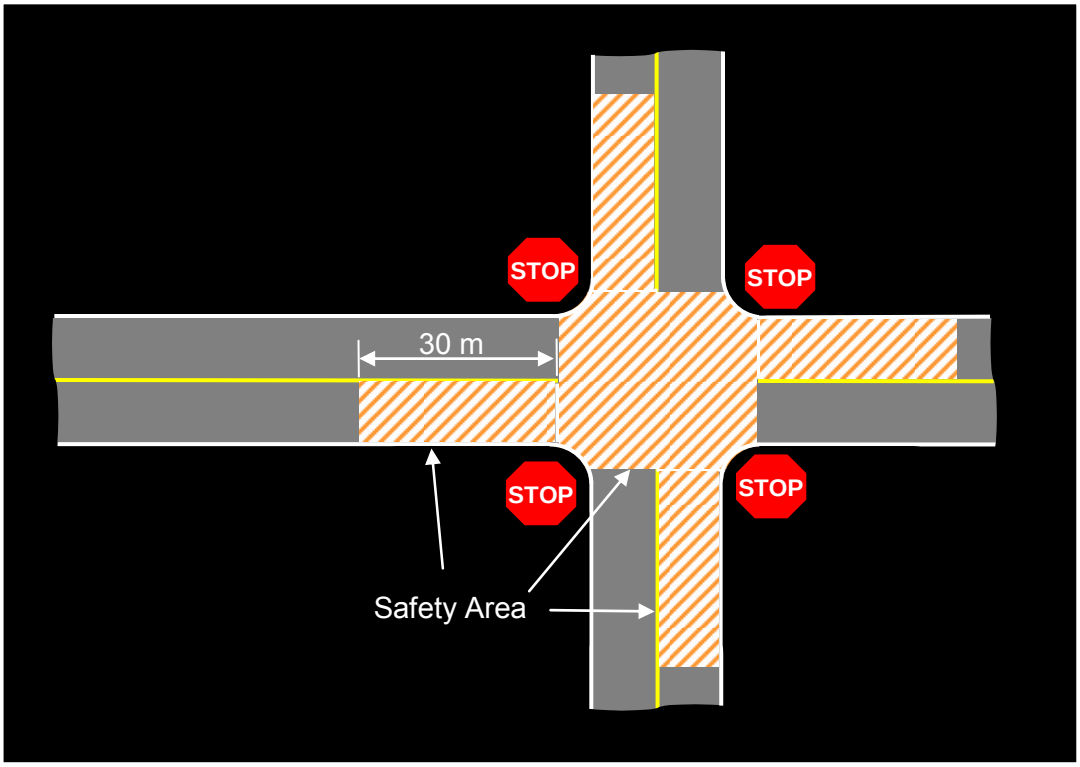

Figure A.9a Safety area at a 4-way intersection

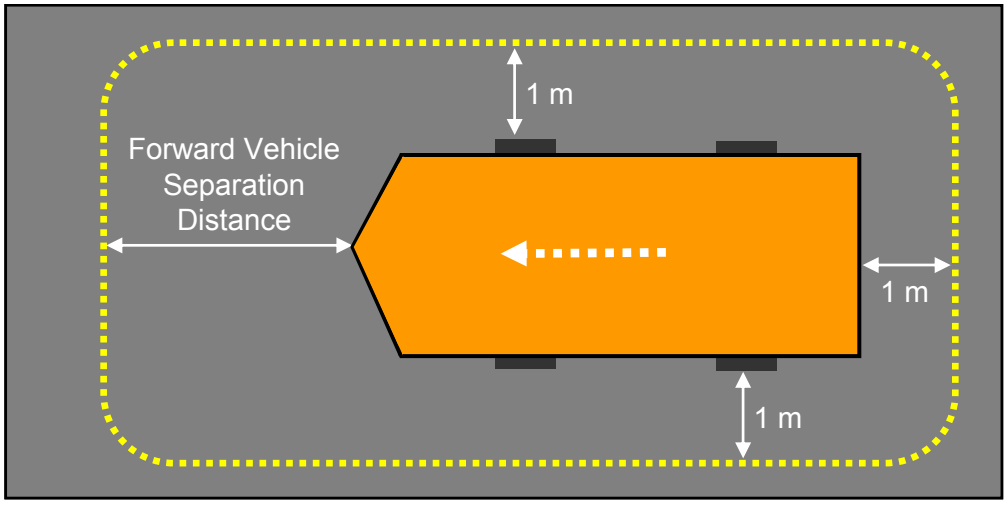

Figure A.9b The yellow dotted line depicts the minimum safety separation for all sides of the vehicle.

A.10. Leaving lane to pass

Vehicle maintains a forward vehicle separation of one vehicle length when leaving lane to initiate a passing maneuver in a travel area.

This is consistent with A.9. Vehicles must always come to a full stop and monitor oncoming traffic before crossing a double yellow line. As shown in Figure A.10, the passing vehicle must initiate the passing maneuver and change lanes before reaching one vehicle length from the rear-most point of the vehicle or obstacle being passed.

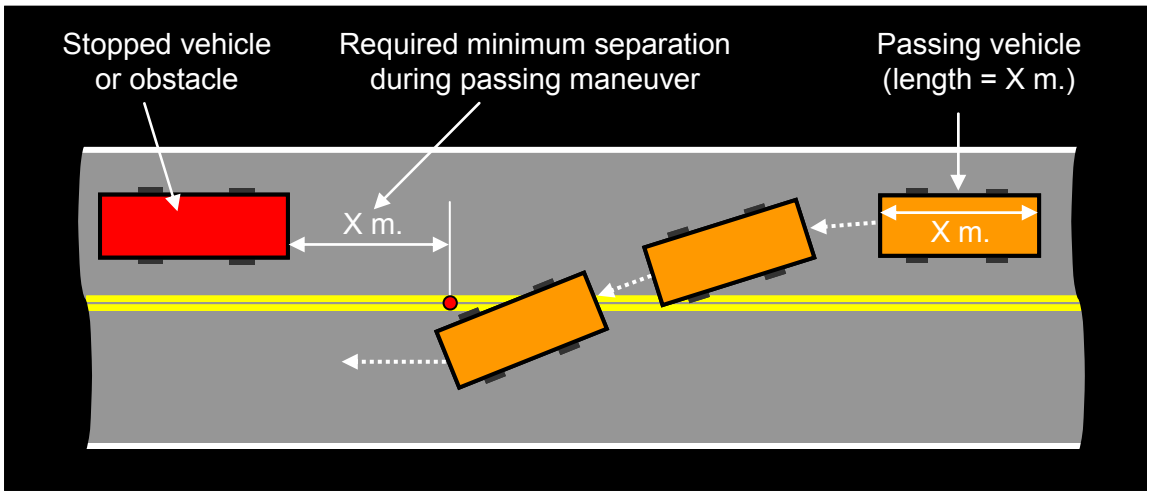

Figure A.10 A vehicle initiating a passing maneuver. The passing maneuver must be completed without driving over the red dot that marks one vehicle length separation from the rear most point of the vehicle or obstacle.

A.11. Returning to lane after pass

Vehicle returns to travel lane between one and four vehicle lengths when completing a passing maneuver.

The vehicle length is the length of the passing vehicle. As shown in the Figure A.11, the passing vehicle must complete the pass by returning to lane in the region between one and four vehicle lengths from the front-most point of the vehicle being passed. This rule is naturally extended when more than one vehicle is being passed.

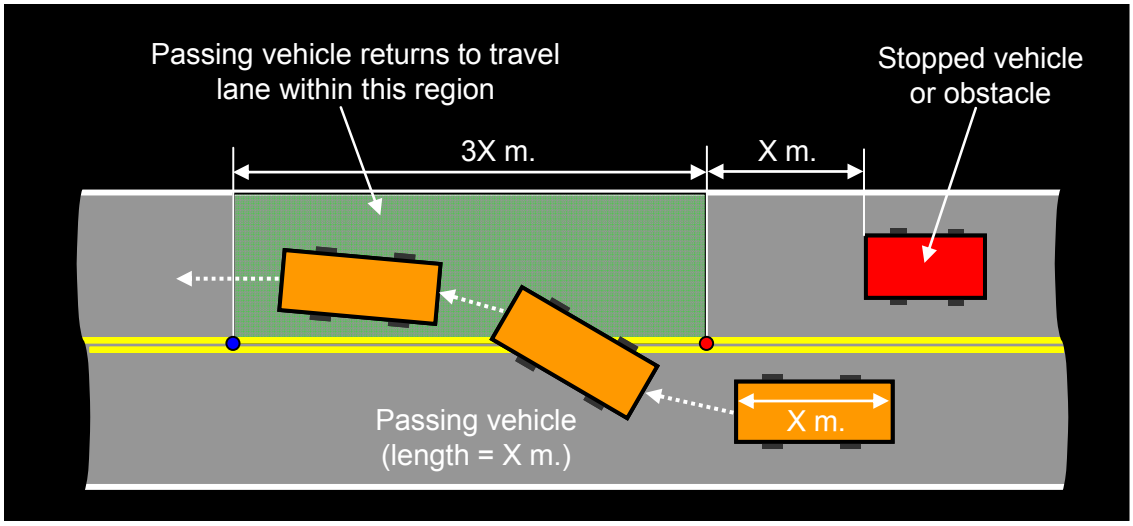

Figure A.11 A vehicle completing a passing maneuver. The red dot marks one vehicle length from the front most point of the vehicle passed and the blue dot marks four vehicle lengths.

A.12. U-turn

Vehicle exhibits ability to perform a U-turn on a 9-meter wide road within a 30-meter road length.

Refer to Figure A.12. U-turns may be used under specific circumstances:

- In the Route Network Definition File (RNDF), the association of an exit point and an entry point in neighboring lanes of the same road segment indicates that a U-turn may be made. This may occur at any location in a road segment.
- If a road is blocked, a vehicle may execute a U-turn at the road blockage irrespective of the RNDF.

A series of three-point turns may be used to complete a U-turn. Before initiating a U-turn that crosses a double yellow line, vehicles should always come to a full stop and yield to any oncoming traffic. U-turns must never be made within the safety zone at an intersection, or on a one-way road segment. At the completion of the U-turn, all wheels of the vehicle should be in the correct lane and the vehicle facing forward within 15 meters of the exit/entry waypoint pair.

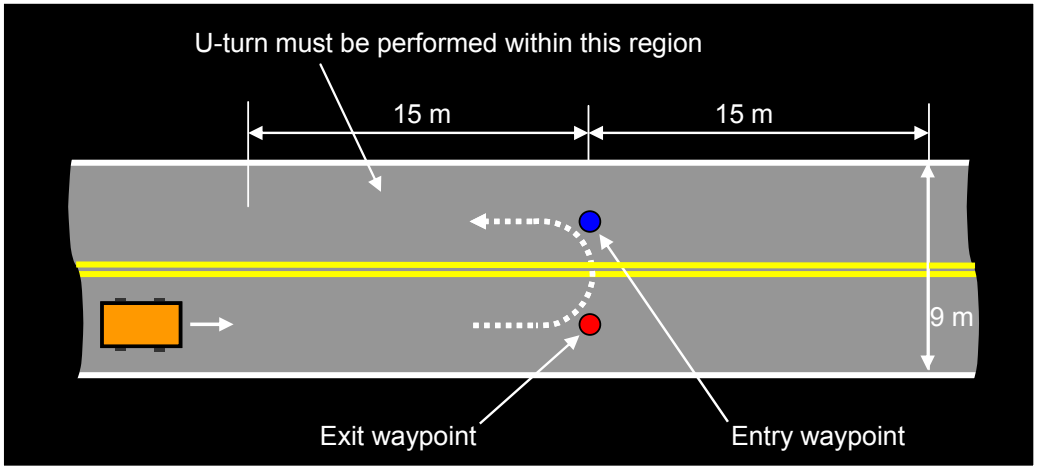

Figure A.12 U-turn area

B. Basic Traffic

B.1. Basic Navigation

Vehicle satisfies all basic navigation test criteria.

B.2. Intersection precedence

Vehicle respects precedence order at intersections and does not proceed out of turn.

The basic rule of precedence at an intersection with more than one stop sign is that the first vehicle to stop at the stop line is the first vehicle to leave.

When arrivals are distinct and correctly sensed by all vehicles, the precedence order is well established. The required behavior is for vehicles to wait their turn and verify all vehicles have cleared the intersection. A vehicle entering the intersection must continually monitor the other vehicles and the path ahead to eliminate the possibility of collision. When precedence order is not well established, criterion D.9 may apply.

B.3. Minimum following distance

When following a moving traffic-vehicle, autonomous vehicle maintains the required forward vehicle separation distance.

This criterion is consistent with A.9, as applied to moving traffic, with a different forward vehicle separation distance in traffic and safety areas. More conservative spacing should be adopted by teams if required by vehicle performance parameters.

B.4. Queueing

Vehicle exhibits correct stop-and-go queueing behavior in a line of stopped vehicles, always maintaining a minimum spacing equal to the forward vehicle separation distance and a maximum spacing of two vehicle lengths.

The length in this case refers to the length of the queueing autonomous vehicle and the forward vehicle separation distance is given in A.9. This criterion applies to any situation in which the vehicle is in a safety area near an intersection or sitting in stop-and-go traffic. The vehicle must correctly infer that the vehicle ahead in line is not a static vehicle that needs to be passed and move forward as the line of traffic moves without excessive delay.

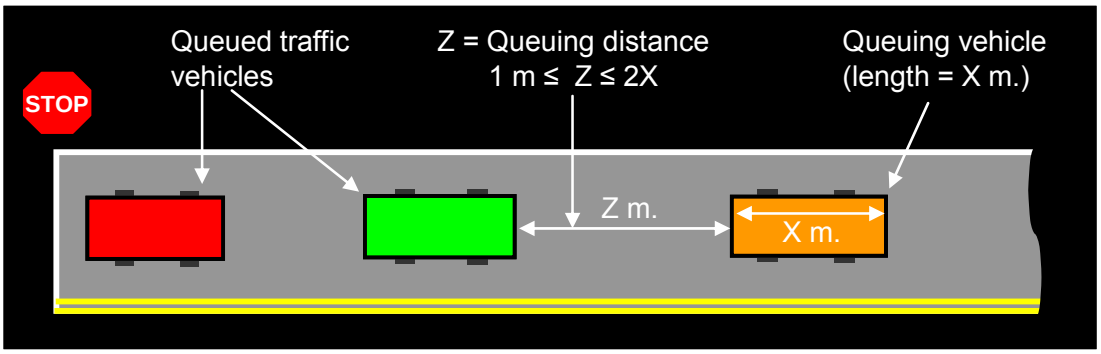

Figure B.4 Queueing distance

C. Advanced Navigation

C.1. Basic Traffic

Vehicle satisfies all basic traffic test criteria.

C.2. Obstacle field

Vehicle demonstrates ability to negotiate obstacle field safely and effectively.

Vehicles are required to operate in unstructured zones where there are no defined travel lanes. These zones may or may not be paved or have markings on the pavement. The travel distance may be 50-200 meters from entrance to exit.

Vehicles must avoid collisions and maintain the required safety separation distance (A.9) while in zones. Although an obstacle such as a tree or boulder may be static, other obstacles may be moving or transient. In the absence of overriding considerations such as collision avoidance, vehicles should generally pull to the right, giving way to the left as depicted in Figure C.2.

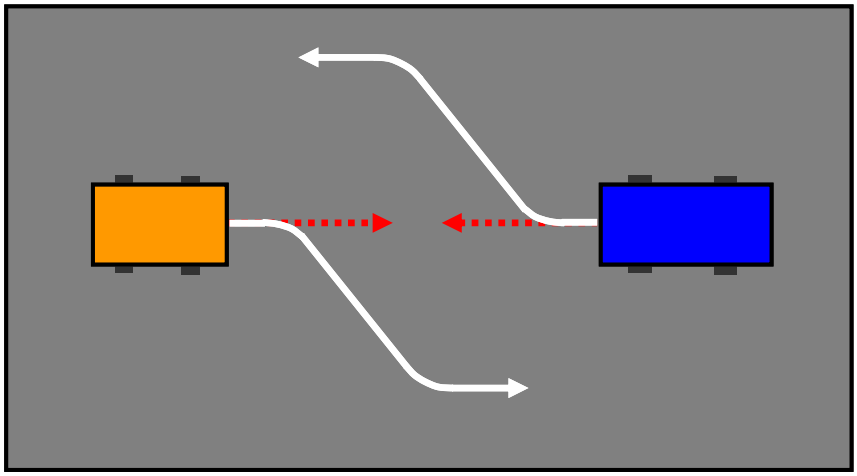

Figure C.2 Two vehicles approaching head on in a zone. Collision is avoided by each vehicle staying to its respective right side.

C.3. Parking lot

Vehicle exhibits correct parking lot behavior and demonstrates the ability to pull forward into and reverse out of a specified parking spot.

The discussion in C.2 applies. The DARPA-supplied RNDF will contain information about all the parking spots in which a vehicle might be required to park (Figure C.3a). The vehicle will not have a priori knowledge of the location of obstacles or other vehicles in a parking lot. Traffic barriers (such as k-rails) may be present, as well as vehicles parked in spots that are not represented in the RNDF. Two vehicles will never be directed to park in the same parking spot.

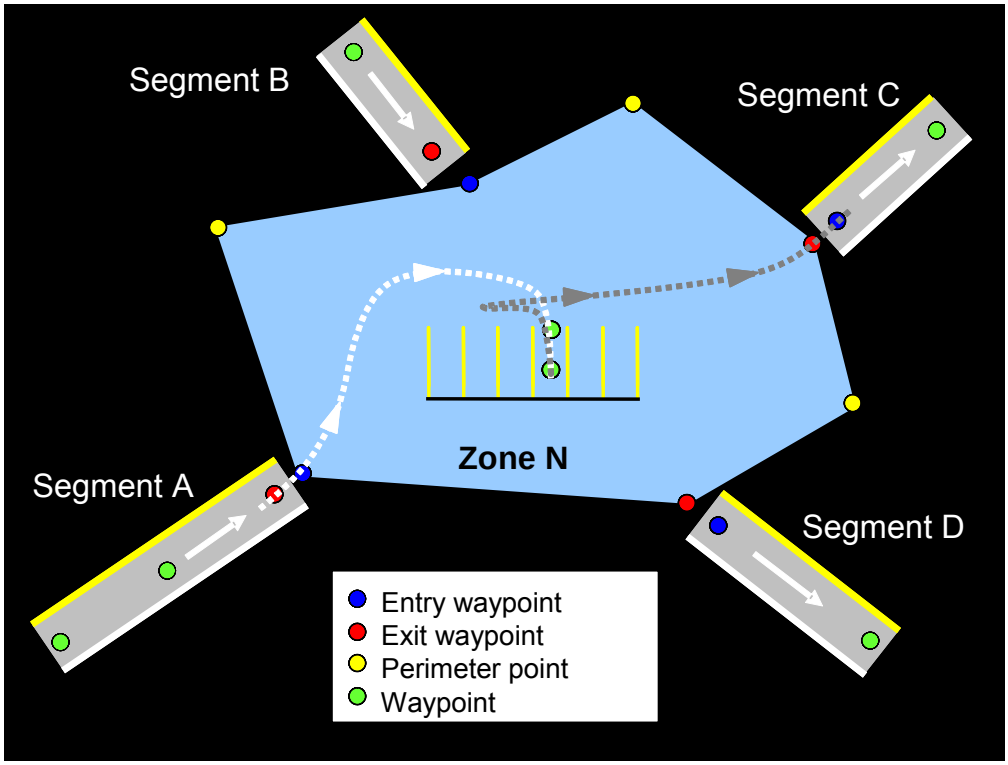

Figure C.3a Parking lot

Figure C.3b shows the parking vehicle must be oriented to cover both parking spot waypoints when visiting a parking spot checkpoint.

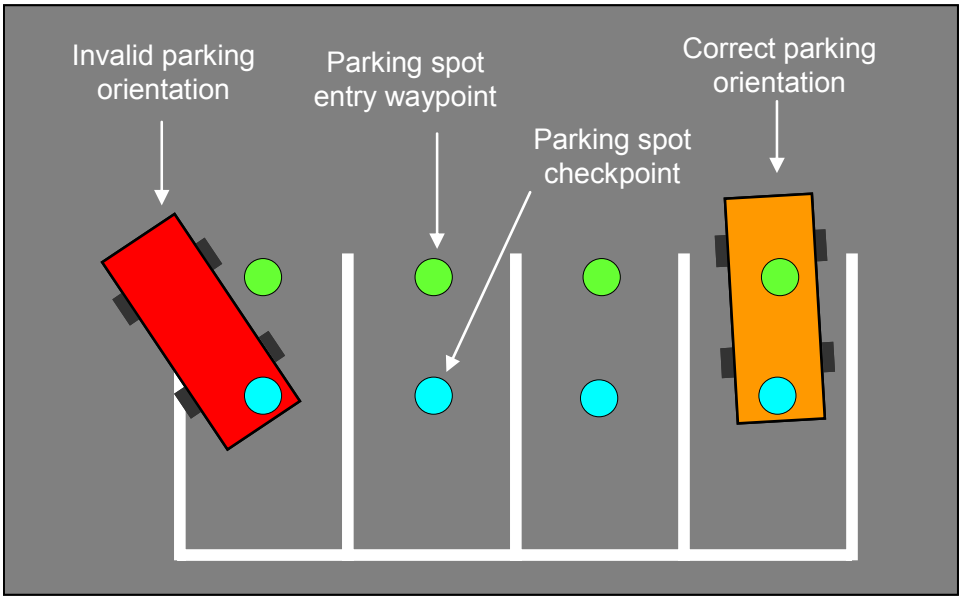

Figure C.3b Correct parking orientation

C.4. Dynamic re-planning

Vehicle exhibits behaviors necessary to achieve objective checkpoints when roads are blocked.

Road blockages will not be indicated in the RNDF, and may be changed during NQE or Urban Challenge final event (UFE). A road may be blocked by a K-rail, line of barrels, or positioned vehicles. An alternate route through the route network will always be available when a road is blocked by DARPA. Vehicles should not attempt to leave the road surface to bypass the roadblock, but should effect a U-turn (see A.12) and use the route network to plan an alternate route. Unless the blockage is near an intersection, vehicles should not attempt to reverse down the road leading to the roadblock. Reverse is limited to three vehicle lengths at all points on the route network.

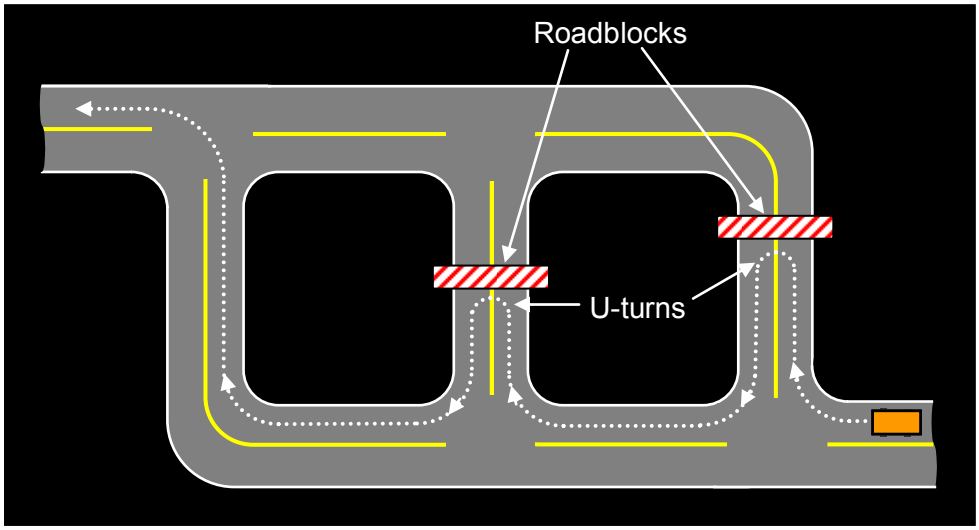

Figure C.4 An example of a road block and dynamic re-planning.

C.5. Road following

Vehicle navigates roads with sparse waypoints and stays in travel lane through road-following by sensing berms or road edges, or by any other sensor-based technique.

DARPA will always supply sufficient waypoints to uniquely specify the route, but road-following will be necessary for vehicle to remain in the travel lane. Vehicle should continuously monitor the roadway for obstacles and drivability, and should have the ability to follow a road around a 90-degree corner without dense waypoints. Vehicle may be required to sense both visual and three-dimensional information to follow the road.

C.6. GPS outage

Vehicle does not exhibit excess delay or leave travel lane due to intermittent loss of navigation signals such as GPS.

Operation with degraded GPS due to foliage or buildings is a requirement. An inertial navigation unit or other technique should be used to enable vehicle to continue to travel safely within lane, possibly at a reduced speed until GPS is re-acquired. A vehicle should pull to the side to re-acquire GPS, however, rather than drift into oncoming traffic.

D. Advanced Traffic

D.1. Advanced Navigation

Vehicle satisfies all advanced navigation test criteria.

D.2. Merge

Vehicle always merges into moving traffic when there is a delay of 10 seconds or more before the arrival of the next traffic-vehicle. Vehicle may pull into a gap of less than 10 seconds when conditions permit.

An autonomous vehicle pulling into traffic will generally be located at a stop sign, waiting for a safe opening to appear in the traffic flow (Figure D.2). The 10 second limit is intended to ensure that vehicles are not overly cautious in entering traffic. Vehicles able to accelerate and come up to speed rapidly will naturally be able to pull into a smaller traffic gap than slower-moving vehicles.

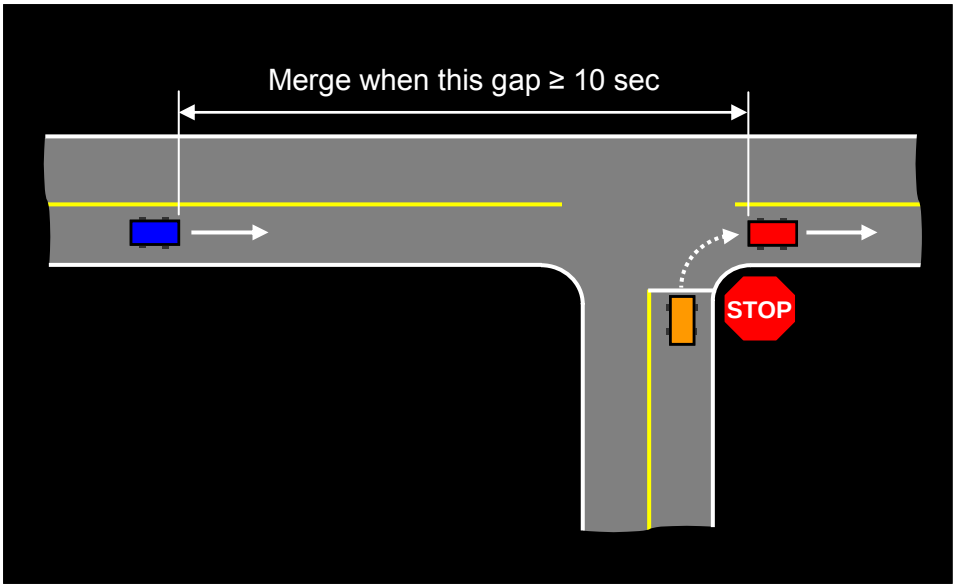

Figure D.2 The orange vehicle must merge into traffic when the indicated gap is greater than 10 seconds.

D.3. Vehicle separation during merge

Vehicle merges between two vehicles into a lane of moving traffic. Vehicle maintains the forward vehicle separation distance to the leading vehicle, and the trailing vehicle does not slow or stop.

A vehicle pulling into traffic must maintain a safe separation from vehicles in front and behind. The vehicle entering traffic must accelerate such that the vehicle behind is able to maintain its safety separation and maintain a constant speed.

The forward vehicle separation definition is consistent with A.9. using the respective speed of the moving traffic-vehicles and the length of the autonomous vehicle pulling into traffic.

D.4. Left turn

Vehicle always completes a left turn across a lane carrying oncoming traffic when there is a delay of 10 seconds or more before the passing of the next on-coming vehicle. Vehicle may complete turn when the delay is less than 10 seconds when conditions permit.

As in D.2, this criterion ensures that vehicles are not overly cautious when pulling into traffic.

Left turns as defined here are of two types: a vehicle stopping in a lane to execute a left turn onto a side street (Figure D.4), or a vehicle making a left turn as it pulls into traffic from a stop sign. Both cases require pulling across a lane of oncoming traffic and merging into a lane of traffic. Vehicles should always come to a full stop before crossing a double yellow line.

When the vehicle arrives, stops, and the intersection is clear, the timer begins running. If the timer reaches 10-seconds, no traffic has arrived, and the vehicle has not moved, then the vehicle is being too cautious and has not satisfied the criterion.

Vehicles may pull out at any time less than 10 seconds provided criterion D.5 is satisfied.

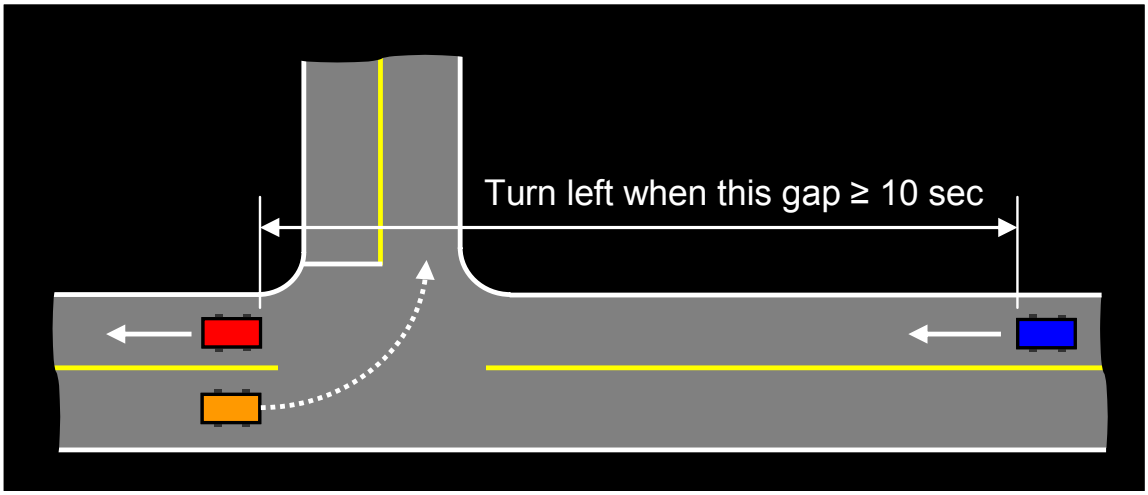

Figure D.4 The orange vehicle must make the left turn across traffic when the indicated gap is greater than 10 seconds.

D.5. Vehicle separation during left turn

Vehicle makes a left turn across a lane of oncoming traffic while preserving forward vehicle separation distances to vehicles in its lane. Vehicle must maintain a two vehicle minimum safety separation from oncoming traffic, without causing oncoming traffic to slow or stop.

This criterion applies to left turns as in D.4 using the forward vehicle separation distance defined in A.9. The additional requirement here is that the autonomous vehicle executing the left turn must allow at least a two vehicle safety buffer to oncoming traffic, as shown in Figure D.5.

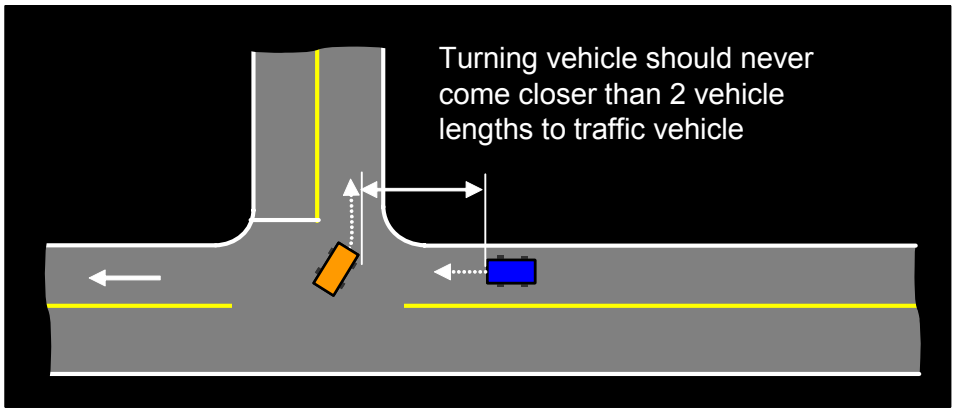

Figure D.5 Safety standoff for left turn

D.6. Zones

Vehicle navigates zones safely and effectively in the presence of moving traffic and other obstacles.

This is consistent with C.2 and C.3, with the addition of moving traffic. Moving traffic in zones creates a particular challenge because of the absence of established traffic lanes. Vehicles must have the ability to detect moving traffic and obstacles from both behind and in front to avoid collisions.

D.7. Emergency braking

Vehicle comes to a complete and safe stop to avoid collision when a moving obstacle suddenly moves into the travel lane.

Autonomous vehicles must continuously monitor and detect dynamic obstacles in their travel path. When a traffic-vehicle pulls unsafely into the travel path from a side-road or driveway, the autonomous vehicle must execute a controlled (non-skidding) emergency stop. The vehicle must come to a safe stop without collision when the anticipated time to collision is 4 seconds or longer. Thus a vehicle traveling 10 miles per hour (4.4 meters per second) must stop in time to avoid collision with an obstacle that enters the vehicle path 17.6 meters in front.

D.8. Defensive driving

Vehicle performs defensive driving maneuvers to avoid impending head-on collision and maintains the required forward vehicle separation distance.

Avoiding collisions in some cases will require active defensive driving maneuvers. There are several situations on the UFE course in which a single vehicle error creates the potential for a head-on collision.

To satisfy this criterion, the autonomous vehicle will be faced with an oncoming traffic-vehicle moving at approximately 5 mph. The robotic vehicle must detect the oncoming vehicle, recognize the threat, and perform an evasive maneuver to avoid collision. This maneuver may involve pulling to the side or backward out of the path of the oncoming vehicle. This behavior is required in zones as well as travel areas.

D.9. Traffic jam

When encountering a partially-blocked intersection, vehicle maneuvers to make forward progress and avoids collisions.

The criterion requires vehicles to demonstrate safe, forward progress at an intersection when confronted with unexpected or aberrant behavior by other vehicles.

At an intersection where this takes place (see Figure D.9) vehicles must wait at least 10 seconds to establish the precedence order has been violated, then proceed through the intersection.

In the event that the desired path through the intersection is impassable, the vehicle should re-route to reach the next checkpoint.

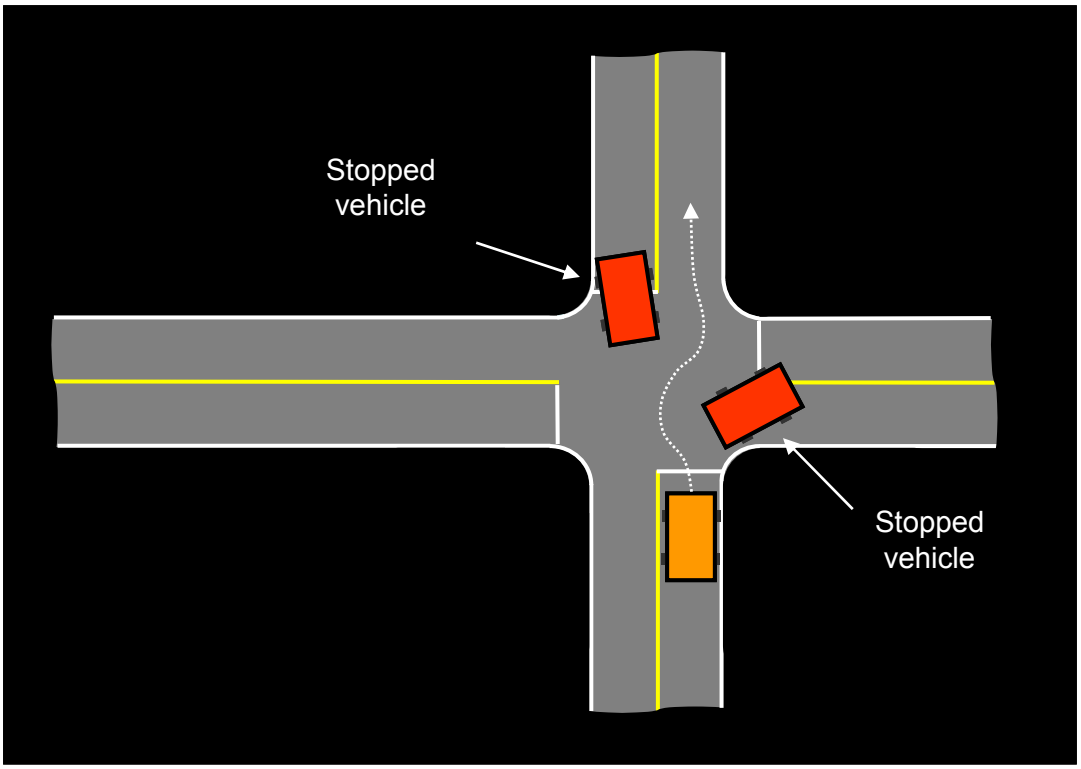

Figure D.9 Stopped vehicles partially blocking an intersection