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The NIST Road Network Database: Version 1.0

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Abstract:

For an autonomous vehicle to be able to navigate a road network, it must be aware of and must respond appropriately to any object it encounters. This includes other vehicles, pedestrians, debris, construction, accidents, emergency vehicles, … and it also includes the roadway itself. The road network must be described in such a way that an autonomous vehicle knows, with sufficient precision and accuracy, where the road lies, rules dictating the traversal of intersections, lane markings, road barriers, road surface characteristics, and other relevant information.

The purpose of this document is to provide detailed information about the Road Network Database being developed at the National Institute of Standards and Technology (NIST) as part of the DARPA Mobile Autonomous Robotics Systems (MARS) Program. The purpose of the Road Network Database is to provide the data structures necessary to capture all of the information necessary about road networks so that a planner or control system on an autonomous vehicle can plan routes along the roadway at any level of abstraction.

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1. Introduction

For an autonomous vehicle to be able to navigate a road network, it must be aware of and must respond appropriately to any object it encounters. This includes other vehicles, pedestrians, debris, construction, accidents, emergency vehicles, … and it also includes the roadway itself. The road network must be described in such a way that an autonomous vehicle knows, with great precision and accuracy, where the road lies, rules dictating the traversal of intersections, lane markings, road barriers, road surface characteristics, and other relevant information.

The purpose of this document is to provide detailed information about the Road Network Database being developed at the National Institute of Standards and Technology (NIST) as part of the Defense Advanced Research Projects Agency (DARPA) Mobile Autonomous Robotics Systems (MARS) Program. The purpose of the Road Network Database is to provide the data structures necessary to capture all of the information necessary about road networks so that a planner or control system on an autonomous vehicle can plan routes along the roadway at any level of abstraction. At one extreme, the database should provide structures to represent information so that a low-level planner can develop detailed trajectories to navigate a vehicle over the span of a few meters. At the other extreme, the database should provide structures to represent information so that a high-level planner can plan a course across a country. Each level of planning requires data at different levels of abstraction, and as such, the Road Network Database must accommodate these requirements.

2. Overview of the Database Structure

In this section, we provide a brief look at the overall structure of the Road Network Database. More details about all of the components of the structure is included throughout the remainder of the document.

The fundamental components of the Road Network Database are described below:

- **Junctions** – A junction is a generic term referring to two or more paths of transportation that come together or diverge, or a controlled point in a roadway. Paths of transportation could be roadway or not roadway paths. Examples of roadway paths that could cause a junction are lanes splits, forks in the road, merges, and intersections. Example of junctions caused by roadway and non-roadway paths are pedestrian crossings, ferry crossings, railroad crossings. Examples of controlled points in the roadway are drawbridges, toll plazas, and guard gates. Junctions are an abstract supertype in the sense that a junction must be one of the types listed above. As of the time this document was published, only the intersection junction-type was included in the database. Other junction types will follow shortly.
- **Intersections** - Intersections are a type of junction in which two or more separate roads come together.
- **Lane Junctions** - A lane junction is a location in a junction in which two or more lanes of traffic overlap. A lane merge contains a lane junction starting at the point in which the two lanes begin to come together and end at the point in which the two lanes are completely together as one. A lane fork contains a lane junction at the point where the lanes begin to fork and ends at the point where the two lanes are completely separated. An intersection contains a lane junction at all points in which the lanes from the two or more intersecting roads overlap.
- **Road** – A road is a stretch of travel lanes in which the name of the travel lanes does not change. An example is “Main Street” or “Route 95.”
- **Road Segment** - A road segment is a uni-directional stretch of roadway bounded by intersections. A road segment is roughly analogous to a “block”. So the uni-directional piece of road bounded by 1st Street and 2nd Street would be a road segment.
- **Road Element** - A road element is a uni-directional stretch of roadway bounded by any type of junction. Unlike road segments, road elements can be bounded by merging lanes, forks in the

road, Junctions include two or more lanes merging together, a fork in the road, a pedestrian crossing, a toll booth, a draw bridge, an intersection, etc.

- **Lane Cluster** - A lane cluster is a set of uni-directional lanes (with respect to flow of traffic) in which no physical attribute of those lanes change over the span of the lane segment. Unlike a road element, lane clusters are not required to be bounded by junctions. Characteristics of the road that cannot change include the addition or subtraction of shoulders, the width of the lane, the separation of lanes to form a median, change in paint striping, and change in lane barriers.
- **Lane** - A lane is a single pathway of travel that is bounded by explicit or implicit lane marking. Lanes span the length of a lane cluster in which they are a part of.
- **Lane Segment** - A lane segment is the most elemental portion of a road network captured by the database structure. Lane segments can be either straight line or constant curvature arcs. In the case of a straight line, the location of the lane segment if fully defined by the beginning and end point of the lane segment. For a constant curvature arc, the lane segment is defined by the beginning and end of the lane segment and the curvature center point. One or more lane segments compose a lane
- **Junction Lane Segments -** A junction lane segment is a constant curvature path through a portion of a lane junction. Apart from some subtle differences pertaining to connectivity of these junction lane segments, they are extremely similar to lane segments as described above.
- **Time Varying Attribute Tables –** There are a number of tables in the database that address attributes of the above structures that may vary as a function of time. These attributes include speed limits on roadways, the average speed on a roadway, the direction of travel on lanes, the accessibility of a lane (e.g., HOV), and the legal traversibility through intersection (e.g., no right turn between 3pm and 6pm on weekdays). In these tables, the pertinent values for these attributes are associated with time intervals.
- **Lookup Tables –** There are a number of lookup tables that include a complete list of all possible values that certain attributes in the certain data structures may have. Lookup tables are used when possible values for a given attribute are finite, and there is value in enumerating them in a table. There are currently seven lookup tables in the database: 1) accessibility restrictions on lanes (e.g., HOV-2, HOV-3, cabs only, police only), 2) possible lane barriers on the side of lanes (e.g., jersey barrier, curb, guard rail), 3) lane markings on the side of lanes (e.g., solid yellow line, double solid yellow line, dashed white line, solid white line), 4) lane types (e.g., traversable, shoulder), 5) road class (e.g., interstate highway, beltway, country road, residential, road), 6) road surface (e.g., asphalt, dirt, pebbles), and 7) special road features (e.g., bridge, tunnel).

It is assumed in this database that sub-components of a road structure are rendered in the same direction as the super-structure, namely:

- Road segments within a road are rendered in the same direction as the road.
- Road elements within a road segment are rendered in the same direction as the road segment.
- Lane clusters within a road element are rendered in the same direction as the road element.
- Lanes within a lane cluster are rendered in the same direction as the lane cluster.
- Lane segments within a lane are rendered in the same direction as the lane.

Note that the way that the road structures are rendered does not dictate the direction of travel of vehicles on that road structure. It only dictates how the structure was rendered internally.

3. How a Planner is Expected to Use The Data Structure

As stated earlier, this data structure is designed to accommodate a control system that may contain planners with various levels of abstraction. This section will provide insight into data structures that will be most appropriate for planners at different levels. The planners, their descriptions, and the data structures which best correspond to their level of responsibility are shown in Table 1.

Planner Name	**Planner Description**	**Appropriate Data Structures**
Destination Planner	Plans the sequence of route segments to get to commanded destination goal. Outputs MapQuest[1]-like directions Plans on the order of 1 to 2 hrs into the future Plans > 10 km distances	Roads Road Segments Intersections Forks (not yet defined) Merges (not yet defined)
Route Segment Planner	Decides on real-time goal lanes for road segments and for negotiating intersections. Deals with intersections, forks, merges, etc. Plans on the order of 10 mins into the future Plans up to 10 km distances	Road Segments Road Elements Intersections Forks (not yet defined) Merges (not yet defined)
Drive Behavior Planner	Develops low-level behaviors for negotiating intersections and deciding when to change lanes. Plans on the order of 100 secs into the future. Plans up to 500 m distances	Lane Clusters Lanes Intersection Forks (not yet defined) Merges (not yet defined)
Elemental Maneuver Planner	Carries out real-time maneuvers to slow down, stop, speed up, and change lateral position. Plans on the order of 10 secs into the future Plans up to 50 m distances	Lanes Lane Segments
Goal Path Trajectory Generator	Calculates the lane segment path dynamic trajectory as a goal path to carry out commanded move while controlling for skid and immediate obstacle response. Plans on the order of 1 s into the future Plans up to 5 m distances	Lane Segments

Table 1: Planner to Data Structure Mapping

[1] The name of commercial products or vendors does not imply NIST endorsement or that this product is necessarily the best for the purpose.

4. Detailed Data Structure Description

Throughout this description, we will use variations of Figure 1 to indicate the part of the road network that is being referenced by the corresponding data structure. In all cases, the shaded region in the figure indicates the extent of the data structure. When implementing the database, a value of –1 should indicate that that field contains a null value.

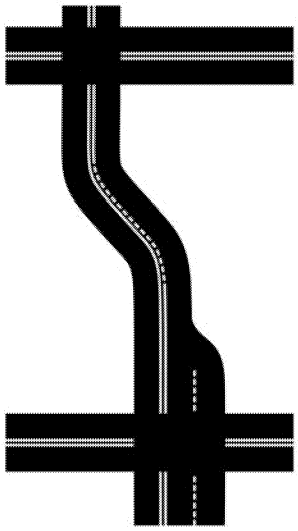

Figure 1: Sample Road Network

4.1. Roadways

4.1.1. Road

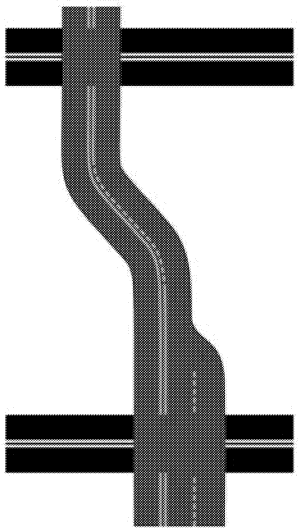

Figure 2: Road

A road is the most general structure in the road network database. Roads are composed of road segments and intersections. A road is primarily identified by its name. A road may also point to a parent road. For example, a given route number (say route 100) may be called Main Street in one area, First street in another area, and Broad street in another area. Each of these street names would be an instance in the road table, and would have a point to the road instance of "Route 100" as their parent road.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Road.Parent_Road, Road_Segment.Road_ID	A unique identifier for this entry in this table	Yes
World_ID	Integer		World.ID		This value indicates which world this entry is associated with. A road may only be associated with a single world. See 4.5.1. for information about worlds.	Yes
Name	Text				The name by which the road is referred to.	Yes
Description	Text				A textual description of this field for human understanding	No
Parent_Road	Integer		Road.ID		The more general road that a road is a part of.	No
Start_X	Double				The X_coordinate (which is the north component of the	Yes

					(Universal Transverse Mercator (UTM) coordinate) of the geometric center of the start of the road (which could lie in the median, if it exists).	
Start_Y	Double				The Y_coordinate (which is the east component of the UTM coordinate) of the geometric center of the start of the road (which could lie in the median, if it exists).	Yes
End_X	Double				The X_coordinate (which is the north component of the UTM coordinate) of the geometric center of the end of the road (which could lie in the median, if it exists).	Yes
End_Y	Double				The Y_coordinate (which is the east component of the UTM coordinate) of the geometric center of the end of the road (which could lie in the median, if it exists).	Yes

Table 2: Road Attributes

4.1.2. Road Segment

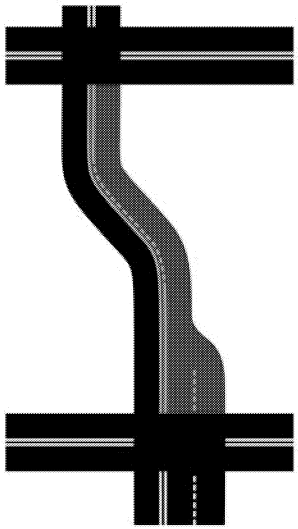

Figure 3: Road Segment

A road segment is a uni-directional stretch of roadway bounded by intersections. A road segment is composed of one or more road elements and zero or more junctions. There are one or more road segments in a road. Unlike road elements, road segments are only bounded by intersection, not any type of junction. A road segment within a road must always be rendered in the same direction as the road. Road segments are used in the planning and control system to provide MapQuest-like directions to the vehicle to allow for route planning.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		RoadElement. RoadSegment_ID, Junction.RoadSegment_ID IntersectionTraversibility.IncomingRoadSegment_ID, IntersectionTraversibility. OutgoingRoadSegment_ID	A unique identifier for this entry in this table	Yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A road segment may only be associated with a single world. See 4.5.1. for information about worlds.	Yes
Description	Text				A textual description of this field for human understanding	No
Road_ID	Integer		Road.ID		A pointer to the element in the Road table in which the road segment is a part of.	Yes
Start_Point_Adjacent_Intersection_ID	Integer		Intersection.ID		A pointer to the element in the Intersection table which precedes the road segment.	Yes
End_Point_Ad	Integer		Intersection.ID		A pointer to the	Yes

jacent_Intersection_ID					element in the Intersection table which follows the road segment.	
Segment_Length	Double				Measured in meters. The length of the road segment measured from center point to center point. This should be derived from the length of the road elements which compose it.	Yes
Road_Segment_Class	Integer		RoadSegmentClass.ID		A pointer to an element in the RoadSegmentClassLookup table which contains the class of road segment which applies to this road segment.	Yes

Table 3: Road Segment Attributes

4.1.3. Road Element

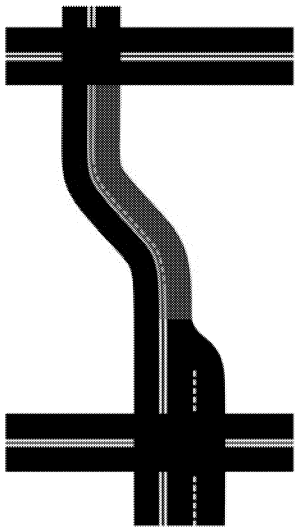

Figure 4: Road Element

A road element is a uni-directional stretch of roadway which is bounded by any type of junction, and in which the sides of the lane clusters in that road element coincide with one another. Junctions include two or more lanes merging together, a fork in the road, a pedestrian crossing, a toll booth, an intersection, a draw bridge, etc. The stretch of uni-directional roadway between any two of these junctions constitute a road element. One or more lane clusters compose a road element. One or more road elements compose a road segment. A road element within a road segment must always be rendered in the same direction as the road segment.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		LaneCluster.Road_Element_ID	A unique identifier for this entry in this table	Yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A road element may only be associated with a single world. See 4.5.1. for information about worlds.	Yes
Description	Text				A textual description of this field for human understanding	No
RoadSegment_ID	Integer		RoadSegment.ID		A pointer to the element in the RoadSegment table in which the road element is a part of.	Yes
Start_Point_Adjacent_Junction	Integer		Junction.ID		A pointer to the element in the Junction table which precedes the road element.	Yes
End_Point_Adjacent_Junction	Integer		Junction.ID		A pointer to the element in the Junction table which follows the road element.	Yes
Element_Length	Douoble				Measured in meters. The	Yes

					length of the road element measured from center point to center point. This should be derived from the length of the lane clusters which compose it.	
Lane_Direction	Integer	0 indicating forward direction, 1 indicating backward direction, with respect to how it was rendered			Shows the direction of travel of the lane segment	No

Table 4: Road Element Attributes

4.1.4. Lane Cluster

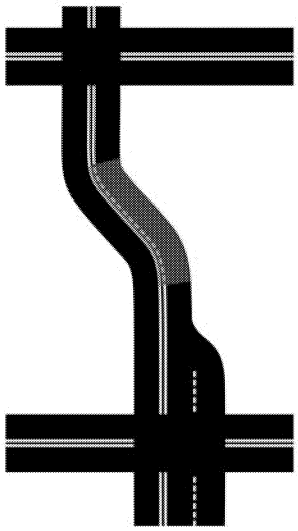

Figure 5: Lane Cluster

A lane cluster is a set of uni-directional lanes (with respect to flow of traffic) in which the sides of the lanes in the lane cluster coincide with one another, and in which no physical attribute of those lanes changes over the span of the lane segment. Characteristics of the road that cannot change include the addition or subtraction of shoulders, the width of the lane, the separation of lanes to form a median, change in paint striping, and change in lane barriers. Lane cluster can only have one or zero lane clusters to the left and one or zero to the right. Lane clusters can be arbitrarily broken to ensure the zero or one restrictions on adjacency. Lane cluster adjacency is only important when one can traverse from one lane cluster to another. If barriers exist that prohibit traversal, adjacency restriction need not be applied. A lane cluster within a road element must always be rendered in the same direction as the road element.

In the case of a lane in a road that changes directions during different times of the day, it is a lane cluster in itself and does not become a part of the adjacent lane cluster that is going the same direction at that time of day. Situations such as one-lane bridges can be handled by specifying the direction of the lane cluster as a time varying attribute and having two entries in the time-varying attribute table indicating that the direction of the road is each direction all day, every day. In the case where a flag person is present, their gestures would override any information in this database.

Lane clusters can either be part of a road element or a junction. A road element is made up of one or more lane clusters. A junction can contain zero or more lane clusters. A lane cluster can have zero or one lane clusters and/or zero or more lane junctions either before it, after it, to the right of it, or to the left of it.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		LaneCluster. Start_Link_LaneCluster_ID, LaneCluster. End_Link_LaneCluster_ID, LaneCluster. Right_Lane_Cluster_ID, LaneCluster. Left_Lane_Cluster_ID, Lane.LaneCluster_ID	A unique identifier for this entry in this table	Yes
World_ID	Integer		World.ID		A pointer to an element in the World	Yes

					table that indicates which world this entry is associated with. A lane cluster may only be associated with a single world. See 4.5.1. for information about worlds.	
Description	Text				A textual description of this field for human understanding	No
Road_Element_ID	Integer		RoadElement.ID		A pointer to the element in the RoadElement table which the lane cluster is a part of. If this is blank, the lane cluster is part of a Junction and the attribute below should be populated.	No
Junction_ID	Integer		Junction.ID		A pointer to the element in the Junction table which the lane cluster is a part of. If this is blank, the lane cluster is part of a Road Segment and the attribute above should be populated.	No
Start_Link_LaneCluster_ID	Integer		LaneCluster.ID		A pointer to an element in the LaneCluster table which contains the lane cluster which directly precedes this lane cluster. If this is blank, the lane cluster is preceded by a junction.	No
End_Link_LaneCluster_ID	Integer		LaneCluster.ID		A pointer to an element in the LaneCluster table which contains the lane cluster which directly follows this lane cluster. If this is blank, the lane cluster is followed by a junction.	No
Special_Road_Feature	Integer		RoadFeatureLookup.ID		A pointer to an element in the RoadFeatureLookup table which indicates any special road features that are associated with this lane cluster.	Yes
Right_Lane_Cluster_ID	Integer		LaneCluster.ID		A pointer to an element in the LaneCluster table that is directly to the right of this lane cluster. The database is defined such that there can be only 0 or 1 lane clusters to the	No

					right of any lane cluster.	
Left_Lane_Cluster_ID	Integer		LaneCluster.ID		A pointer to an element in the LaneCluster table that is directly to the left of this lane cluster. The database is defined such that there can be only 0 or 1 lane clusters to the left of any lane cluster.	No
Left_LaneJunction	Integer		LaneJunction.ID		A pointer to an element in the LaneJunction table which is directly to the left of this lane cluster. Lane junctions can only be to the left of lane cluster in junction, and there can be either 0 or 1 lane junction to the left of the lane cluster.	No
Right_LaneJunction	Integer		LaneJunction.ID		A pointer to an element in the LaneJunction table which is directly to the right of this lane cluster. Lane junctions can only be to the right of lane cluster in junction, and there can be either 0 or 1 lane junction to the right of the lane cluster.	No
Start_LaneJunction	Integer		LaneJunction.ID		A pointer to an element in the LaneJunction table which directly precedes this lane cluster. This attribute can only be populated when the lane cluster is part of a junction (not a road segment).	No
End_LaneJunction	Integer		LaneJunction.ID		A pointer to an element in the LaneJunction table which directly follows this lane cluster. This attribute can only be populated when the lane cluster is part of a junction (not a road segment).	No
Length	Double				Measured in meters. This is the length of the lane cluster, measured from centerpoint to centerpoint. This value should be derived from the length of the lanes	Yes

					which compose it.	
Number_of_Lanes	Integer	>= 1			Indicates the number of lanes in the lane cluster. This is derived by looking at the number of lane entries in the lane table that point to this lane cluster.	Yes
Width	Double	>= 0			The width of the entire man-made prepared surface of the lane cluster.	

Table 5: Lane Cluster Attributes

4.1.5. Lane

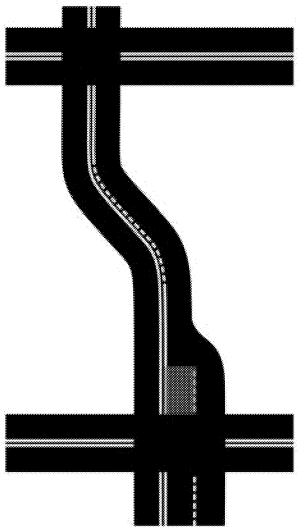

Figure 6: Lane

A lane is a single pathway of travel that is bounded by explicit or implicit lane marking. Lanes are composed of lane segments and span the entire length of a lane cluster which it is a part of. Lanes have a direction of travel, which indicates the direction that traffic flows. A shoulder is also considered a lane, but the lane would be indicated as being a shoulder through its lanetype_id attribute. A lane within a lane cluster must always be rendered in the same direction as the lane. Lanes are primarily used within the control system and planning algorithms to provide information about the legal paths along the road network, and allow the vehicle to position itself properly to make turns.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Lane.Start_Link_Lane_ID, Lane.End_Link_Lane_ID, Lane.Right_Link_Lane_ID Lane.Left_Link_Lane_ID, LaneSegment.Lane_ID, LaneTimeVaryingAttribute .Lane_ID	A unique identifier for this entry in this table	Yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A lane may only be associated with a single world. See 4.5.1. for information about worlds.	Yes
Description	Text				A textual description of this field for human understanding	No
LaneCluster_ ID	Integer		LaneCluster.ID		A pointer to an element in the LaneCluster Table which this lane is a part of.	Yes
Length	Double	>0			The length of this	Yes

					lane measured in meters. This should be derived from the length of the lane segments that compose it.	
Start_Link_Lane_Segment_ID	Integer		LaneSegment.ID		A pointer to the lane segment that is the first lane segment in the lane. The start of the lane is determined by the way it was rendered.	Yes
End_Link_Lane_Segment_ID	Integer		LaneSegment.ID		A pointer to the lane segment that is the last lane segment in the lane. The end of the lane is determined by the way it is rendered.	Yes
Width	Double	Greater than zero.			The average width of the lane, measured in meters.	Yes
Road_Surface ID	Integer		RoadSurface.ID		A pointer to an entry in the RoadSurface table that indicates the type of surface on the roadway.	Yes
Start_Link_Lane_ID	Integer		Lane.ID		A pointer to the lane that directly precedes this lane. If this field is blank, an intersection directly precedes this lane.	No
End_Link_Lane_ID	Integer		Lane.ID		A pointer to the lane that directly follows this lane. If this field is blank, an intersection directly precedes this lane.	No
Right_Lane_ID	Integer		Lane.ID		A pointer to the lane that is directly to the right of this lane. The database is defined such that there can be only 0 or 1 lanes to the right of any lane.	No
Left_Lane_ID	Integer		Lane.ID		A pointer to the lane that is directly to the left of this lane. The database is defined such that there can be only 0 or 1 lanes to the right of any lane.	No
LaneType_ID	Integer		LaneTypeLookup.ID OR LaneTimeVaryingAttribute.ID		A pointer to an entry in the LaneTypeLookup table which indicates what type of lane it is. If -2, you must look at the LaneTimeVaryingAttribute table using	Yes

					the ID of the Lane and "Lane_Type" for the Attribute_Type	
Accessibility	Integer		LaneAccessibilityLookup.ID OR LaneTimeVaryingAttribute.ID		A pointer to an entry in the LaneAccessibilityLookup table which indicates what the accessibility of the lane is. If -2, you must look at the LaneTimeVaryingAttribute table using the ID of the Lane and "Accessibility" for the Attribute_Type	Yes
Lane_Number	Integer	>= 1			Shows the number of the lane, numbered from the center lane marking out. Lane numbers are unique only within a lane cluster.	Yes
Left_Lane_Marking_ID	Integer		LaneMarkings.ID		A pointer to an element in the lane markings table that shows the type of lane marking to the left of lane, with respect to how it was rendered	yes
Right_Lane_Marking_ID	Integer		LaneMarkings.ID		A pointer to an element in the lane markings table that shows the type of lane marking to the right of lane, with respect to how it was rendered	yes
Left_Lane_Barrier_ID	Integer		LaneBarrier.ID		A pointer to an element in the lane barriers table that shows the type of lane marking to the left of lane, with respect to how it was rendered	yes
Right_Lane_Barrier_ID	Integer		LaneBarrier.ID		A pointer to an element in the lane barriers table that shows the type of lane barrier to the right of lane, with respect to how it was rendered	yes

Table 6: Lane Attributes

4.1.6. Lane Segment

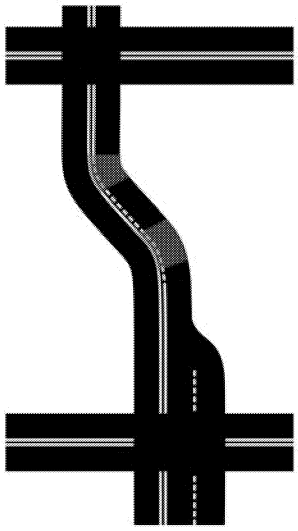

Figure 7: Lane Segment

A lane segment is the most elemental portion of a road network captured by the database structure. Lane segments can be either straight line or constant curvature arcs. In the case of a straight line, the location of the lane segment is fully defined by the beginning and end point of the lane segment. For a constant curvature arc, the lane segment is defined by the beginning and end of the lane segment and the curvature center point. Lane segments can be arbitrarily cut off at intermediate points to ensure adjacency between other lane segments to the left or right. Lane segments can have zero or one lane segments that follow it, and zero or one lane segments that precede it. Lane segments can have zero or one junction lane segments that follow it and zero or junction lane segments that precede it. When no lane segments precede it, it means that the lane segment begins at a lane junction. When no lane segments follow it, it means that the lane segment ends at a lane junction. One or more lane segments compose a lane, and are rendered with the end of one segment next to the start of the following lane segment, if it exists. Due to this constraint on the database, there should never be a case where the start of one lane segment is next to the start of the next lane segment, or vice versa. A lane segment within a lane must always be rendered in the same direction as the lane. The lane segments are primarily used within a control system or planner to generate the detailed path that a vehicle is expected to follow.

This table only houses the attributes and values that are specific to a lane segment and are different that a junction lane segment. The common attributes between the two can be found in the generic lane segment table. The generic lane segment (in the generic lane segment table) which has the same ID as this lane segment will contain the corresponding attribute and values.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Lane.Start_Link_Lane_Segment_ID, Lane.End_Link_Lane_Segment_ID,	A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A lane segment may only be associated with a single world. See	yes

					4.5.1. for information about worlds.	
Right_Link_Lane_Generic_Segment	Integer		GenericLaneSegment.ID		A pointer to the lane segment to the right of this lane segment, with respect to how it was rendered.	no
Left_Link_Lane_Generic_Segment	Integer		GenericLaneSegment.ID		A pointer to the lane segment to the left of this lane segment, with respect to how it was rendered.	no
Lane_ID			Lane.ID		A pointer to an element in the lane table that indicates the Lane which this lane segment is part of.	yes
Start_Link_Lane_Generic_Segment	Integer		Generic_LaneSegment.ID		A pointer to an element in the generic lane segment table which shows which generic lane segment comes directly before this lane segment. This could either be a lane segment or a junction lane segment. This is not populated only if it is a dead end.	no
End_Link_Generic_Lane_Segment	Integer		Generic_LaneSegment.ID		A pointer to an element in the generic lane segment table which shows which generic lane segment comes directly after this lane segment. This could either be a lane segment or a junction lane segment. This is not populated only if it is a dead end.	no
Right_Lane_Segment_Same_Direction	Integer	0 for yes, 1 for no			An indication if the direction of travel for the lane segment on the right is the same as the current lane segment.	no
Left_Lane_Segment_Same_Direction	Integer	0 for yes, 1 for no			An indication if the direction of travel for the lane segment on the left is the same as the current lane segment.	no

Table 7: Lane Segment Attributes

4.1.7. Generic Lane Segment

The generic lane segment is an abstract supertype of lane segment and junction lane segment. All common attributes are stored within this table. Attributes that are only specific to a lane segment are stored in the lane segment table, and attributes that are specific to a junction lane segment are stored in the junction lane segment table. Mapping between the generic lane segment and the lane segment and junction lane segment are done in two ways. First, the attribute named "lane_segment_type" in the generic lane segment table indicates whether this generic lane segment is of type "lane segment" or "junction lane segment". Second, the ID of the generic lane segment matches the ID of either the lane segment or the junction lane segment, whichever is appropriate.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		LaneSegment. Start_Link_Lane_Segment_ID, LaneSegment. End_Link_Lane_Segment_ID, LaneSegment. Right_Link_Lane_Segment_ID, LaneSegment. Left_Link_Lane_Segment_ID, JunctionLaneSegment. Start_Link_Generic_Lane_Segment_1, JunctionLaneSegment. Start_Link_Generic_Lane_Segment_2, JunctionLaneSegment. Start_Link_Generic_Lane_Segment_3, JunctionLaneSegment. End_Link_Generic_Lane_Segment_1, JunctionLaneSegment. End_Link_Generic_Lane_Segment_2, JunctionLaneSegment. End_Link_Generic_Lane_Segment_3, LaneSegmentTimeVaryingAttribute. Lane_Segment_ID, LaneJunctionTraversibility. Incoming_LaneSegment_ID, LaneJunctionTraversibility. Outgoing_LaneSegment_ID	A unique identifier for this entry in this table	Yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A generic lane segment may only be associated with a single world. See 4.5.1. for information about worlds.	Yes
Description	Text				A textual description of this field for human understanding	No
Radius	Double				The radius of the arc that is used to	No

					generate the lane segment. If the lane segment is a straight line, the radius is 0.	
Start_Point_X	Double				The X coordinate of the start point of the lane segment, which is the north component of the UTM coordinate.	Yes
Start_Point_Y	Double				The Y coordinate of the start point of the lane segment, which is the east component of the UTM coordinate.	Yes
End_Point_X	Double				The X coordinate of the end point of the lane segment, which is the north component of the UTM coordinate.	Yes
End_Point_Y	Double				The Y coordinate of the end point of the lane segment, which is the east component of the UTM coordinate.	Yes
Curvature_Center_X	Double				The X coordinate of the curvature center point of the lane segment, which is the north component of the UTM coordinate. This will not be populated if the lane segment is a straight line.	No
Curvature_Center_Y	Double				The Y coordinate of the curvature center point of the lane segment, which is the east	No

					component of the UTM coordinate.This will not be populated if the lane segment is a straight line.	
Line_Type	Integer	0 – straight line, 1 – arc			Indicates whether the lane segment is a straight line or an arc.	Yes
Direction_Rendered	Integer	0 for clockwise, 1 for counter-clockwise			For arc lane segments, indicates which way to render the lane segment.	no
Lane_Segment_Type	Integer	0 indicates lane_segment, 1 indictaes lane_junction_lane_segment			Shows the type of lane segment that this generic lane segment is (either a lane_segment or a lane_junction_lane_segment)	
Direction_of_Travel	Integer	0 indicates the direction of travel of the lane is the way it is rendered, 1 indicates the direction of travel of the lane is opposite the way it is rendered			Show the direction of travel of the lane with respect to the way it is rendered. If -2, you must look at the GenericLaneSegmentTimeVaryingAttribute table using the ID of the GenericLaneSegment and "Direction_of_Travel" for the Attribute_Type	
Speed_Limit	Integer				The posted speed limit for the lane segment, in m/s. If the value is –2, you must look in the GenericLaneSegmentTimeVaryingAttribute table to determine the speed limit.	yes
Average_Speed	Integer				The average speed for vehicles traveling on the lane segment, in	no

					m/s. If the value is –2, you must look in the GenericLaneSegmentTimeVaryingAttribute table to determine the average speed.	
Length	Double				The length of the lane, measured from center point to center point. This should be derived from the other information in this table.	yes
Orientation	Double	Any number between 0 and 2 PI			Radians in absolute coordinates, 0 is north facing, increasing clockwise	no
Left_Lane_Marking_ID	Integer		LaneMarkings.ID		A pointer to and element in the lane marking table that shows the type of lane marking to the left of a generic lane segment, with respect to how it was rendered.	no
Right_Lane_Marking_ID	Integer		LaneMarkings.ID		A pointer to an element in the lane markings table that shows the type of lane marking to the right of a generic lane segment, with respect to how it was rendered.	no
Left_Lane_Barrier_ID	Integer		LaneBarrier.ID		A pointer to an element in the lane barrier table that shows the type of lane barrier to the left of a generic lane segment, with respect to how it was rendered.	no
Right_Lane_Barrier_ID	Integer		LaneBarrier.ID		A pointer to an element in the lane	no

					barriers table that shows the type of lane barrier to the right of a generic lane segment, with respect to how it was rendered.	

Table 8: Generic Lane Segment Attributes

4.2. Lookup Tables

4.2.1. Lane Accessibility Lookup

The LaneAccessibilityLookup table contains all possible accessibility restrictions on lanes of a road. Some entries in this table include high occupancy vehicle (HOV) restrictions, taxi-only lanes, and bus-only lanes. Many of these accessibility restrictions will be time-dependent (e.g., a HOV may only be in effect certains hours of certain days). This will be handled by the LaneTimeVaryingAttributes table. In future versions of the database, an exhaustive list of lane accessibility types will be included in the databases itself.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Lane.Accessibility	A unique identifier for this entry in this table	yes
Accessibility_ Type	Text				The accessibility restriction on the lane. (e.g., none, HOV-2, HOV-3, cabs-only, etc.)	yes
Description	Text				A textual description of this field for human understanding	no

Table 9: Lane Accessibility Lookup Attributes

4.2.2. Lane Barrier Lookup

The LaneBarrierLookup table contains all possible barriers that could exist on the side of a lane. Lane barriers could include jersey barrier, curb, guard rail, etc. There could be a barrier to the left and/or to the right of a lane, hence there are two pointers from the lane segment table to this barrier table. In future versions of the database, an exhaustive list of lane barriers will be included in the databases itself.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		LaneSegment.Left_Lane_Barrier_ID, LaneSegment.Right_Lane_Barrier_ID, GenericLaneSegment. Left_Lane_Barrier_ID, GenericLaneSegment. Right_Lane_Barrier_ID, JunctionLaneSegment. Left_Lane_Barrier_ID, JunctionLaneSegment. Right_Lane_barrier_ID,	A unique identifier for this entry in this table	yes
Barrier_Type	Text				The barrier type on a side of a lane. (e.g., none, jersey barrier, curb, guard rail. etc.)	yes
Description	Text				A textual description of this field for human understanding	no

Table 10: Lane Barrier Lookup Attributes

4.2.3. Lane Markings Lookup

The LaneMarkingsLookup table contains all possible lane markings that could exist on the left or right of a lane segment, as defined by the Department of Transportation. This could include no markings, white or yellow dashed lines, white or yellow solid lines, etc. In the case of a double yellow line in between two lanes, this table would only include the part of that marking which pertains to your lane, namely, the single solid yellow line directly to the left of the lane. Similarly, the lane going the opposite direction would also have a single yellow line to its left, indicating the other half of the double yellow line. In future versions of the database, an exhaustive list of lane markings will be included in the databases itself.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		LaneSegment. Left_Lane_Marking_ID, LaneSegment. Right_Lane_Marking_ID, GenericLaneSegment. Left_Lane_Marking_ID, GenericLaneSegment. Right_Lane_Marking_ID, JunctionLaneSegment. Left_Lane_Marking_ID, JunctionLaneSegment. Right_Lane_Marking_ID	A unique identifier for this entry in this table	yes
Marking _Type	Text				The lane marking type on a side of a lane. (e.g., none, solid yellow, dashed yellow, solid white, dashed white, etc.)	yes
Description	Text				A textual description of this field for human understanding	no

Table 11: Lane Markings Lookup Attributes

4.2.4. Lane Type Lookup

The LaneTypeLookup table contains additional information about a lane that is not evident from the other attributes of a lane. In the database, lanes could be either traversable lanes or shoulders. The lane table thus points to the LaneTypeLookup table to indicate which it is. There are cases when shoulder on roads open up to become traversable lanes. This is handled by the LaneTimeVaryingAttributes table. In future versions of the database, an exhaustive list of lane types will be included in the databases itself.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Lane.LaneType_ID	A unique identifier for this entry in this table	yes
Lane_Type	Text				The lane type (e.g., traversable, shoulder, etc.)	yes
Description	Text				A textual description of this field for human understanding	no

Table 12: Lane Type Lookup Attributes

4.2.5. Road Segment Class Lookup

The RoadSegmentClassLookup table contains information about the class of road that is prevalent along the span of the road segment. Classes of road segments include interstate highway, beltway, country road, residential street, etc. This type of information allows for better path planning by allowing one to prefer passage via a certain type of road. In future versions of the database, an exhaustive list of road segment classes will be included in the databases itself.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		RoadSegment. RoadSegmentClass	A unique identifier for this entry in this table	yes
Road_Type	Text				The road segment type (e.g., interstate highway, beltway, country road, residential street, etc.)	yes
Description	Text				A textual description of this field for human understanding	no

Table 13: Road Segment Class Lookup Attributes

4.2.6. Road Surface Lookup

The RoadSurfaceLookup table contains information about the road surface types for a lane. The road surface types include asphalt, pebbles, dirt, etc. The coefficient of friction values indicate the approximate coefficient of friction for the different types of road surfaces during generally wet and generally dry conditions. In future versions of the database, an exhaustive list of road surface types will be included in the databases itself.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Lane.RoadSurface_ID	A unique identifier for this entry in this table	yes
Surface_Type	Text				The surface type for a lane(e.g., asphalt, pebbles, dirt, etc.).	yes
Description	Text				A textual description of this field for human understanding	no
Coefficient_of_Friction_Wet	Number				Indicates the approximate coefficient of friction of a road surface when the road conditions are wet (when known).	no
Coefficient_of_Friction_Dry	Number				Indicates the approximate coefficient of friction of a road surface when the road conditions are dry (if known).	no

Table 14: Road Surface Lookup Attributes

4.2.7. Special Road Feature Lookup

The SpecialRoadFeatureLookup table contains information about any special features that exist on the road. Special features could indicate that the stretch of road is part of a tunnel, bridge, etc. In future versions of the database, an exhaustive list of road feature types will be included in the databases itself.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		LaneCluster. Special_Road_Feature	A unique identifier for this entry in this table	yes
Road_Feature_Type	Text				The special road feature (e.g., bridge, tunnel, etc.)	yes
Description	Text				A textual description of this field for human understanding	no

Table 15: Special Road Feature Lookup Attributes

4.3. Time Varying Attributes

In many cases, road attributes can vary over time. Lane directions can change as a function of the time of day, shoulders can open up for travel, high occupancy vehicle (HOV) restrictions may or may not be in effect, speed limits can change depending if schools are letting out, etc. A series of time varying attributes tables address this by associating dates and times with different attributes of the data structures.

4.3.1. Generic Lane Segment Time Varying Attributes

Within the lane segment table, three attributes may be time varying: speed limit, average speed, and lane direction. In the case when these attributes are not time varying, the value for these attributes are entered directly in the appropriate attribute value spot in the lane segment table. In the case when these attributes are time varying, a –2 will be entered as the value to indicate that one must look in this table to get the value. A unique row in this table is identified by passing the ID of the lane segment, the attribute that is being queried (one of speed_limit, average_speed, or lane direction), and the time that one wants to check. In the case of speed limit and average speed, the value returned will be in meters/second. In the case of lane_direction, a 0 indicates positive direction and a 1 indicates negative direction, with respect to how the lane segment was rendered.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one			A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A time varying attribute may only be associated with a single world. See 4.5.1. for information about worlds.	yes
Lane_Segment_ID	Integer		GenericLaneSegment.ID		A pointer to the element in the LaneSegment table which this time varying attribute is associated with.	yes
Attribute_Type	Text	Speed_Limit, Average_Speed, Direction_of_Travel			The attribute in the GenericLaneSegment table which the time varying attributes refers to.	yes
Begin_Date_and_Time	Date/Time				The date and time that the value for the attribute takes effect. Note that this mention and all future mentions of date/time is a placeholder. A more detailed representation, which will most likely involve a dedicated table, will be included in future versions.	yes
End_Date_and_Time	Date/Time				The date and time that the value for the attribute ends.	yes
Value	Integer				The value associated with the attribute. In the case of average_speed and speed_limit, the units are neters/second. In the case of lane_direction, 0 indicates positive direction and 1 indicates negative direction.	yes
Description	Text				A textual description of this field for human understanding	no

Table 16: Generic Lane Segment Time Varying Attributes

4.3.2. Lane Time Varying Attributes

Within the lane table, two attributes may be time varying: lane type and lane accessibility. In the case when these attributes are not time varying, the value for these attributes are entered directly in the appropriate attribute value spot in the lane table. In the case when these attributes are time varying, a –2 will be entered as the value to indicate that one must look in this table to get the actual value. A unique row in this table is identified by passing the ID of the lane, the attribute that is being queried (one of lane_type or lane_accessibility), and the time that one wants to check. In the case of lane_accessibility, a pointer to an element in the LaneAccessibilityLookup table is returned. In the case of lane_type, a pointer to an element in the LaneTypeLookup table is returned.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Lane. LaneType_ID, Lane. Accessibility	A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A time varying attribute may only be associated with a single world. See 4.5.1. for information about worlds.	yes
Lane_ID	Integer		Lane.ID		A pointer to the element in the Lane table which this time varying attribute is associated with.	yes
Attribute_Type	Text	Lane_Type, Lane_Accessibility			The attribute in the Lane table that the time varying attributes refers to.	yes
Begin_Date_and_Time	Date/Time				The date and time that the value for the attribute takes effect.	yes
End_Date_and_Time	Date/Time				The date and time that the value for the attribute ends.	yes
Value	Integer		LaneAccessibility Lookup.ID OR LaneTypeLookup. ID		The value associated with the attribute. In the case of lane accessibility, this is a pointer to an element in the LaneAccessibility lookup table. In the case of lane_type, this is a pointer to an element in the LaneTypeLookup table.	yes
Description	Text				A textual description of this field for human understanding	no

Table 17: Lane Time Varying Attributes

4.3.3. Lane Junction Traversibility Time Varying Attributes

Within the lane junction traversibility table, the permissibility attributes may be time varying. For example, the legality for traversing from one lane segment that is entering an intersection to another lane segment that is exiting the intersection may change at different times of the day. This may be captured by a sign which states "No right turn between 3:00pm and 6:00pm Monday through Friday". In the case when this attribute is not time varying, the value for this attribute is entered directly in the permissibility attribute value spot in the lane junction traversibility table. In the case when this attribute is time varying, a –2 will be entered as the value in the lane junction traversibility table to indicate that one must look in this time varying attribute table to get the actual value. A unique row in this table is identified by passing the ID of the lane_junction_traversibility and the time that one wants to check.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one			A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A time varying attribute may only be associated with a single world. See 4.5.1. for information about worlds.	yes
LaneJunctionTraversibility_ID	Integer		LaneJunction Traversibility. ID		A pointer to the element in the LaneJunctionTraversibility table which this time varying attribute is associated with.	yes
Begin_Date_and_Time	Date/Time				The date and time that the value for the attribute takes effect.	yes
End_Date_and_Time	Date/Time				The date and time that the value for the attribute ends.	yes
Permissibility	Integer				The value associated with the attribute. '0' indicates legal, '1' indicates illegal, '2' indicates impossible.	yes
Description	Text				A textual description of this field for human understanding	no

Table 18: Lane Junction Traversibility Time Varying Attributes

4.3.4. Intersection Traversibility Time Varying Attributes

Within the intersection traversibility table, the permissibility attributes may be time varying. For example, the legality for traversing from one road segment that is entering an intersection to another road segment that is exiting the intersection may change at different times of the day. This may be captured by a sign which states "No right turn between 3:00pm and 6:00pm Monday through Friday". In the case when this attribute is not time varying, the value for this attribute is entered directly in the permissibility attribute value spot in the intersection traversibility table. In the case when this attribute is time varying, a –2 will be entered as the value in the intersection traversibility table to indicate that one must look in this time varying attribute table to get the actual value. A unique row in this table is identified by passing the ID of the intersection_traversibility and the time that one wants to check.

The information is this table is very similar to, and can be derived from, the information in the lane junction traversibility time varying attribute table. This table is included in the database to facilitate route planning and higher levels in a control hierarchy by allow the control system to be able to understand traversibility at intersection between road segments without having to dive down into the lane segments level.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one			A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A time varying attribute may only be associated with a single world. See 4.5.1. for more information about worlds.	yes
IntersectionTraversibility_ID	Integer		LaneJunction Traversibility. ID		A pointer to the element in the LaneJunctionTraversibility table which this time varying attribute is associated with.	yes
Begin_Date_and_Time	Date/Time				The date and time that the value for the attribute takes effect.	yes
End_Date_and_Time	Date/Time				The date and time that the value for the attribute ends.	yes
Permissibility	Integer				The value associated with the attribute. '0' indicates legal, '1' indicates illegal, '2' indicates impossible.	yes
Description	Text				A textual description of this field for human understanding	no

Table 19: Intersection Traversibility Time Varying Attributes

4.4. Junctions

4.4.1. Junction

Junctions are a general term to refer to two or more paths of transportation that come together or diverge, or a controlled point in a roadway. Paths of transportation could be roadway or not roadway paths. Example of roadway paths that could cause a junction are lanes splits, forks in the road, merges, and intersections. Example of junctions caused by roadway and non-roadway paths are pedestrian crossings, ferry crossings, railroad crossings. Examples of controlled points in the roadway are draw bridges, toll plazas, and guard gates. Junctions are an abstract supertype in the sense that a junction must be one of the types listed above. As of the time this document was published, only the intersection junction-type was included in the database. Other junction types will follow shortly.

Junctions are made up of one or more lane junction and zero or more lane junctions. Roads are made up of one or more road segment and zero or more junctions.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Road_Element. Start_Point_Adjacent_Junction, Road_Element. End_Point_Adjacent_Junction, LaneCluster.Junction_ID, LaneCluster.Left_LandJunction, LaneCluster.Right_LaneJunction, LaneCluster.Start_LaneJunction, LaneCluster.End_LaneJunction, LaneJunction.Junction_ID	A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A junction may only be associated with a single world. See 4.5.1. for more information about worlds.	yes
Description	Text				A textual description of this field for human understanding	no
RoadSegment_ID	Integer		Road_Segment.ID		A pointer to the element in the road segment table that this junction is a part of.	yes

Table 20: Junction Attributes

4.4.2. Intersections

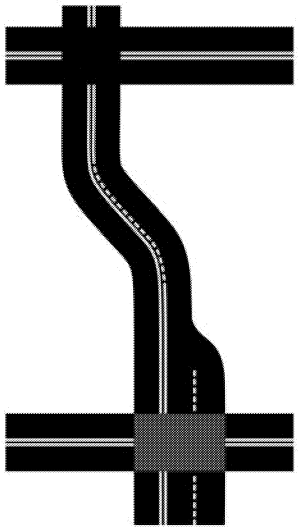

Figure 8: Intersection

Intersections are a type of junction in which two or more separate roads come together. The bounds of an intersection coming from any roadway that enters the intersection are decided in the following order:

1. If a stop line exists (a line in the road that indicates where a vehicle is suppose to stop), the side of the line that is furthest from the intersection.
2. If a crosswalk exists, the side of the crosswalk that is furthest from the intersection.
3. If a traffic sign exist to control the intersection, one would use the location of that sign to draw a line perpendicular to the direction of traffic.
4. If lane markings in the road exist that separate different lanes of travel, the last point in which the lane marking is visible. One would then use that point to draw a line across the roadway perpendicular to the direction of traffic.
5. If none of the above exists, a line should be draw connecting the corners of the road where it touches the intersection.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		RoadSegment. Start_Point_Adjacent_Intersection_ID, RoadSegment. End_Point_Adjacent_Intersection_ID, IntersectionTraversibility. Intersection_ID	A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. An intersection may only be associated with a single world. See 4.5.1. for information about worlds.	yes
Description	Text				A textual description of	no

					this field for human understanding	
Junction_ID	Integer	Any whole number greater or equal to one	Junction.ID		A pointer to the junction that this intersection is a type of.	yes

Table 21: Intersection Attributes

4.4.3. Intersection Traversibility

The intersection traversibility table captures, at a road segment level, the permissible traversibility through an intersection. In other words, for every pair of road segments that is connected to an intersection (e.g., RoadSegment1 and RoadSegment2), there are two entries in this table, one that describes the permissibility of going from RoadSegment1 to RoadSegment2 and one that describes the permissibility of going from RoadSegment2 to RoadSegment1. Therefore, for an intersection that is bounded by 8 road segments, there would be 8 entering road segments * 7 possible exiting road segments (since you can't exit on the path that you entered) = 56 entries in the table for that intersection. Permissibility can take one of three values: 1) *legal* meaning that it is possible and legal to traverse that path; 2*) illegal* meaning that it is possible but illegal to traverse that path; and 3) *impossible* meaning that it is not physically possible to traverse that path. An impossible path may occur when a barrier exists between the entering road segment and the existing road segment.

In some cases, the permissibility of the intersection traversibility may be time varying. In this case, the value in this table for the permissibility attribute will be –2, which indicates that one must look in the intersection traversibility time varying attribute table to determine the permissibility at a given point in time.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one			A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. An intersection traversibility may only be associated with a single world. See 4.5.1. for information about worlds.	yes
Description	Text				A textual description of this field for human understanding	no
Intersection_ID	Integer		Intersection.ID		A pointer to the element in the intersection table that an element in this table applies to.	yes
Incoming_Road Segment_ID	Integer		RoadSegment.ID		A pointer to an element in the RoadSegment table that indicates the road segment that is to be evaluated as entering the intersection.	yes
Incoming_Road Segment_Side	Integer	0 or 1			This is the side of the incoming road segment which is adjacent to the intersection. '0' indicates that the beginning of the road segment is adjacent to the intersection, '1' indicates that the end of the road segment is adjacent to the intersection (based upon how the road segment is rendered).	yes
Outgoing_Road Segment_ID	Integer		RoadSegment.ID		A pointer to an element in the RoadSegment table that indicates the road segment that is be evaluated as exiting the intersection.	yes
Outgoing_Road Segment_Side	Integer	0 or 1			This is the side of the outgoing road segment which is adjacent to the intersection. '0' indicates that the beginning of the road segment is adjacent to the intersection, '1' indicates	yes

					that the end of the road segment is adjacent to the intersection (based upon how the road segment is rendered).	
Permissibility	Integer				Indicates the permissibility through the intersection. '1' indicates legal, '2' indicates illegal, '3' indicated impossible. '-2' indicates that it is timevarying, and one must look at the IntersectionTraversibilityTimeVaryingAttribute table using the ID of the IntersectionTraversibility to determine the permissibility	yes
Relative_Direction	Integer	1, 2, or 3			Indicated the direction in which the outgoing road segment as compared to the incoming lane segment. This is only applicable when that lane segment has traffic that is entering the intersection. All other times, this field is left empty. 0 – opposite (straight ahead) 1 – left (from the left of straight ahead) 2 – right (from the right of straight ahead)	

Table 22: Intersection Traversibility Attributes

4.4.4. Lane Junction

A lane junction is a location in a road network in which two or more lanes of traffic overlap. A lane merge contains a lane junction starting at the point in which the two lanes begin to come together and end at the point in which the two lane are completely together as one. A lane fork contains a lane junction at the point where the lanes begin to fork and ends at the point where the two lanes are completely separated. An intersection contains a lane junction at all points in which the lanes from the two or more intersecting roads overlap.

Paths through lane junctions are defined using junction lane segments. Lane junctions are primarily used by the lower levels of a control system to define the path a vehicle should take to traverse the lane junction and to understand the permissibility of traversing through different paths of the lane junction.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		LaneJunctionTraversibility .LaneJunction_ID	A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A lane junction may only be associated with a single world. See 4.5.1. for more information about worlds.	yes
Description	Text				A textual description of this field for human understanding	no
Junction_ID	Integer		Junction.ID		A pointer to the element in the junction table that an element in this table applies to.	yes
Lane_Junction_Center_X	Double				The X_coordinate center location of the lane junction, which is the north component of the UTM coordinate.	no
Lane_Junction_Center_Y	Double				The Y_coordinate center location of the lane junction, which is the east component of the UTM coordinate.	no

Table 23: Lane Junctions Attributes

4.4.5. Junction Lane Segments (JLS)

Paths through lane junctions are defined using junction lane segments. A junction lane segment is a constant curvature path through a portion of a lane junction. JLSs are very similar to lane segments in that they:

- can be either straight line or constant curvature arcs. In the case of a straight line, the location of the lane segment if fully defined by the beginning and end point of the lane segment. For a constant curvature arc, the lane segment is defined by the beginning and end of the lane segment and the curvature center point.
- can be arbitrarily cut off at intermediate points
- are primarily used within a control system or planner to generate the detailed path that a vehicle is expected to follow.

JLSs are different than lane segments in that there can be up to three JLSs that come directly after a given JLS and there can be up to three JLSs that come directly before a given JLS. Also, multiple junction lane segment do not compose a lane, they simply show a path through a lane junction.

Any given JLS can have either a single lane segment or one to three JLS before it. Any given JLS can have either a single lane segment or one to three JLS after it.

This table only houses the attributes and values that are specific to a junction lane segment and are different that a lane segment. The common attributes between the two can be found in the generic lane segment table. The generic lane segment (in the generic lane segment table), which has the same ID as this junction lane segment will contain the corresponding attribute and values.

A small junction lane segment should be placed just priori to every entrance to a lane junction, just after the last lane segment that approaches the lane junction.

Lane junctions are primarily used by the lower levels of a control system to define the path a vehicle should take to traverse the lane junction and to understand the permissibility of traversing through different paths of the lane junction.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		JunctionLaneSegment. Right_JunctionLaneSegment_ID, JunctionLaneSegment. Left_JunctionLaneSegment_ID, JunctionLaneSegment_Connectivity. Incoming_JunctionLaneSegment_ID, JunctionLaneSegment_Connectivity. Outgoing_JunctionLaneSegment_ID	A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A junction lane segment may only be associated with a single world. See 4.5.1. for more information about worlds.	yes
Lane_Junction_ID	Integer		LaneJunction.ID		A pointer to the lane junction which the junction lane segment is in.	no
Junction_ID	Integer		Junction.ID		A pointer to the	yes

					junction which the junction lane segment is in.	
Left_Lane_Marking_ID	Integer		LaneMarkings.ID		A pointer to and element in the lane marking table that shows the type of lane marking to the left of a junction lane segment, with respect to how it was rendered. Markings are sometimes present in intersections to separate two lanes that are turning the same direction.	no
Right_Lane_Marking_ID	Integer		LaneMarkings.ID		A pointer to an element in the lane markings table that shows the type of lane marking to the right of a junction lane segment, with respect to how it was rendered. Markings are sometimes present in intersections to separate two lanes that are turning the same direction.	no
Left_Lane_Barrier_ID	Integer		LaneBarrier.ID		A pointer to an element in the lane barrier table that shows the type of lane barrier to the left of a junction lane segment, with respect to how it was rendered.	no
Right_Lane_Barrier_ID	Integer		LaneBarrier.ID		A pointer to an element in the lane barriers table that shows the type of lane barrier to the right of a junction lane segment, with respect to how it was rendered.	no
Right_JunctionLaneSegment_ID	Integer		JunctionLaneSegment.ID		A pointer to an element in the junction lane segment to the right of this junction lane segment, with respect to how it was rendered.	no
Left_JunctionLaneSegment_ID	Integer		JunctionLaneSegment.ID		A pointer to an element in the junction lane segment to the left of this junction lane segment, with respect to how it was rendered.	no

Beginning_ Control	Integer				An indication of a traffic control mechanism that governs how a vehicle should behave at the beginning of that junction lane segment. 1 – stop sign 2 – yield sign 3 – traffic light 4 – gate 5 – no control 6 – lane segment exiting the intersection	
Start_Link_ Generic_La ne_Segment _1	Integer		Generic_La neSegment. ID		A pointer to an element in the generic lane segment table that show the generic lane segment which comes directly before this junction lane segment, if it exists. An entry of –1 indicates that a start_link_generic _lane_segment does not exist, and thus a dead-end is present. This field is populated unless it is a dead end. This field could either hold a lane segment, or the left most junction lane segment with respect to how the junction lane segment is rendered.	no
Start_Link_ Generic_La ne_Segment _2	Integer		Generic_La neSegment. ID		A pointer to an element in the generic lane segment table that shows the generic lane segment which comes directly before this junction lane segment, if it exists. This field only holds the second left most junction lane segment with respect to how the junction lane segment is rendered, if it exists.	no
Start_Link_ Generic_La ne_Segment _3	Integer		Generic_La neSegment. ID		A pointer to an element in the generic lane segment table that shows the generic	no

					lane segment which comes directly before this junction lane segment, if it exists. This field only holds the third left most junction lane segment with respect to how the junction lane segment is rendered, if it exists.	
End_Link_Generic_Lane_Segment_1	Integer		Generic_LaneSegment.ID		A pointer to an element in the generic lane segment table that shows the generic lane segment which comes directly after this junction lane segment, if it exists. An entry of –1 indicates that an end_link_generic_lane_segment does not exist, and thus a dead-end is present. This field could either hold a lane segment, or the left most junction lane segment with respect to how the junction lane segment is rendered.	no
End_Link_Generic_Lane_Segment_2	Integer		Generic_LaneSegment.ID		A pointer to an element in the generic lane segment table that shows the generic lane segment which comes directly after this junction lane segment, if it exists. This field only holds the second left most junction lane segment with respect to how the junction lane segment is rendered, if it exists.	no
End_Link_Generic_Lane_Segment_3	Integer		Generic_LaneSegment.ID		A pointer to an element in the generic lane segment table that shows the generic lane segment which comes directly after this	no

					junction lane segment, if it exists. This field only holds the third left most junction lane segment with respect to how the junction lane segment is rendered, if it exists.	
Road_Surface_ID	Integer		RoadSurfaceLookup.ID		A pointer to an element in the RoadSurfaceLookup table indicating the type of road surface on the Junction Lane Segment	

Table 24: Junction Lane Segments Attributes

4.4.6. Lane Junction Traversibility

The lane junction traversibility table captures, at a lane segment level, the permissible traversibility through a lane junction. In other words, for every pair of lane segments that is connected to a lane junction (i.e., LaneSegment1 and LaneSegment2), there are two entries in this table, one that describes the permissibility of going from LaneSegment1 to LaneSegment2 and one that describes the permissibility of going from LaneSegment2 to LaneSegment1. Therefore, for a lane junction that is bounded by 8 lane segments, there would be 8 entering lane segments * 7 possible exiting lane segments (since you can't exit on the path that you entered) = 56 entries in the table for that lane junction. Permissibility can take one of three values: 1) *legal* meaning that it is possible and legal to traverse that path; 2*) illegal* meaning that it is possible but illegal to traverse that path; and 3) *impossible* meaning that it is not physically possible to traverse that path. An impossible path may occur when a barrier exists between the entering road segment and the existing road segment. Note that this table does not address the issue of "right of way", since that is a real-time determination based upon the location of vehicles and objects on the roadway as opposed to characteristics of the roadway itself.

In some cases, the permissibility of the lane junction traversibility may be time varying. In this case, the value in this table for the permissibility attribute will be –2, which indicates that one must look in the lane junction traversibility time varying attribute table to determine the permissibility at a given point in time.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		IntersectionTraversibilityTimeVaryingAttribute.LaneJunctionTraversibility_ID	A unique identifier for this entry in this table	yes
World_ID	Integer		World.ID		A pointer to an element in the World table that indicates which world this entry is associated with. A lane junction traversibility may only be associated with a single world. See 4.5.1. for information about worlds.	yes
Description	Text				A textual description of this field for human understanding	no
LaneJunction_ID	Integer		LaneJunction.ID		A pointer to the element in the lane junction table that an element in this table applies to.	yes
Incoming_LaneSegment_ID	Integer		GenericLaneSegment.ID		A pointer to an element in the GenericLaneSegment table that indicates the lane segment that is be evaluated as entering the lane junction.	yes
Incoming_LaneSegment_Side	Integer	0 or 1			This is the side of the incoming lane segment that is adjacent to the lane junction. '0' indicates that the beginning of the lane segment is adjacent to the lane junction, '1' indicates that the end of the lane segment is adjacent to the lane junction (based upon how the lane segment is rendered).	yes
Outgoing_LaneSegment_ID	Integer		GenericLaneSegment.ID		A pointer to an element in the GenericLaneSegment table that indicates the lane segment that is be evaluated as exiting the lane junction.	yes
Outgoing_LaneSegment_Side	Integer	0 or 1			This is the side of the outgoing lane segment that is	yes

					adjacent to the lane junction. '0' indicates that the beginning of the lane segment is adjacent to the lane junction, '1' indicates that the end of the lane segment is adjacent to the lane junction (based upon how the lane segment is rendered).	
Permissibility	Integer				Indicates the permissibility through the lane junction. '0' indicates legal, '1' indicates illegal, '2' indicated impossible. '-2' indicates that it is timevarying, and one must look at the LaneJunctionTraversibilityTimeVaryingAttribute table using the ID of the LaneJunctionTraversibility to determine the permissibility	yes

Table 25: Lane Junctions Traversibility Attributes

4.5. Administrative Tables

4.5.1. World

Every road network resides in a world. The world provides a reference point in which all coordinates are measured. Currently there is no interaction between worlds – only road "elements" that are in the same world may be related to one another. Future versions of the database will allow for interactions between worlds.

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
ID	Integer	Any whole number greater or equal to one		Road.World_ID, RoadSegment.World_ID, RoadElement.World_ID, LaneCluster.World_ID, Lane.World_ID, LaneSegment.World_ID, GenericLaneSegment,World_ID, LaneSegmentTimeVaryingAttribute. World_ID, LaneTimeVaryingAttribute.World_ID, LaneJunctionTimeVaryingAttribute. World_ID, IntersectionTraversibilityTimeVarying Attribute.World_ID, Junction.World_ID, Intersection.World_ID, IntersectionTraversibility.World_ID, LaneJunction.World_ID, JunctionLaneSegment.World_ID, JunctionLaneSegment_Connectivity .World_ID, LaneJunctionTraversibility.World_ID	A unique identifier for this entry in this table	yes
Name	Text				This is a name to refer to the World, for human understanding.	no
Description	Text				A textual description of the world for human understanding	no
X_Offset	Double				An offset in the X direction, measured in meters.	yes
Y_Offset	Double				An offset in the Y direction, measured in meters.	yes
Zone	Integer				The UTM in which the world is located.	yes
Export_Timestamp	Text				The date and time in which this world was exported.	yes

Table 26: World Attributes

4.5.2. Version Control

The version control table provides a mechanism to track changes as they are made to the database. There are nine legal change actions currently permissible:

- added attr - added a new attribute to a table
- added table – added a new table to the database
- changed attr. name – change the name of an attribure
- changed table name – changed the name of a table in the database
- removed attr – removed an attribute from a table
- removed table – removed a table from the database
- redefinition – redefined the meaning of an attribute
- moved attr – moved an attribute from one table to another
- changed value for attr – changed the possible value for an attribute (e.g., from text to integer)

Attribute	Data Type	Value Restrictions	Points To	Is Pointed To From	Description	Required Value?
Version	Double	Any positive number			The version number which the change applies.	yes
Date	Date/Time				The date in which the change was made.	yes
Table1	Text				The table that was affected by the change.	yes
Table2	Text				When moving attributes from one table to another, Table1 is the source table and Table2 is the destination table.	yes
Action	Text	Added attr., added table, changed attr. name, changed table name, removed attribute, removed table, moved attr, changed value for attr., redefinition,			The action that was performed on the table.	yes
Description	Text				Further description about the action that was performed.	yes

Table 27: Version Control Attributes

5. Conclusion

This document describes the Road Network Database being developed as part of the NIST efforts in enabling autonomous on-road driving. The database is currently at Version 1.0, and has been implemented as part of two planners being developed within NIST (a cost-based and a finite state machine-based planner) within a simulated environment.

Though a considerable amount of time and effort has been put into the database, there is still quite a bit of work that has yet to be accomplished. Additional types of junctions must be included, including merges, forks, pedestrian crossings, and railroad crossings. More information about roads also needs to be included, such as the overall width of the road, so that obstacles can be placed on the roads cleanlier. The database also needs to continue to be "stress tested" in simulated and real environments to ensure its consistency and completeness.