The queries are triggered for the maneuver's specific timestamp (0.5s). A maneuver accomplished in several timestamps. For example, a 5s maneuver consists of 100 timestamps (0.05s). [See chapter 7 for more about timestamps explanation].

# **Atom 1: vehicle\_IsTurningLeft (5)**

## **Query 1: Is the TV giving the left indicator signal? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_goingleft

WHERE

{

ab:vehicle-2 (TV) ab:is\_goingleft ?is\_goingleft

}

Answer Example: "0.0"^^<http://www.w3.org/2001/XMLSchema#string>

### **Explanation**

Through the below condition, it is determined whether the overtaken vehicle is giving the right indicator signal.

**Condition:**

if (q.result == 1)

then “Vehicle is giving right indictaor signal”;

left\_indicator\_signal = 1;

else

left\_indicator\_signal = 0;

## **Query 2: What is the TV lane number? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_lanenumber

WHERE

{

ab:vehicle-2 ab:is\_lanenumber ?is\_lanenumber

}

Answer Example: "2.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 3: How many lanes in the road? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_totallane

WHERE

{

as:time as:is\_totallane ?is\_totallane. // as:5.9 as:is\_totallane ?is\_totallane.

}

Answer Example: "3.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 4: Is TV is in the intersection? (AV\_Behaviour) (AV\_Environment)**

### **SubQuery 1: Is it an intersection at the time (t)?**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_intersection

WHERE

{

as:time as:is\_intersection ?is\_intersection.

}

#### **Explanation**

In the below condition, it is determined whether this road is multi-lane or not. If this query outcome is 1 then it is considered that TV is in the intersection.

**Condition:**

if (q.result == 1)

then “TV is in intersection”;

intersection = 1;

else

intersection = 0;

### **Explanation**

If time (t), TV is driving and it is an intersection, then the Query 4 outcome is TV is in the intersection.

## **Explanation for Atom 1**

Based on Query 1- Query 4 result, atom 5 is determined whether it is true or false.

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 | TV is giving left indicator signal | True |
| Query 2 & Query 3 | TV lane number == 1 | TV lane number == 2 | True |
| Query 4 | TV is in intersection | True |

**THEN:** The atom is considered a True atom for the specific timestamp.

**ELSE**: (if any of the query results becomes opposite to the expected outcome)

The atom is considered a False atom.

# **Atom 2: vehicle\_IsMakingUturn (5)**

## **Query 1: How many lanes in the road? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_totallane

WHERE

{

as:time as:is\_totallane ?is\_totallane. // as:5.9 as:is\_totallane ?is\_totallane.

}

Answer Example: "3.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 2: What is the TV lane number? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_lanenumber

WHERE

{

ab:vehicle-2 ab:is\_lanenumber ?is\_lanenumber

}

Answer Example: "2.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 3: Is the TV giving the right indicator signal? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_goingright

WHERE

{

ab:vehicle-2 (TV) ab:is\_goingright ?is\_goingright

}

Answer Example: "0.0"^^<http://www.w3.org/2001/XMLSchema#string>

### **Explanation**

Through the below condition, it is determined whether the overtaken vehicle is giving the right indicator signal.

**Condition:**

if (q.result == 1)

then “Vehicle is giving right indictaor signal”;

right\_indicator\_signal = 1;

else

right\_indicator\_signal = 0;

## **Query 4: Is TV is in the intersection? (AV\_Behaviour) (AV\_Environment)**

### **SubQuery 1: Is it an intersection at the time (t)?**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_intersection

WHERE

{

as:time as:is\_intersection ?is\_intersection.

}

#### **Explanation**

In the below condition, it is determined whether this road is multi-lane or not. If this query outcome is 1 then it is considered that TV is in the intersection.

**Condition:**

if (q.result == 1)

then “TV is in intersection”;

intersection = 1;

else

intersection = 0;

### **Explanation**

If time (t), TV is driving and it is an intersection, then the Query 4 outcome is TV is in the intersection.

## **Explanation for Atom 2**

Based on Query 1- Query 4 result, atom 5 is determined whether it is true or false.

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 & Query 2 | TV lane number == Total lane | TV lane number == Total lane -1 | True |
| Query 3 | TV is giving right indicator signal | True |
| Query 4 | TV is in intersection | True |

**THEN:** The atom 8 is considered a True atom for the specific timestamp.

**ELSE**: (if any of the query results becomes opposite to the expected outcome)

The atom is considered a False atom.

# **Atom 3: vehicle\_IsOn\_centreOfRoad (2)**

## **Query 1: How many lanes in the road? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_totallane

WHERE

{

as:time as:is\_totallane ?is\_totallane.

}

Answer Example: "3.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 2: What is the TV Lane Number? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_lanenumber

WHERE

{

ab:vehicle-2 ab:is\_lanenumber ?is\_lanenumber

}

Answer Example: "2.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Explanation for Atom 3**

Based on Query 1-2 result, atom 9 is determined whether it is true or false.

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 & Query 2 | TV lane number ≥ Floor (totallane / TV lane number) & TV lane number < totallane | True |

**THEN:** The atom is considered a True atom for the specific timestamp.

**ELSE**: (if any of the query results becomes opposite to the expected outcome)

The atom is considered a False atom.

# **Atom 4: vehicle\_IsStationary (1)**

## **Query 1: What is TV speed? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_speed

WHERE

{

ab:vehicle-2 ab:is\_speed ?is\_speed

}

Answer Example: "39.1796836853"^^<http://www.w3.org/2001/XMLSchema#string>

## **Explanation for Atom 4**

Based on Query 1 result, atom 10 is determined whether it is true or false.

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 | TV speed == 0 | True |

**THEN:** The atom is considered a True atom for the specific timestamp.

**ELSE**: (if the query result becomes opposite to the expected outcome)

The atom is considered a False atom.

# **Atom 5: driver\_IsDrivingOn\_MultiLaneRoad (1)**

## **Query 1: How many lanes in the road? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_totallane

WHERE

{

as:time as:is\_totallane ?is\_totallane.

}

Answer Example: "3.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Explanation for atom 5**

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 | Totallane > 1 | True |

**THEN:** The atom is considered a True atom for the specific timestamp.

**ELSE**: (the query result ≤ 1)

The atom is considered a False atom.

# **Atom 6: vehicle\_Display\_doNotOvertakeTurningVehicleSign (1)**

## **Query 1: Does TV displaying do not overtake sign? (AV\_Environment)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_donotovertakesign

WHERE

{

ab:vehicle-2 (TV) ab:is\_donotovertakesign ?is\_donotovertakesign

}

Answer Example: "0.0"^^<http://www.w3.org/2001/XMLSchema#string>

#### **Explanation**

In the below condition, it is determined whether the TV is displaying do not overtake sign or not. If this query outcome is 1 then it is considered that TV is displaying do not overtake sign.

**Condition:**

if (q.result == 1)

then “TV is displaying do not overtake sign”;

do\_not\_overtake\_sign = 1;

else

do\_not\_overtake\_sign = 0;

## **Explanation for Atom 6**

Based on Query 1 result, atom 10 is determined whether it is true or false.

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 | do\_not\_overtake\_sign == 1 | True |

**THEN:** The atom is considered a True atom for the specific timestamp.

**ELSE**: (if the query result becomes opposite to the expected outcome)

The atom is considered a False atom.

# **Atom 4: markedLane\_IsToTheLeftOf\_vehicle (3)**

## **Query 1: Is the road is marked lane?**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_markedlane

WHERE

{

as:time as:is\_markedlane ?is\_markedlane.

}

Answer Example:

"1.0"^^<http://www.w3.org/2001/XMLSchema#string>

#### **Explanation**

Through the below condition, it is determined whether this road is a multi-lane road or not.

**Condition:**

if (q.result == 1)

then “It is a Marked Lane Road”;

markedlane = 1;

else

markedlane = 0;

## **Query 2: What is the TV Lane Number? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_lanenumber

WHERE

{

ab:vehicle-2 ab:is\_lanenumber ?is\_lanenumber

}

Answer Example: "2.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 3: How many lanes in the road? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_totallane

WHERE

{

as:time as:is\_totallane ?is\_totallane. // as:5.9 as:is\_totallane ?is\_totallane.

}

Answer Example: "3.0"^^<http://www.w3.org/2001/XMLSchema#string>

### **Explanation**

Through the below condition, it is determined whether this road is a multi-lane road or not.

**Condition:**

if (q.result > 1)

then “It is Multi-Lane Road”;

multilaneroad = 1;

else

multilaneroad = 0;

## **Explanation for Atom 7**

Based on Query 1- Query 3 result, atom 4 is determined whether it is true or false.

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 | The road is a marked lane | True |
| Query 2 | TV lane number > 1 | True |
| Query 3 | Multi-lane road | True |

**THEN:** The atom is considered a True atom for the specific timestamp.

**ELSE**: (if any of the query results becomes opposite to the expected outcome)

The atom is considered a False atom.

# **Atom 8: IsSafeToPassIn\_MarkedLane (19)**

# **Atom 9: IsSafeToOvertakeIn\_MarkedLane (19)**

# **Atom 10: IsSafeToPassToTheLeftOf\_vehicle (19)**

# **Atom 11: IsOtherwiseSafeToPassToTheLeftOf\_vehicle (19)**

# **Atom 12: IsSafeToOvertakeToTheLeftOf\_vehicle (19)**

# **Atom 13: driver\_DrivePastToTheLeftOf\_vehicle (19)**

# **Atom 14: driver\_OvertakeToTheLeftOf\_vehicle (19)**

# **Atom 15: IsOtherwiseSafeToOvertakeToTheLeftOf\_vehicle (19)**

\*For all these atoms, the following queries are cosidered.

## **Query 1: Which vehicle is driving in time (t)? (AV\_Environment)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?vehicle

WHERE

{

ab:time ab:driving ?vehicle

}

Answer Example:

Vehicle1 (AV)

Vehicle2 (TV-1)

Vehicle3 (TV-2)

### **Explanation**

From this query result, it is identified how many vehicles is around the AV.

## **Query 2: How many lanes in the road? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_totallane

WHERE

{

as:time as:is\_totallane ?is\_totallane.

}

Answer Example: "3.0"^^<http://www.w3.org/2001/XMLSchema#string>

### **Explanation**

Through the below condition, it is determined whether this road is a multi-lane road or not.

**Condition:**

if (q.result > 1)

then “It is Multi-Lane Road”;

multilaneroad = 1;

else

multilaneroad = 0;

## **Query 3: What is AV Lane Number? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_lanenumber

WHERE

{

ab:vehicle-1 ab:is\_lanenumber ?is\_lanenumber

}

Answer Example: "2.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 4: What is TV lane number? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_lanenumber

WHERE

{

ab:vehicle-2 ab:is\_lanenumber ?is\_lanenumber

}

Answer Example: "2.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 5: What is AV speed? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_speed

WHERE

{

ab:vehicle-2 ab:is\_speed ?is\_speed

}

Answer Example:

"56.1796836853"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 6: What is road allowed speed at the time (t)? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_roadspeed

WHERE

{

as:time as:is\_roadspeed ?is\_roadspeed.

}

Answer Example:

"80.0"^^<http://www.w3.org/2001/XMLSchema#string>

## **Query 7: Is AV is at a safe distance? (AV\_Behaviour)**

### **Subquery 1: What is AV curvilinear coordinates in time (t)? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_positionx ?is\_positiony

WHERE

{

ab:vehicle-1 ab:is\_positionx ?is\_positionx.

ab:vehicle-1 ab:is\_positiony ?is\_positiony

}

Answer Example:

"285.551116943"^^<http://www.w3.org/2001/XMLSchema#string>

"164.853302002"^^<http://www.w3.org/2001/XMLSchema#string>

#### **Explanation**

From these curvilinear coordinates, the distance of the vehicles is measured by the following equation,

Vehicle\_distance = abs | root (x\*x + y\*y) |

### **Subquery 2: What is TV curvilinear coordinates in time (t)? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_positionx ?is\_positiony

WHERE

{

ab:vehicle-1 ab:is\_positionx ?is\_positionx.

ab:vehicle-1 ab:is\_positiony ?is\_positiony

}

Answer Example:

"277.459075928"^^<http://www.w3.org/2001/XMLSchema#string>

"164.853302002"^^<http://www.w3.org/2001/XMLSchema#string>

#### **Explanation**

From these curvilinear coordinates, the distance of the vehicles is measured by the following equation,

Vehicle\_distance = abs | root (x\*x + y\*y)

### **Subquery 3: What is the velocity of AV in time (t)? (AV\_Behaviour)**

#### **Nested Subquery 1: What is the speed of the AV in time (t)? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_speed

WHERE

{

ab:vehicle-1 ab:is\_speed ?is\_speed

}

Answer Example:

"56.1796836853"^^<http://www.w3.org/2001/XMLSchema#string>

#### **Nested Subquery 2: What is the direction of AV in time (t)? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_heading

WHERE

{

ab:vehicle-1 ab:is\_heading ?is\_heading

}

Answer Example:

"0.0"^^<http://www.w3.org/2001/XMLSchema#string>

#### **Explanation**

From the speed and heading, the velocity of the vehicle is determined.

Vehicle\_velocity = vehicle\_speed \* heading (direction).

### **Subquery 4: What is the velocity of TV in time (t)?**

#### **Nested Subquery 1: What is the speed of the TV in time (t)? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_speed

WHERE

{

ab:vehicle-2 ab:is\_speed ?is\_speed

}

Answer Example:

"39.31300354" ^^<http://www.w3.org/2001/XMLSchema#string>

##### **Explanation**

From the speed and heading, the velocity of the vehicle is determined.

Vehicle\_velocity = vehicle\_speed \* heading (direction).

**Nested Subquery 2: What is the direction of TV in time (t)? (AV\_Behaviour)**

SPARQL:

prefix ab:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-137#>

SELECT ?is\_heading

WHERE

{

ab:vehicle-2 ab:is\_heading ?is\_heading

}

Answer Example:

"0.0" ^^<http://www.w3.org/2001/XMLSchema#string>

#### **Explanation**

From the speed and heading, the velocity of the vehicle is determined.

Vehicle\_velocity = vehicle\_speed \* heading (direction).

### **Subquery 5: What is the reaction time of AV1 and TV in time (t)?**

#### **Nested Subquery 1: What is the reaction time of AV in time (t)? (AV\_Behaviour)**

Reaction time is considered as 0s

#### **Nested Subquery 1: What is the reaction time of TV in time (t)? (AV\_Behaviour)**

Reaction time is considered as 0s

### **Explanation**

After retrieving all these subqueries (1⎯5) result, the query-7 result is made through the below assumptions and equations.

Based on three specific assumptions, this safe distance mechanism works. These assumptions are:

* 0 ≤ vav  ˄ 0 ≤ vtv  ; the velocity of automated vehicle (vav) and target vehicle (vtv) are non-negative.
* aav ˂ 0 ˄ atv ˂ 0 ; acceleration of automate vehicle (aav) and target vehicle (atv) is negative.
* s0, av ˂ s0, tv ; target vehicle position (s0, tv) is ahead of automated vehicle position (s0, av).

Equations are:

|  |  |
| --- | --- |
|  | (3) |

|  |  |
| --- | --- |
| = | (4) |

|  |  |
| --- | --- |
|  | (5) |

Here = 0.7 is coefficient friction, and 9.8 ms-2 is the gravitational acceleration.

|  |  |
| --- | --- |
|  | (6) |

|  |  |
| --- | --- |
|  | (7) |

|  |  |
| --- | --- |
|  | (8) |

This research considered these safe distance equations as the ground truth for the safe distance terms. Based on the above assumptions and equations, if any of the safe distances (equation 7, 8, 9) becomes true, this research considered that the AV is at a safe distance and yields the result '1' as a positive outcome for this Query 7. Otherwise, the result becomes '0' indicates the Query 7 outcome is negative (AV is not in the safe distance).

## **Query 8: Can AV safely change the lane? (AV\_Behaviour) (AV\_Environment)**

### **Subquery 1: Is the road is marked lane? (AV\_Environment)**

SPARQL:

prefix as:<http://www.semanticweb.org/bhuiyanh/ontologies/2020/5/untitled-ontology-139#>

SELECT ?is\_markedlane

WHERE

{

as:time as:is\_markedlane ?is\_markedlane.

}

Answer Example:

"1.0"^^<http://www.w3.org/2001/XMLSchema#string>

#### **Explanation**

This query result determines whether the road is a marked lane or not. The '1' indicates the road is a marked lane.

## **Explanation for Atom 2**

Based on the Query 1-Query 8 result, atom 3 is determined whether it is true or false. For this atom, some queries result can be determined through the outcome, such as Query 3, Query 4, etc. However, some queries result is made based on the computational processes of their subqueries outcome, such as Query 7, Query 8, etc.

**IF:**

|  |  |  |
| --- | --- | --- |
| Queries | Result | Expected outcome |
| Query 1 | AV and there is TV | True |
| Query 2 | The road is a multi-lane road | True |
| Query 3 | AV lane number > 0 | True |
| Query 4 | TV lane number > 0 | True |
| Query 5 | AV speed > 0 | True |
| Query 6 | No condition | True / False |
| Query 7 | AV is in safe distance with TV and other vehicles. | True |
| Query 8 | The road is a marked lane | True |

**THEN:** The atom is considered a True atom for the specific timestamp.

**ELSE**: (if any of the query results becomes opposite to the expected outcome)

The atom is considered a False atom.

**Total 170 Queries including subqueries and nested subqueries**