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## MONITORING AND REPORTING THE SAFETY PERFORMANCE OF DIFFERENT MODELS AND VERSIONS OF AUTONOMOUS VEHICLES

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### ABSTRACT

Presented herein are techniques that enable an administrative authority (e.g., city, municipality, *etc.*) to determine when a vehicle is under autonomous control, as well as to specifically determine the vendor and software version of the autonomous control system controlling the vehicle. If the vehicle has problems navigating the environment, the details of that problem are reported directly to the administrative authority. Any trending problems detected after a software update to the control systems can be proactively detected and reported to the vehicle vendor and upstream aggregation systems.

### DETAILED DESCRIPTION

It is expected that, in the future, there will be hundreds of thousands of autonomous vehicles (AVs) roaming the streets of our cities, potentially with inconsistent capabilities. That is, the AVs will be made by different companies, using different technical approaches (different sensors, ML techniques, *etc.*), and have different functions, safety features, *etc.* (i.e., some AVs will be safer than others) and many AV systems will have bugs.

Administrative authorities face a number of challenges with AVs, including:

- AV systems will be constantly changing via over-the-air software updates that may make the AVs safer. However, updates may cause new problems (a regression) that, in fact, make the AVs less safe. As such, administrative authorities cannot assume that all versions of AV software for a vendor going forward will be safer than the last version and over-the-air updates may cause the safety levels to change over time with each new update.

- Administrative authorities are different and different AV models and versions will work better or worse in different areas/cities. For example, different cities have specific roads and features (e.g., lane markings, street lights, potholes, *etc.*) that are unique to their city, and those features will trigger negative edge cases in the neural-net processing of different AV models and versions.

For example shown in FIGs. 1A and 1B, below, are street grids for Boston and for Salt Lake City, respectively.



**FIG. 1A**



**FIG. 1B**

As can be seen, the streets shown in FIGs. 1A and 1B are very different and an AV system that has been proven to work great in Salt Lake City may not operate properly in Boston (i.e., cannot blindly trust AVs to work as well in all locations). Moreover, a first software version (e.g., AV version A) might work well for Boston, but a subsequent version (e.g., AV version B) may introduce a regression causing it to have problems with sharp left turns, causing the corresponding AV to suddenly become unsafe in Boston. For example, an update to a neural network control system might cause a regression that is triggered by a specific feature of a specific city (a specific winding road for example).

In conventional systems, users are reporting that new regressions are introduced when companies push out AV system updates over-the-air. These regressions have greater impacts in certain areas than in other areas.

Administrative authorities want to control of how AVs operate in their area. However, with a flood of new vendors offering AVs, administrative authorities have no way to measure the safety of the many different types of AVs that operate in their jurisdictions. The administrative authorities have no way to distinguish which AV types are safer than others, nor do they have the tools needed to know which vehicles are in autonomous mode. As such, a technical solution is needed that provides administrative authorities with the tools needed to determine the safety capabilities of the AVs operating in their jurisdictions, as well as the tools needed to determine which specific AV software versions and models are safer than others. While hardware components and communication stacks can conform to hardware and communication standards, software implementations can vary between manufacturers. While there is no means to control that implementation, administrative authorities need the ability to assess the safety and performance of AVs and, as needed, invoke actions to both hardware and software AV implementations.

Adding to the potential of full Autounomosity of a vehicle, it has been proposed to maintain full communication between AVs and the administrative authority infrastructure so as to exchange relevant information that could benefit the other entity. This is defined as Vehicle to Anything (V2X), which incorporates a more specific type of communications such as the Vehicle to Vehicle (V2V) and the Vehicle to Infrastructure (V2I) communications. The main motivations toward having V2X communications are road safety, traffic efficiency, and energy savings. There are two types of V2X communication technology depending on the underlying technology being used:

- Wireless LAN - based technology: Based on IEEE 802.11p and IEEE 1609 serve as the underlying technology for Dedicated Short-Range Communications (DSRC) that is defined under ITS-G5 by the EU.
- Cellular-based technology (C-V2X): 3GPP standard-based describing the V2X Standard started from Release 14 and recently expanded in Release 15 and to be enhanced in Release 16. It is also known LTE-V2X (4G version) and recently 5G-

V2X in release 15 (promoted by 5G Automotive Association). C-V2X enables the communications with the wider network in addition to V2V, V2I, unlike IEEE 802.11p in which defines V2V and V2I communications only.

While both IEEE 802.11p/1609 and 3GPP defines the data transport features that enable V2X, it does not include V2X semantic content but proposes the usage of Dedicated Short-Range Communications (DSRC) defined under ITS-G5 standards. The DSRC utilize J2735 messages format, the structure of messages, data frames, and data elements defined by SAE application for V2V communication and V2V communication (with units called Roadside Units). Some of these messages are:

- BasicSafetyMessage (BSM): For V2V safety message and it is broadcasted by vehicles to provide situational data (location, heading, speed, etc.) to surrounding vehicles, used to assess threat potentials
- SPaT/Map: Signal Phase and Timing (SPaT) and it is broadcasted by Roadside Units (RSU) to provide the current signal status (color) by lane and when the status is expected to change. MAP: It is broadcast by RSUs to provide a geometric layout of an intersection and used in conjunction with SPaT
- PersonalSafetyMessage (PSM): It is broadcasted by Vulnerable Road User (VRU) devices (onboard of Pedestrians, Bicycles, Roadworks, etc.) to announce their presence to approaching vehicles.
- Cooperative Awareness Messages (CAM) and Decentralized Environmental NotificationMessage (DENM). CAMs are a kind of heartbeat messages periodically broadcasted by each vehicle to its neighbors to provide information of presence, position, temperature, and basic status. On the contrary, DENMs are event-triggered messages broadcasted to alert Road Side Units and hence Road users of a hazardous event
- TestMessages: Define testing messages

The message structure in this stack define applications to improve roadway safety and efficient operation. However, this can get complicated without applying governance on the underlying software implementations, version variations for different models (and

for the same model, and potential abnormal behavior against standard road structure or expected and unexpected situation.

The techniques presented herein propose to utilize the current V2X communication stack and extend it to provide administrative authority the tools to assess and govern the behavior of an AV and, potentially, invoke an action to it (i.e., define a measurement messaging between the Vehicle in Autonomous mode and the administrative authority infrastructure for data-driven assessment).

The techniques presented herein enable administrative authorities to collect and aggregate safety information about the AVs that operate within their jurisdictions/domains. Rather than waiting for citizens and police to report problems with AVs (and specific versions of AV control systems from a vendor), the techniques presented herein enable the relevant administrative authority to be proactive in determining which AV control systems might have safety problems within the roads in their jurisdictions. The information can be further up-leveled to a hosted cloud service for more analytics and aggregation. As self-driving vehicles begin to transform the way people get around, city and municipal planners around the world are beginning to think about how the AVs will affect their areas, while changing the way humans live and interact with vehicles.

In general, the techniques presented are described with reference to an Autonomous Vehicle level 5 driving mode as defined by the Society of Automotive Engineers (SAE). An Autonomous Vehicle (AV), by this definition, excludes a motor vehicle enabled with active safety systems or driver- assistance systems. Instead, an Autonomous Vehicle mode in this context is capable of sensing its environment and moving with no human intervention or input. An Autonomous Vehicle combines the outputs from a variety of sensors to perceive their surroundings (e.g., Radar, LIDAR, SONAR, GPS, Odometry, Inertial Measurement Units, *etc.*), all controlled by an on-board control system that interprets sensory information and identifies navigation paths, obstacles, and relevant traffic signage.

The techniques presented herein are explained in the context of several primary operations, namely:

1. Vehicles report autonomous control state advertisements to the administrative authority infrastructure.

2. Vehicles report problems observed with navigating the area.
3. The infrastructure uses its own sensors to monitor the performance of AVs in its area and records any deviations.
4. The administrative authority evaluates the aggregate performance of the different AV system versions and reports problems to a cloud aggregator service.

Each of these operations is described in greater detail below.

### **Vehicles Report Autonomous Control State Advertisements to the Infrastructure**

AVs operating within the jurisdiction of an administrative authority use the Vehicle to Infrastructure to advertise when they have initiated autonomous control, as well as details about the autonomous control system. The AVs also use the Vehicle to Infrastructure to advertise when they disengage from autonomous control. This allows the infrastructure to understand details of the system guiding the vehicle, as well as what AVs are operating autonomously.

An example of data structure of the autonomous control state advertisement is:

```
{
"autonomous_control": true,
"autonomous_level": 5,
"autonomous_control_enabled_time": 1562090547000,
"device_UUID": "72150660-8343-42c0-98dd-d78fa7ac4022",
"vendor": "Autodrive ",
"model": "2018 – CAR Type Z",
"vendor_autonomy_system": "Autodrive - Full Autonomy",
"vendor_autonomy_version": "12.3.2.12",
"vendor_autonomy_version_release_date": 1554227981,
"vendor_autonomy_previous_version": "12.3.2.11",
"sensor_suite_version": "12.332.21",
"sensor_list": ["forward_camera", "rear_camera", "forward_lidar", "rear_lidar"]
}
```

It is noted that not only are the vendor and the autonomy level reported, but the *version* and *model* of the autonomy system are also reported. This information is key to the administrative authority understanding what edge cases might exist in the neural

networks running on the different versions of the control systems. It is to be appreciated that the techniques presented herein also extends to reporting additional details of the autonomous capabilities, such as the specific hardware versions and capabilities, sight and sensor distance, *etc.*

In operation, the AV data is transmitted as a beacon that announces key facts about the state of the autonomous system. The data is leveraged by the administrative authority using a connected city platform to derive insights, as explained further below.

### **Vehicles Report Problems Observed with Navigating the Area**

The AVs may also advertise any problems they encounter with navigation and driving in the area (e.g., jurisdiction) of the administrative authority. These advertisements may occur at any time, such as when the AV is unable to navigate safely with confidence.

#### ***Example - Reporting problems caused by poor lane markings:***

As shown in FIG. 2, below, an AV may be unable to distinguish the lane markings in a certain area. Therefore, the AV may, for example, report this inability to the city so some action could be taken.



**FIG. 2**



An example data structure of the autonomous vehicle reporting a problem with recognizing lane markings, as in FIG. 2, is:

```
{
  "autonomous_control": true,
  "autonomous_level": 5,
  "incident_location": "32??16'12.9"N+81??18'47.1"W @ 213deg @ 40mph",
  "device_UUID": "72150660-8343-42c0-98dd-d78fa7ac4022",
  "incident_type": "Unrecognized lane markings",
  "record_data": "http://connected_platform.cisco.com/kinetic/evidence/72150660-8343-42c0-98dd-d78fa7ac4022/12312.png",
  "vendor_autonomy_system": "Autodrive - Full Autonomy",
  "vendor_autonomy_version": "12.3.2.12",
  "vendor_autonomy_version_release_date": 1554227981,
  "vendor_autonomy_previous_version": "12.3.2.11",
}
```

In certain circumstances, the reports might be triggered by true positives, where the vehicle has detected a legitimate problem with the environment and, by reporting it to the administrative authority, the problem might be corrected by the administrative authority sooner (than if it is not reported). For example, if a number of vehicles report lane-line reading problems to the administrative authority, it can dispatch workers to improve those lines.

In other circumstances, the reports might be false positives that are not caused by a problem with the roads. In such cases, the specific autonomous control system has a problem understanding a legitimate environment and this problem needs to be solved by the vendor.

***Example - Reporting problems caused by local weather conditions:***

If poor weather is contributing to the situational awareness for the vehicle, then that can be reported as well. For example, if certain streets in San Francisco are reported to be very foggy (with reduced visibility) between 6-8 AM each day, then this can be aggregated by the administrative authority to let it predictively alert other vehicles that there might be a problem during that time. An example data structure of such an example is:

```

{
"autonomous_control": true,
"autonomous_level": 5,
"incident_location": "32??16'12.9"N+81??18'47.1"W @ 213deg @ 40mph",
"device_UUID": "72150660-8343-42c0-98dd-d78fa7ac4022",
"incident_type": "Poor visibility due to weather (fog)",
"visibility_depth": "100m",
"windshield_wipers": true,
"record_data": "http://connected_platform.cisco.com/kinetic/evidence/72150660-8343-42c0-98dd-d78fa7ac4022/12312.png",
"vendor_autonomy_system": " Autodrive - Full Autonomy",
"vendor_autonomy_version": "12.3.2.12",
"vendor_autonomy_version_release_date": 1554227981,
"vendor_autonomy_previous_version": "12.3.2.11",
}

```

***Example - Reporting potential Future problems:***

The system can also be used to report where there might be a problem in the future. For example, if an AV is able to recognize a stop sign that is partially covered by foliage, then that problem has a potential to grow worse. It is beneficial to the AV reports this information to the administrative authority. FIG. 3, below, illustrates stop signs detected by an AV, where two stop signs are partially obscured.



**FIG. 3**

An example data structure for reporting a partially obscured stop sign is:

```
{  
  "autonomous_control": true,  
  "autonomous_level": 5,  
  "incident_location": "32??16'12.9"N+81??18'47.1"W @ 213deg @ 40mph",  
  "device_UUID": "72150660-8343-42c0-98dd-d78fa7ac4022",  
  "incident_type": "Poor visibility of navigation instruction sign (stop sign)",  
  "type": "stop_sign",  
}
```

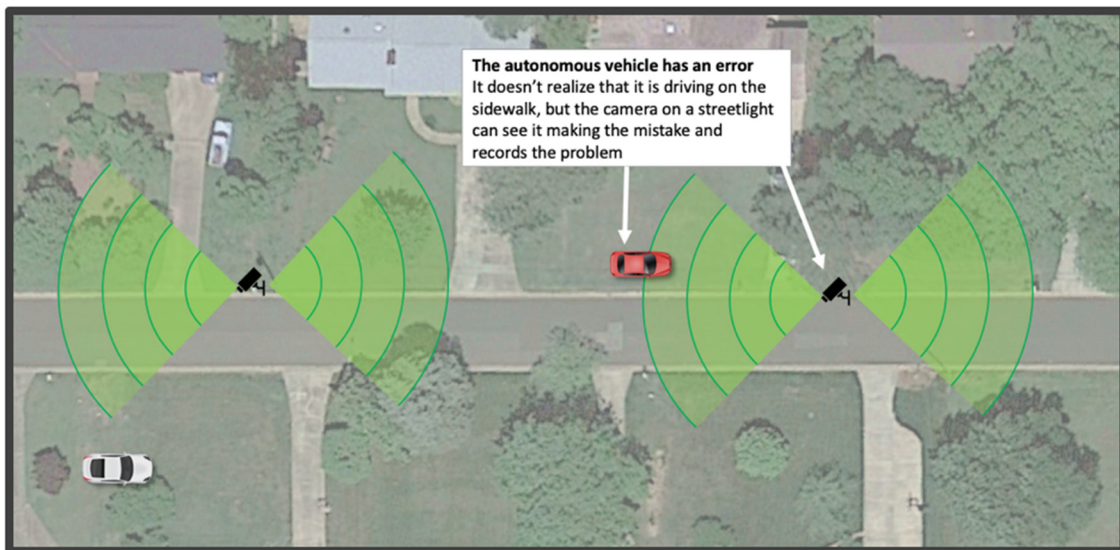
```

"confidence_percent": "21",
"record_data": "http://connected_platform.cisco.com/kinetic/evidence/72150660-8343-42c0-98dd-d78fa7ac4022/12312.png",
"vendor_autonomy_system": "Autodrive - Full Autonomy",
"vendor_autonomy_version": "12.3.2.12",
"vendor_autonomy_version_release_date": 1554227981,
"vendor_autonomy_previous_version": "12.3.2.11",
}

```

### **The Infrastructure uses its own Sensors to Monitor the Performance of AVs in its Area and Records any Deviations**

In some cases, the AVs will not know that they have a problem and they will encounter a false negative since they do not detect their own problem. Therefore, it is important that the administrative authority leverages its own infrastructure to monitor the performance of the AVs from its own perspective (its own traffic cameras, for example) and detect, save, aggregate and report any problems that it sees. An example of such monitoring is shown in FIG. 4, below.



**FIG. 4**

Due to the use of the AV beacon advertisement, the infrastructure can correlate the vehicle that advertised its beacon with the vehicle that it *observes having a problem*.

### **The Administrative Authority Evaluates the Aggregate Performance of the Different AV system Versions and Reports Problems to a Cloud Aggregator Service**

The connected vehicle infrastructure platform now has the systems in place to measure the safety problems of the AVs in its area. The connected vehicle infrastructure platform can also calculate the overall safety levels of not just the different AV vendors, but also the specific autonomous control system versions for each vendor. As such, the administrative authority can now determine when a new AV control system update is having trouble navigating the environment or experiencing some other safety problem.

#### ***Cloud Aggregator Service***

The above description has focused on the individual city-centric solution, where each administrative authority runs their own unique instance of the solution on-prem. However, a hybrid solution may include sending the data to a cloud service for additional analysis. In such examples, the cloud service can be a trusted source of AV data for administrative authorities that are looking to unlock their cities to AVs, but in a safe, smart way. For example, if a new version of Autodrive is deployed, the vehicles that pick up that new version will announce that change in their autonomous control state advertisements. Any significant problems with certain versions of AV control systems are sent to a cloud aggregator service, which then does more processing on the problems reported by other administrative authorities. Such examples may provide a better view of how different AV control system versions are working across the country.

### **Administrative Authority using a "Trusted" AV vendor to Audit their Environment Prior to Allowing all AVs**

One question that may arise is how an administrative authority can be confident that their driving environment is safe for most AVs before they allow AVs in their areas? In another use case of the techniques presented herein, before allowing all AVs to navigate the area, an administrative authority could allow only a highly-rated AV system to navigate their environment and report back any problems that are detected (e.g., bad lane-lines,

ambiguous signs, *etc.*) with their streets. For example, the cloud aggregator service could determine that the roads of Raleigh, North Carolina are very similar to Topeka, Kansas, and that Autodrive Version 3.221.12 works very well in Topeka. As such, the cloud aggregator service could indicate that Raleigh should allow vehicles of that specific version of Autodrive to operate in its environment to detect and report any problems with the infrastructure.

In summary, the techniques presented herein propose the use of a vehicle advertisement to the administrative authority (e.g., city, municipality, etc.) infrastructure. This vehicle advertisement may indicate, for example, that the AV is operating autonomously, the autonomy level, software version (neural net version) running, and/or other details. Additionally, the AVs report to the infrastructure when they detect problems due to the driving environment (which might help explain why it had trouble driving). AVs may report, for example, if they can recognize an important object (like a stop sign), but the recognition confidence is low or might become lower (due to obstruction by a tree for example). Moreover, the infrastructure uses its own sensors to monitor the performance of the AVs and records any deviations from acceptable driving behavior. The infrastructure may determine if certain versions/vendors of AVs have problems with specific roads, or time of day, etc. The infrastructure may also determine if there are certain specific roads or areas that could cause problems for AVs that need to be resolved before they allow all AVs to travel autonomously. In certain examples, the infrastructure reports observations to a central authority for sharing and aggregation with other organizations.