A Study on Data Analysis for Improving Driving Safety in Field Operational Test (FOT) of Autonomous Vehicles

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Abstract: In this study, an autonomous driving test was conducted from the perspective of FOT (field operational test). For data analysis and improvement methods, scenarios for FOT were classified and defined by considering autonomous driving level (SAE J3016) and the viewpoints of the vehicle, driver, road, environment, etc. To obtain data from FOT, performance indicators were selected, a data collection environment was implemented in the test cases, and driving roads were selected to obtain driving data from the vehicle while it was driven on an actual road. In the pilot FOT course, data were collected in various driving situations using a test vehicle, and the effect of autonomous driving-related functions on improving driving safety was studied through data analysis of discovered major events.

Keywords: autonomous vehicle; field operational test; test scenarios; data analysis

1. Introduction

As ADAS (advanced driving-assisted system) and autonomous driving-related technologies improve, projects and research on their demonstration are continuously being developed. In Europe, co-operative autonomous technology demonstrations such as Adaptive (2014–2017) [1] and DriveMe (2014–2017) [2], which provide guidelines and technology demonstrations, and in which 100 vehicles have participated, are promoted as the most advanced projects. In addition, the FESTA handbook [3] presents a methodology consisting of a V-cycle divided into FOT preparation, data acquisition, and analysis.

The major European FOT cases for autonomous driving-related demonstration are euroFOT (2008–2012) [4], FOTsis (2011–2014) [5], DriveC2X (2011–2014) [6], TeleFOT (2008–2012) [7], and the Pegasus Project (2016–2019) [8], etc. In the case of the United States, there is the PATH project (2000–2012) [9], Safety Pilot (2011–2013) [10], IVBSS (2005–2011) [11], M-city (2015) [12], etc. In Japan, there is the Woven City (2021-present) project [13]. In South Korea, there are various demonstration environments and service demonstration cases, such as K-city (2015–2017), 5G infrastructure construction projects (2020–present), and the establishment of a future car digital convergence industry demonstration platform (2021–present). In addition to self-driving-related demonstrations, research on scenarios and ODD (operational design domain) is constantly being carried out.

Regarding autonomous driving-related research, various studies are being conducted based on levels 0–5 proposed by SAE [14]. As studies on self-driving cars on SAE levels 0–2 continue, the mass production of autonomous vehicles designed to function in environments without traffic lights, such as on more remote highways, is gradually emerging.

As self-driving demonstrations and studies increase, it is necessary to study the systematic process of these research methods and, based on this, to develop an analysis method for the experimental results. In particular, autonomous driving-related accidents have continuously occurred since the operation of autonomous vehicles, and according to statistics released for California, USA, as of June 2022, 483 self-driving vehicle crashes have
been reported [15]. To improve the safety of autonomous vehicles, it is necessary to improve the autonomous driving function through demonstrations in various environments.

Throughout this study, various scenario types were classified and defined using the FOT procedure and FOT scenarios. These scenarios were evaluated through simulations and vehicle test results from studies conducted during real road driving. Finally, improvements in data analysis methods were derived. A detailed data analysis allowed us to identify cases where driver intervention occurred the most, such as due to cut-ins in front of the vehicle.

2. FOT Procedure for Autonomous Vehicles

The FOT procedure is defined as establishing the data collection environment, collecting the data while driving on the road, analyzing these data, and selecting research topics [16–18] for operation. We considered existing FOT procedures and the FOT procedure for autonomous vehicles, as shown in Table 1.

Table 1. Overall procedure of FOT for autonomous vehicles.

| No. | Process         | Description                                                                                                                                 |
|-----|-----------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Preparation     | Research questions (RQ) and hypothesis establishment, activity definition, vehicle, performance indicators (PIs) selection, data acquisition plan, scenario definition, etc. |
| 2   | Baseline settings | Define baseline data, re-establish performance metric data, acquisition criteria (measurement type/scope, resolution, sampling rate...), etc.        |
| 3   | Pilot FOT       | Modeling, simulation analysis, data collection environment, small-scale FOT implementation and data collection, preliminary data analysis (event identification), searching for key research topics for the full-scale FOT, etc. |
| 4   | Full-scale FOT  | Perform full-scale FOT, build data analysis center, collect data by multiple vehicles and drivers, build data base (DB), analyze data, etc.       |
| 5   | Detailed FOT    | Perform FOT for issues, re-run for completeness of data collection when necessary, etc.                                                        |
| 6   | Impact assessment | DB analysis, impact analysis (considering safety, efficiency, mobility, environment aspects), scale-up by statistical analysis, etc.              |

3. FOT Scenarios for Autonomous Vehicles

FOT scenarios for autonomous vehicles were constructed based on the FOT procedure described above. In total, 38 initial scenarios were defined based on a literature review, and then 84 scenarios were defined for this study, including 46 newly identified scenarios, considering the definitions of the functions and systems of test vehicles, derivation of use cases, establishment of hypotheses and research problems, and running tests. The scenarios of the driving routes were defined, and the situations of the autonomous vehicle on the road were illustrated.

The defined scenarios can be referenced to identify various events in driving situations, and some of the improved scenarios can also be used for proving the ground-based or simulation-based assessments of autonomous vehicles.

3.1. Scenario Classification

3.1.1. Criteria of Scenario Classification

Scenario classification is necessary to produce FOT scenarios. For reasonable scenarios, the objects from the driving situations (vehicle, driver) and autonomous technology (environment, road, function, level) are selected as criteria for scenario classification. The chapters below describe each criterion.
3.1.2. Scenario Classification—Vehicle

Vehicles are the principal objects found on the road and are subject to test scenarios for autonomous vehicles. Therefore, vehicles are defined as criteria for the scenario classification. A vehicle can be categorized according to two parameters: type and maneuvers. Table 2 shows the scenario classification according to the vehicle.

Table 2. Scenario classification—vehicle.

| Name                        | Value |
|-----------------------------|-------|
| Vehicle type                | Truck |
|                             | Car   |
| Collision time              | Long  |
|                             | Short |
| Distance                    | Long  |
|                             | Short |
| Level (SAE J3016)           | 0~5   |
| Velocity                    | High  |
|                             | Mid.  |
|                             | Low   |
| Vehicle maneuver (with autonomous driving) | |
| Control                     | Strong|
|                             | Normal|
|                             | Weak  |
| Headway time                | Long  |
|                             | Mid.  |
|                             | Short |
| Trigger control             | Auto  |
| Communication               | User accept |
|                             | User input |
|                             | Use    |
|                             | Unuse  |

3.1.3. Scenario Classification—Driver

A driver is also one of the most important research objects in this scenario. The driver of an autonomous vehicle has a significant effect on the results of its function and movement. Therefore, the driver is defined as one of the criteria for scenario classification. Table 3 shows the scenario classification focusing on the driver.

3.1.4. Scenario Classification—Environment

The environment is an important test object since the environment can affect a vehicle’s maneuvers. The environment is characterized by three parameters, including traffic, road, and visibility. Table 4 shows the scenario classification according to the environment.
### Table 3. Scenario classification—driver.

| Name               | Value     |
|--------------------|-----------|
| Driver qualification | Non-professional  |
|                    | Professional  |
| Driver location    | Inner           |
|                    | Outer          |
|                    | Remote         |
| Driver detection   | Necessary       |
|                    | Unnecessary     |
| Driver condition   | Focused         |
|                    | Unfocused      |
|                    | Drowsy         |
|                    | Asleep         |
| Driving possibility| No (unwell)     |
|                    | No (intoxicated)|
|                    | No (disabled)   |
|                    | Yes            |

### Table 4. Scenario classification—environment.

| Name | Value     |
|------|-----------|
| Traffic jam | Yes                  |
|         | No                   |
| Participant | Non-vehicle        |
|          | Low-speed vehicle   |
|          | High-speed vehicle  |
| Flow    | Non-density        |
|         | Low-density        |
|         | Heavy-density      |
| Type    | Highway            |
|         | Urban road         |
|         | Speed limit area   |
|         | Parking area       |
| Condition | Normal          |
|          | Slip               |
|          | Uneven             |
| Road    | Straight           |
| Geometry | Curve             |
|         | Steep              |
|         | Tollgate           |
|         | Lane               |
|         | Guard rail         |
|         | Emergency lane     |
|         | Traffic sign       |
|         | Traffic light      |
| Infra.  | Vehicle           |
|         | Infra.             |
| Obstacles | Fog             |
| Visibility | Weather  |
|           | Rain             |
|           | Snow             |
3.1.5. Scenario Classification—Road

Roads are an impact factor for vehicle tests. Roads affect vehicle motion through their various conditions. Roads in South Korea can be categorized into seven types: highway, urban road, interchange, construction zone, rural road, and parking area. Each road type has different conditions across two categories of infrastructure and non-infrastructure. With these two categories, Tables 5 and 6 show the scenario classification focusing on the road.

Table 5. Scenario classification—road (infrastructure).

| Road          | Traffic Light | Guardrail | Emergency Lane | Lane Mark |
|--------------|--------------|-----------|----------------|-----------|
| Highway      | X            |           | ○              | ○         |
| Urban road   | ○            | X         | X              | ○         |
| Interchange  | X            | ○         | △              | ○         |
| Intersection | ○            | X         | X              | ○         |
| Construction zone | △  | ○      | X              | X         |
| Rural road   | X            | X         | X              | △         |
| Parking area | X            | X         | X              | X         |

○: relevant. X: not relevant. △: may or may not be related.

Table 6. Scenario classification—road (non-infrastructure).

| Road          | Speed     | Curve   | Pedestrians/Obstacles | Mixed Traffic |
|--------------|-----------|---------|-----------------------|---------------|
| Highway      | High      | Mid./Low| Low                   | ○             |
| Urban road   | Mid.      | Mid./Low| High                  | ○             |
| Interchange  | High      | High    | Low                   | ○             |
| Intersection | Mid./Low  | High    | High                  | ○             |
| Construction zone | High/Mid./Low | High/Mid./Low | High | ○ |
| Rural road   | Mid./Low  | Mid./Low| Low                   | X             |
| Parking area | Low       | -       | High                  | X             |

○: relevant. X: not relevant.

3.1.6. Scenario Classification—Function

Function refers to autonomous vehicle techniques using an advanced driving-assisted system (ADAS). Functions can be defined according to an autonomous level from 1 to 5 (SAE standard). The functions have different actions or stop conditions, and the categories are separated by six conditions, such as road, distance, speed, trigger, driver location, and vehicle. Table 7 shows the organization of these functions.

Table 7. Scenario classification—function.

| Function                        | Level | Road          | Distance | Speed | Trigger     | Driver Location | Vehicle     |
|---------------------------------|-------|---------------|----------|-------|-------------|-----------------|-------------|
| Cruise Control                  | 1     | Highway, Urban Road | Long     | High  | User Input  | Inner           | Car, Truck  |
| Adaptive Cruise Control (ACC)   | 1     | Highway, Urban Road | Long     | High  | User Input  | Inner           | Car, Truck  |
| Lane Keeping Assistance (LKA)   | 1     | Highway, Urban Road | Long     | High  | User Input  | Inner           | Car, Truck  |
Table 7. Cont.

| Function                        | Level | Road                          | Distance | Speed | Trigger  | Driver Location | Vehicle         |
|---------------------------------|-------|-------------------------------|----------|-------|----------|-----------------|-----------------|
| Lane Change Assistance (LCA)    | 1     | Highway, Urban Road           | Short    | High  | User Input| Inner           | Car, Truck      |
| Combined ACC and LKA            | 2     | Highway, Urban Road           | Long     | High  | User Input| Inner           | Car, Truck      |
| Narrowing Assistance            | 2     | Rural Road, Parking Area      | Long     | Mid.  | User Input| Inner           | Car, Truck      |
| Highway Assistance              | 2     | Highway, Urban Road           | Long     | High  | User Input| Inner           | Car, Truck      |
| Parking Assistance - Steering   | 2     | Parking Area                  | Short    | Low   | User Input| Inner           | Car             |
| Active Traffic Light Assistance | 3     | Urban Road                    | Short    | Mid.  | User Input| Inner           | Car, Truck      |
| Construction Site Assistance    | 3     | Construction Zone             | Long     | Mid.  | User Input| Inner           | Car, Truck      |
| Overtaking Assistance           | 3     | Highway, Urban Road           | Short    | High  | User Input| Inner           | Car, Truck      |
| Traffic Jam Assistance          | 3     | Highway, Urban Road           | Long     | Mid.  | User Input| Inner           | Car, Truck      |
| Parking Assistance - Steering and Pedal | 3 | Parking Area                  | Short    | Low   | User Input| Inner           | Car             |
| Platooning                      | 4     | Highway                       | Long     | High  | User Input| Outer           | Car, Truck      |
| Remote Parking                  | 4     | Parking Area                  | Short    | Low   | User Input| Remote          | Car, Truck      |
| Highway Autonomous Pilot        | 4     | Highway                       | Long     | High  | User Input| Outer           | Car, Truck      |
| Overtaking Autonomous Pilot     | 4     | Highway                       | Short    | High  | Auto     | Outer           | Car, Truck      |
| Traffic Jam Autonomous Pilot    | 4     | Highway                       | Long     | Mid.  | User Input| Outer           | Car, Truck      |
| Autonomous Parking              | 5     | Parking Area                  | Long     | Low   | User Input| -               | Car             |
| Robot Taxi                      | 5     | Everywhere                   | Long     | Mid.  | Auto     | -               | Car             |
| Autonomous Mining Vehicle       | 5     | Everywhere                   | Long     | Mid.  | Auto     | -               | Truck           |
| Autonomous Truck                | 5     | Everywhere                   | Long     | Low   | Auto     | -               | Truck           |

3.1.7. Scenario Classification—Level

Currently, SAE J3016 is considered the standard for studying autonomous driving levels. Figure 1 illustrates the concept of SAE autonomy levels.

![Figure 1. SAE autonomous level.](image_url)
The level can be separated into several categories, including level grade (1–5), speed (low, middle, high), road (parking area, rural road, etc.), and function (ACC, LKA, etc.). Table 8 shows the organization of each level.

| Level | Low Speed | Mid. Speed | High Speed |
|-------|-----------|------------|------------|
| Lv.1  | Road      | -          | -          | Highway, Urban Road |
|       | Function  | -          | -          | ACC, LKA |
| Lv.2  | Road      | Parking Area | Rural Road | Combined ACC and LKA, Highway Assistance |
|       | Function  | Parking Assistance | Narrowing Assistance | |
| Lv.3  | Road      | Parking Area | Urban Road | Highway, Urban Road |
|       | Function  | Parking Assistance - Steering and Pedal | Active Traffic Light Assistance, Construction Site Assistance, Active Traffic Jam Driving | Active Overtaking Driving, Active Highway Driving |
| Lv.4  | Road      | Parking Area | Urban Road | Overtaking Autonomous Pilot, Highway Autonomous Pilot, Platooning |
|       | Function  | Remote Parking | Traffic Jam, Autonomous Pilot | |
| Lv.5  | Road      | Parking Area | Everywhere | Autonomous Parking |
|       | Function  | Autonomous Parking | Robot Taxi, Autonomous Mining Vehicle and Truck | |

3.2. Scenario Selection

3.2.1. Criteria for Scenario Selection

The FOT scenarios are defined and constructed following scenario classification. Regarding safety, the road is an important condition for selecting the corresponding scenario. Therefore, three criteria were selected: straight, curve, and tunnel. The chapters below describe the three criteria in greater detail regarding the scenario selection.

3.2.2. Scenario Selection—Straight

For a straight road, there are many scenarios that take into account various situations and objects that can be detected. A total of twenty-four cases are introduced for a straight road. To organize these cases, five categories are used: keeping distance, detection, alarm, manage, and lane change. Keeping distance has one case: vehicle-to-vehicle. Detection has eleven cases: danger factor, traffic light, lane mark, slow lane mark, bus lane mark, non-stop tollgate entrance, highway entrance, shoulder lane, road bump, changeable road, and traffic sign. For alarm, there are two cases: emergency situation and unmovable situation. For manage, there is one case: harsh weather conditions (blizzard, heavy fog, etc.). For lane change, there are nine cases: front vehicle moving into object lane, front vehicle moving into a different lane, existing front vehicle in the object lane, existing front vehicle and oncoming side vehicle, rear vehicle moving into object lane, side vehicle moving into current lane, other lane vehicle moving into object lane, and traffic jam. Table 9 organizes each of the cases for a straight road.
Table 9. Scenario selection—straight.

| Category               | Case                                  |
|------------------------|---------------------------------------|
| Keeping distance       | Vehicle-to-vehicle                     |
|                        | Dangerous factor                       |
|                        | Traffic light                          |
|                        | Lane mark                              |
|                        | Slow lane mark                         |
|                        | Bus lane mark                          |
|                        | Non-stop tollgate entrance             |
|                        | Highway entrance                       |
|                        | Shoulder lane                          |
|                        | Road bump                              |
|                        | Changeable road                        |
|                        | Traffic sign                           |
| Detection              |                                      |
|                        |                                      |
| Alarm                  | Emergency stop situation               |
|                        | Unmovable situation                    |
|                        | Harsh weather conditions (blizzard, heavy fog, etc.) |
|                        | The front vehicle moving into object lane |
|                        | The front vehicle moving into different lane |
|                        | Existing front vehicle in object lane  |
|                        | Existing front vehicle and side vehicle |
|                        | Existing front vehicle and oncoming side vehicle |
|                        | The rear vehicle moving into object lane |
|                        | The side vehicle moving into current lane |
|                        | The other lane vehicle moving into object lane |
| Manage                 |                                      |
|                        |                                      |
|                        | Traffic jam                            |

3.2.3. Scenario Selection—Curve

On a curved road, there are many scenarios when considering numerous situations and object detection. For a curved road situation, a lane change is not possible. Except for the lane change situation, there are a total of seven cases for a curved road. Four categories are used to organize these cases: keeping distance, detection, alarm, and manage. For keeping distance, there is one case: vehicle-to-vehicle. For detection, there are two cases: dangerous factors and lane marks. For the alarm, there are three cases: emergency stop situation, danger factor, and unmovable situation. For manage, there is one case: harsh weather conditions (blizzard, heavy fog, etc.). Table 10 organizes each of the cases for the curved road.
### 3.2.4. Scenario Selection—Tunnel

For a tunnel road, there are many scenarios considering various situations and objects. Since lane change and communication are impossible on a tunnel road, there are a total of seven cases. Three categories are used to separate these cases: keeping distance, detection, and alarm. For keeping distance, there is one case: vehicle-to-vehicle. In detection, there are three cases: danger factor, lane mark, and shoulder lane. For alarm, there are three cases: emergency stop situation, danger factor, and unmovable situation. Table 11 presents each case for a tunnel.

### Table 11. Scenario selection—tunnel.

| Category      | Case                                |
|---------------|-------------------------------------|
| Keeping distance | Vehicle-to-vehicle                     |
|                | Dangerous factor                      |
| Detection      | Lane mark                             |
|                | Emergency stop situation              |
| Alarm          | Dangerous factor                      |
|                | Unmovable situation                   |
| Manage         | Harsh weather conditions (blizzard, heavy fog, etc.) |

### 4. Selection of Performance Indicators (PIs)

Performance indicators are quantitative or qualitative indicators derived from one or several measures that are agreed upon beforehand, and these are expressed as a percentage, index, rate, or another value, monitored at regular or irregular intervals, and which can be compared to one or more criterion. For this study, several PIs related to vehicle safety were selected for the pilot FOT, as shown in Table 12, including information on the distance from the preceding vehicle and the brake and steering wheel operation information, to confirm whether the driver is involved in the automatic operation.

### Table 12. Parts of PIs for safety assessment of the pilot FOT.

| PI        | Unit      | Description                                           |
|-----------|-----------|-------------------------------------------------------|
| Brake_Act | 0/1       | Brake operation by the driver                         |
| Steer_Ang | deg.      | Steering angle                                        |
| MDPS_Tq   | Nm        | MDPS torque                                           |
| Vehicle_Spd | km/h   | Vehicle speed                                         |
| ACC_Obj_Dist | m   | Front object longitudinal distance                    |
| ACC_Obj_Rel_Spd | km/h | Front object longitudinal relative speed               |
| Obstacle_Pos_X | m  | Front object longitudinal distance (Mobileye)         |
| Obstacle_Rel_Vel_X | km/h | Front object longitudinal relative speed (Mobileye)  |
5. Implementation of Data Acquisition Environment

To obtain autonomous driving FOT data, a vehicle that had level 2 autonomous functions such as ACC, LKAS, and HDA (highway driving assistance) was used. Additionally, the vehicle had a license for Korea autonomous driving level 2. The functions of autonomous driving are manufactured by OEM. We implemented a data acquisition environment on the test vehicle to collect vehicle behavior information including PIs during the pilot FOT and environmental data both inside and outside the vehicle. Therefore, we applied a multi-sensor environment to the vehicle, including Mobileye, radar, laser scanner, GPS/GNSS receiver, multi-channel video cameras, and DAS (Data Acquisition System) [19]. The sensors were only used for gathering data, not autonomous functions. Figure 2 shows the data acquisition environment of the autonomous vehicle for FOT.

![Implementation of data acquisition environment](image)

**Figure 2.** Implementation of data acquisition environment.

6. Selection of the Driving Routes

We selected the routes for data acquisition, which included Korea’s national highways, expressways, and city roads. In selecting these routes, we considered the area covered by the digital maps provided by the National Geographic Information Institute (NGII) of Korea. The traffic accident points of the past two years were also included in the driving routes referring to Traffic Accident Analysis System (TAAS) data in Korea. This was carried out to simulate various driving situations at points where fatal traffic accidents occurred before testing the vehicles on actual roads to predict how the autonomous driving functions would work at such points.

Figure 3 shows a sample set of the driving route-making factors and simulation results. The driving route considers the map information, simulation environment, scenario, and previous simulation results. By using Prescan, which is a tool for autonomous driving simulation, the driving route was developed and simulated. By using the result of simulating driving situations, the area of autonomous driving was created.

![Selection of driving routes and simulating driving situations](image)

**Figure 3.** Selection of driving routes and simulating driving situations.
7. Test

7.1. Test Purpose

The main purpose of this test is to examine the entire process for data acquisition through the pilot FOT and figure out what is needed to develop autonomous driving technology. We can also automate parts of the data analysis process to prepare for a larger data collection in a full-scale FOT. It is also possible to analyze the data acquired at the pilot FOT stage to predict the outcome of a full-scale FOT at a relatively lower cost in a shorter time frame. Therefore, we prepared Section 5 (implementation of data acquisition environment) and Section 6 (selection of the driving routes) to test the pilot FOT.

Approximately 3000 km of driving data of domestic highways, expressways, and city roads were collected for autonomous driving modes, such as ACC, LKAS, and HDA. Among these data, 701 events were classified, and the elements classified in Section 3 were used to analyze the classification. In the 701 events, only 32 anomalous events occurred regarding situations of misuse, such as tailgating the vehicle in front and driving in the wrong lane. Table 13 shows the number and types of events where the driver intervened during the autonomous driving operation [20,21].

Table 13. Number of events—driver intervened during the autonomous driving functions operation.

| Event                                      | Driver Intervention |
|--------------------------------------------|---------------------|
| Front vehicle not recognized               | 23                  |
| Front vehicle recognition delay            | 5                   |
| Unstable lane keeping                      | 4                   |
| Total                                       | 32                  |

7.2. Identification of Events

Among the identified events, there were 32 driver interventions (brake or steering by the driver). The number of driver interventions for front-vehicle-recognition-related situations was 28, accounting for 87.5% of driver interventions. The number of steering interventions from drivers due to unstable lane keeping maneuvers was 4 and accounted for 12.5% of driver interventions.

To identify safety-related events of the pilot FOT phase, we conducted a preliminary data analysis by comparing the collected data of the DAS, including video data and scenarios. We even referred to the notes written by a passenger on a laptop computer while driving. An important criterion for identifying risk and incidents in a preliminary data analysis is whether the driver engaged the brake or steering wheel during autonomous driving. Table 14 shows typical cases among events involving the driver during an autonomous driving operation. Cases 1 through 4 are related to the front vehicle detection performance, and cases 5 and 6 are related to the lane detection performance.

Table 14. Key situations in which the driver intervened among the identified events.

| Case | Description                              | Conditions                          | Driving Situation            |
|------|------------------------------------------|-------------------------------------|-----------------------------|
| 1    | Delayed recognition of front cut-in vehicle | ACC on, LKAS on, HDA on, (straight road) | ![Image](image1.png) |
| 2    | Delayed recognition of front vehicle     | ACC on, LKAS on, HDA on, (curved road) | ![Image](image2.png) |
Table 14. Cont.

| Case | Description                          | Conditions                                      | Driving Situation |
|------|--------------------------------------|-------------------------------------------------|-------------------|
| 3    | Delayed recognition of forward stop vehicle | ACC on,                                        | ![Image](image1.png) |
|      |                                      | LKAS on,                                        |                   |
|      |                                      | HDA off,                                        |                   |
|      |                                      | (downhill after uphill)                         |                   |
| 4    | Failed recognition of another forward stop vehicle after forward vehicle cut-out | ACC on,                                        | ![Image](image2.png) |
|      |                                      | LKAS on,                                        |                   |
|      |                                      | HDA off,                                        |                   |
|      |                                      | (curved downhill)                               |                   |
| 5    | Lane recognition error in branch path | ACC on,                                        | ![Image](image3.png) |
|      |                                      | LKAS on,                                        |                   |
|      |                                      | HDA on,                                        |                   |
|      |                                      | (branch road)                                   |                   |
| 6    | Lane recognition error in construction section | ACC on,                                        | ![Image](image4.png) |
|      |                                      | LKAS on,                                        |                   |
|      |                                      | HDA on,                                        |                   |
|      |                                      | (construction section)                          |                   |

8. Result and Analysis

Case 1 is the delayed recognition of a front cut-in vehicle with a straight highway road, and the ego vehicle’s condition is ACC, LKAS, and HDA being on. In other words, case 1 shows that when a forward vehicle cuts in, particularly when only a part of the forward vehicle enters the lane of the test vehicle (ego vehicle), the ego vehicle is late in detecting the preceding vehicle. As shown in Figure 4, even if the ego vehicle senses the front vehicle, the driver senses the danger first and activates the brake. In addition, the additional sensor (Mobileye) attached for this test detects the front vehicle earlier than the original radar sensor equipped by the vehicle manufacturer.

![Image](image5.png)

**Figure 4.** Preliminary data analysis for case 1.

Case 2 is the delayed recognition of a front vehicle on a curved highway road, and the ego vehicle’s condition is ACC, LKAS, and HDA being on. In other words, case 2 shows that when a forward vehicle is far away in the same lane, the ego vehicle recognizes the front vehicle late. The reason for this was that the curvature of the road was very high. Therefore, it was difficult to determine if the front vehicle was in the same lane. The data
of the ego vehicle’s operation and its delayed detection of the front vehicle are shown in Figure 5.

![Figure 5](image1.png)

Figure 5. Preliminary data analysis for case 2.

Case 3 is the delayed recognition of the forward vehicle stopping while traveling downhill after traveling on an uphill road, and the ego vehicle’s condition is ACC and LKAS being on. In other words, case 3 shows that when the ego vehicle was moving uphill or downhill on a slope with a steep gradient, the angle and range of the sensors in the ego vehicle were limited. Therefore, the front vehicle in the same lane was detected late and the driver applied the brakes to safely stop the vehicle. The data of the ego vehicle’s operation and delayed detection of the front vehicle are shown in Figure 6.

![Figure 6](image2.png)

Figure 6. Preliminary data analysis for case 3.

Case 4 is the failed recognition of another forward vehicle stopping after it cuts out on a curved road while traveling downhill, and the ego vehicle’s condition is ACC and LKAS being on. In other words, case 4 shows that when the ego vehicle was moving downhill along a very curved road, the front vehicle moved adjacent to the ego vehicle, in front of which was another vehicle. However, because of the driving situation (high curve and steep downhill slope), the indication performance of the ego vehicle was lower than the normal situation. Therefore, the ego vehicle could not detect another front vehicle and
the driver controlled the vehicle movement. The data of the ego vehicle’s operation and inability to detect the front vehicle are shown in Figure 7.

Figure 7. Preliminary data analysis for case 4.

Case 5 is the lane recognition error in the branch path, and the ego vehicle’s condition is ACC, LKAS, and HDA being on. In other words, case 5 occurs when the ego vehicle is moving through a junction on the road where one branch lane is created as an alternative route, and the lane of the ego vehicle misunderstands the line of the branch lane as the driving lane. Therefore, the ego vehicle travels on the line between the two lanes. The data of the ego vehicle’s operation and its unusual movements are shown in Figure 8.

Figure 8. Preliminary data analysis for case 5.

Case 6 is the lane recognition error when traveling through a construction site, and the ego vehicle’s condition is ACC, LKAS, and HDA being on. In other words, case 6 shows that when the ego vehicle is moving through a construction section of the road, the ego vehicle misunderstood the road lane because the white color of the road on the construction site is similar to the color of cement. Therefore, the ego vehicle changed lanes between the normal road and construction site road. The data of the ego vehicle’s operation and its unusual movements are shown in Figure 9.
9. Discussion and Conclusions

With the results of event situations that occurred in the FOT of the autonomous vehicle (with autonomous level 2) to classify and define various scenario types through simulations and actual vehicle tests, the FOT procedure for autonomous vehicles is shown below:

(1) FOT scenarios for autonomous vehicles;
(2) Selection of PIs;
(3) Implementation of data acquisition environment;
(4) Selection of the driving routes;
(5) Test;
(6) Result and analysis.

From the result and analysis, autonomous functions did not operate well in some events. In this study, it is proposed that some additional parameters be added to the existing control input parameters to ensure the safe operation of autonomous vehicles.

\[ y = F(x, a_z, \text{Map}) \]

where

- \( y \) = control result
- \( x \) = ordinary parameters (ex : object speed)
- \( a_z \) = acceleration of \( z \) - axis
- \( \text{Map} \) = domestic high definition map information

\( y \) is the result of the autonomous vehicle control; \( x \) is the ordinary control parameters, such as object information (e.g., speed, velocity, classification, etc.) of sensor detection,
local information from a GPS, vehicle information (e.g., speed, steering angle, etc.); $a_z$ is the acceleration of the $z$-axis, which is used to accelerate the autonomous vehicle on a slope. Map is domestic high-definition map information, including lane information, cross-road information, etc. As Map is included as a variable in the formula, it is possible to reduce the effect of malfunctions caused by vehicles in other lanes because the autonomous vehicle accurately recognizes information regarding its own lane.

By using $a_z$ as the control parameter, the autonomous vehicle can move more safely in case 3 (downhill after uphill situation) and 4 (curved downhill situation) events. Additionally, by using Map as the control parameter, the autonomous vehicle can detect the objects in front of it and different lanes on the roads, as demonstrated in case 2 (curved road situation), case 5 (branch road situation), and case 6 (construction section) events.

As a result of this procedure, control methods for autonomous vehicles encountering various events on a slope will be studied in the future. In addition, we plan to study the development of autonomous driving functions using V2X infrastructure information to support autonomous driving functions in dangerous and malfunctioning events. Tables 15 and 16 show the V2X infrastructure list and scenario examples.

Table 15. V2X infrastructure list.

| No. | Name          | Description                              |
|-----|---------------|------------------------------------------|
| 1   | RSU           | Road side unit                           |
| 2   | TSC           | Traffic signal controller                 |
| 3   | AIDS          | Automatic incident detection system       |
| 4   | RWIS          | Road weather information system           |
| 5   | DGPS          | Differential global positioning system    |
| 6   | LIS           | Lidar infrastructure system              |

Table 16. V2X scenario examples.

| Case | Description                  | Driving Situation                                      |
|------|------------------------------|--------------------------------------------------------|
| 1    | Cross road—right turn        | ![Diagram of a cross road](image)                     |
| 2    | Cross road—odd cyclical signal| ![Diagram of a cross road](image)                     |

**Author Contributions:** Writing—original draft preparation, S.-S.S.; writing—review and editing, S.-S.S., H.-J.K. and S.-J.K.; visualization, S.-S.S.; supervision, S.-J.K.; project administration, S.-J.K.; funding acquisition, S.-J.K. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the Korea Institute for Advancement of Technology (KIAT) and funded by the Ministry of Trade, Industry and Energy (MOTIE) of the Korean Government (No. P0013840).

**Conflicts of Interest:** The authors declare no conflict of interest.
References

1. Adaptive Project. Available online: https://www.adaptive-ip.eu (accessed on 28 June 2022).
2. Hansson, L. Regulatory governance in emerging technologies: The case of autonomous vehicles in Sweden and Norway. Res. Transp. Econ. 2020, 83, 100967. [CrossRef]
3. FESTA Handbook. Available online: http://fot-net.eu (accessed on 28 June 2022).
4. EuroFOT. Available online: https://www.eurofot-ip.eu/ (accessed on 28 June 2022).
5. FOTsis. Available online: https://wiki.fot-net.eu/index.php/FOTsis (accessed on 28 June 2022).
6. DriveC2X. Available online: https://wiki.fot-net.eu/index.php/DRIVE_C2X (accessed on 28 June 2022).
7. TeleFOT. Available online: https://wiki.fot-net.eu/index.php/TeleFOT (accessed on 28 June 2022).
8. Pegasus Project. Available online: https://www.pegasusprojekt.de/en/home (accessed on 28 June 2022).
9. PATH Project. Available online: https://path.berkeley.edu/ (accessed on 28 June 2022).
10. U.S. Department of Transportation. Safety Pilot Model Deployment: Test Conductor Team Report; DOT HS 812 171; U.S. Department of Transportation: Washington, DC, USA, 2015.
11. IVBSS. Available online: https://wiki.fot-net.eu/index.php/IVBSS (accessed on 28 June 2022).
12. M-City. Available online: https://mcity.umich.edu/ (accessed on 28 June 2022).
13. Woven City. Available online: https://www.woven-city.global/ (accessed on 28 June 2022).
14. J3016_202104; Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. SAE: Warrendale, PA, USA, 2014.
15. Autonomous Vehicle Collision Reports (State of California). Available online: https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-collision-reports/ (accessed on 28 June 2022).
16. Yoshida, T.; Kuroda, H.; Nishigaito, T. Adaptive Driver-assistance Systems. Hitachi Rev. 2004, 53, 213.
17. Kang, H.; Kwon, S. An Investigation on FOT Trends and a Suggestion of FOT Methodology for Autonomous Vehicle. In Proceedings of the KSME Annual Conference (Spring), Daegu, Korea, 20 May 2016.
18. Barnard, Y.; Innamaa, S.; Koskinen, S.; Gellerman, H.; Svanberg, E.; Chen, H. Methodology for Field Operational Tests of Autonomous Vehicles. Transp. Res. Procedia 2016, 14, 2188–2196. [CrossRef]
19. Kang, H.; Kim, B.; Kwon, S. A Study on Methodology for Field Operational Tests of Autonomous Vehicles Applying FESTA Methodology. In Proceedings of the KSME Annual Conference (Spring), Daegu, Korea, 16–19 November 2016.
20. Kang, H.; Shin, S.; Jang, K.; Kwon, S. A Study on Pilot FOTs for Safety Evaluation of Autonomous Vehicle. In Proceedings of the KSME Annual Conference (Autumn), Yeosu, Korea, 9–11 February 2017.
21. Shin, S.-S.; Kang, H.-J.; Kwon, S.-J.; Lee, B.-H. A Study on the FOT (Field Operational Test) Scenarios for Proving Safety of Autonomous Vehicles. In Proceedings of the JSME Annual Congress (Spring), Yokohama, Japan, 24–26 May 2017.