

## Article

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

Seok-San Shin, Ho-Joon Kang and Seong-Jin Kwon \* 

Vehicle Safety R&D Center, Korea Automotive Technology Institute (KATECH), 201, Gukgasandanse-ro, Guji-myeon, Dalseong-gun, Daegu 43011, Korea

\* Correspondence: sjkwon@katech.re.kr; Tel.: +82-53-719-7831

**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



**Citation:** Shin, S.-S.; Kang, H.-J.; Kwon, S.-J. A Study on Data Analysis for Improving Driving Safety in Field Operational Test (FOT) of Autonomous Vehicles. *Machines* **2022**, *10*, 784. <https://doi.org/10.3390/machines10090784>

Academic Editors: Shuai Li, Dechao Chen, Mohammed Aquil Mirza, Vasilios N. Katsikis, Dunhui Xiao and Predrag Stanimirović

Received: 26 July 2022

Accepted: 5 September 2022

Published: 7 September 2022

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Copyright:** © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

## 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 euro-FOT (2008–2012) [4], FOTs (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
Vehicle maneuver (with autonomous driving)	Collision time	Long
		Short
	Distance	Long
		Short
	Level (SAE J3016)	0~5
	Velocity	High
		Mid.
		Low
	Control	Strong
		Normal
		Weak
	Headway time	Long
		Mid.
		Short
	Trigger control	Auto
		User accept
		User input
	Communication	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	Traffic jam	Yes
		No
	Participant	Non-vehicle
		Low-speed vehicle
		High-speed vehicle
	Flow	Non-density
		Low-density
		Heavy-density
	Road	Type
Urban road		
Speed limit area		
Parking area		
Condition		Normal
		Slip
		Uneven
Geometry		Straight
		Curve
		Steep
Infra.		Tollgate
		Lane
		Guard rail
		Emergency lane
		Traffic sign
	Traffic light	
Visibility	Obstacles	Vehicle
		Infra.
	Weather	Fog
		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	Infrastructure			
	Traffic Light	Guardrail	Emergency Lane	Lane Mark
Highway	X	○	○	○
Urban road	○	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	Non-Infrastructure			
	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
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.

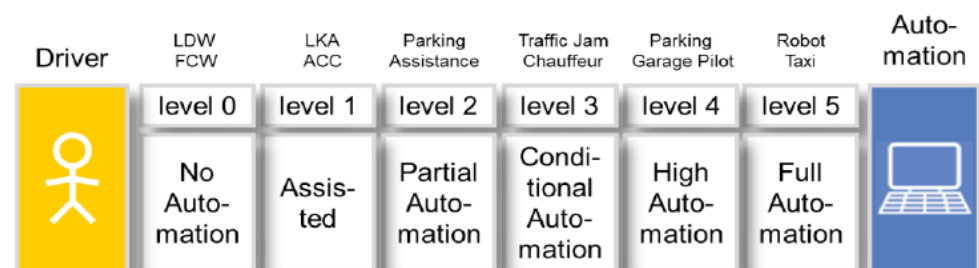


Figure 1. SAE autonomous level.

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.

**Table 8.** Scenario classification—level.

Level		Low Speed	Mid. Speed	High Speed
Lv.1	Road	-	-	Highway, Urban Road
	Function	-	-	ACC, LKA
Lv.2	Road	Parking Area	Rural Road	Highway, Urban Road
	Function	Parking Assistance -Steering	Narrowing Assistance	Combined ACC and LKA, Highway 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	Highway, Urban Road
	Function	Remote Parking	Traffic Jam, Autonomous Pilot	Overtaking Autonomous Pilot, Highway Autonomous Pilot, Platooning
Lv.5	Road	Parking Area	Everywhere	
	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
Detection	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
Alarm	Emergency stop situation
	Unmovable situation
Manage	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
	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.



**Table 10.** Scenario selection—curve.

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

### 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
Detection	Dangerous factor
	Lane mark
	Shoulder lane
Alarm	Emergency stop situation
	Dangerous factor
	Unmovable situation

## 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.

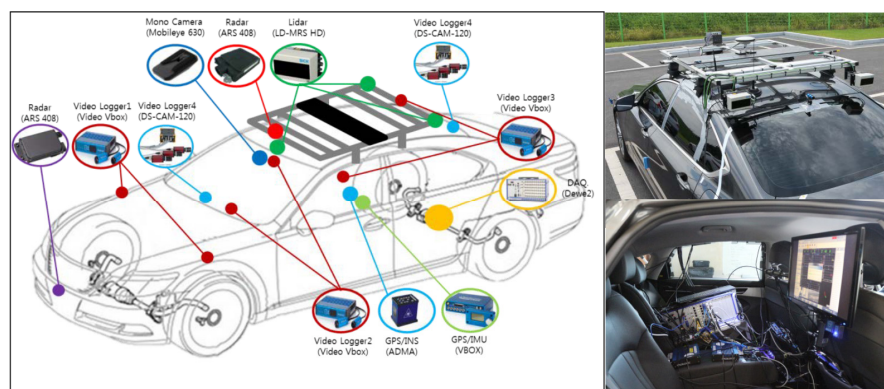


Figure 2. Implementation of data acquisition environment.

## 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.

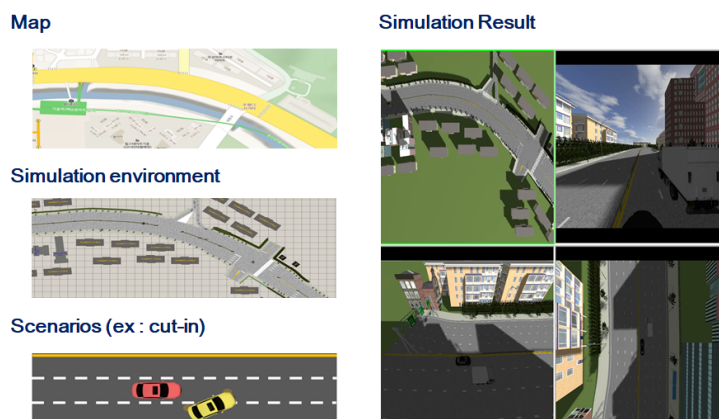


Figure 3. Selection of driving routes and simulating driving situations.

## 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)	
2	Delayed recognition of front vehicle	ACC on, LKAS on, HDA on, (curved road)	

Table 14. Cont.

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

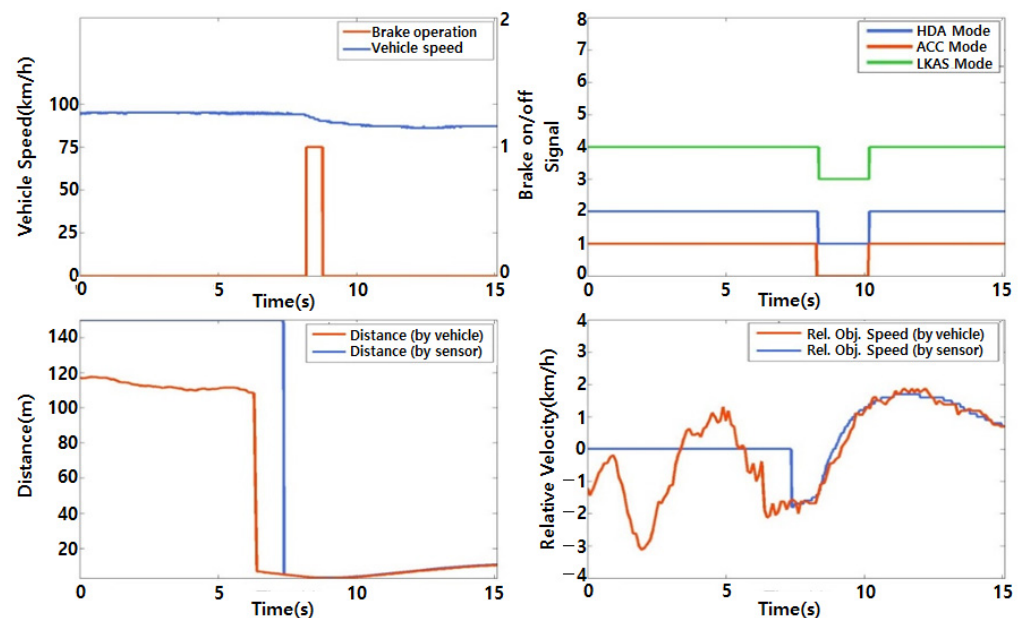


Figure 4. Preliminary data analysis for case 1.

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.

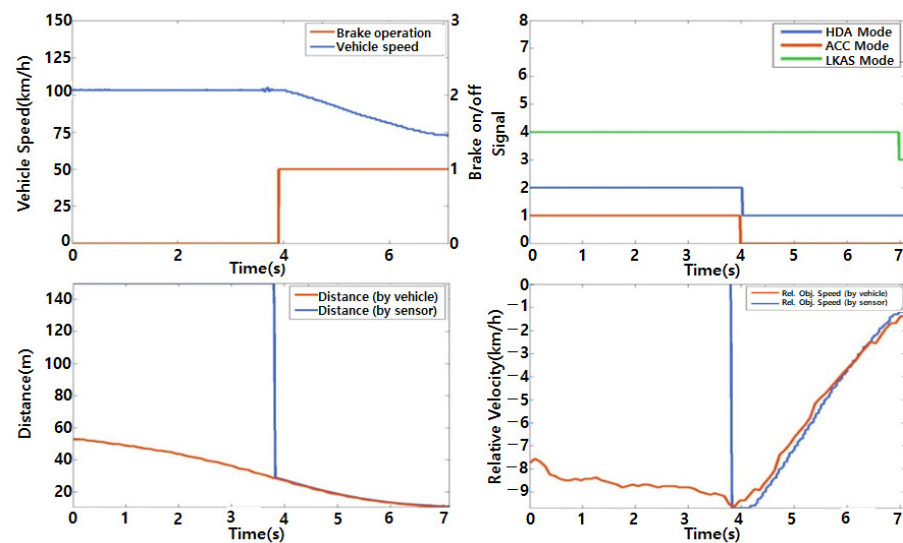


Figure 5. Preliminary data analysis for case 2.

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.

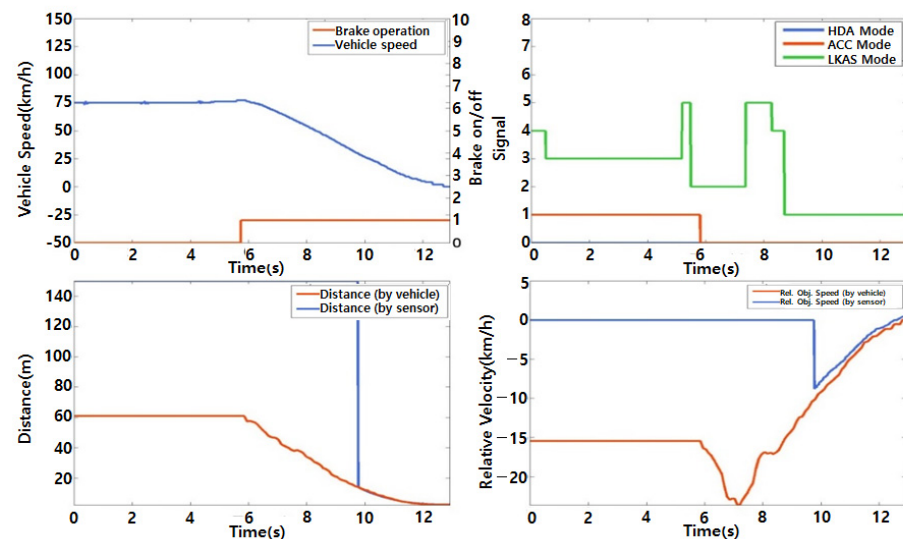


Figure 6. Preliminary data analysis for case 3.

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.

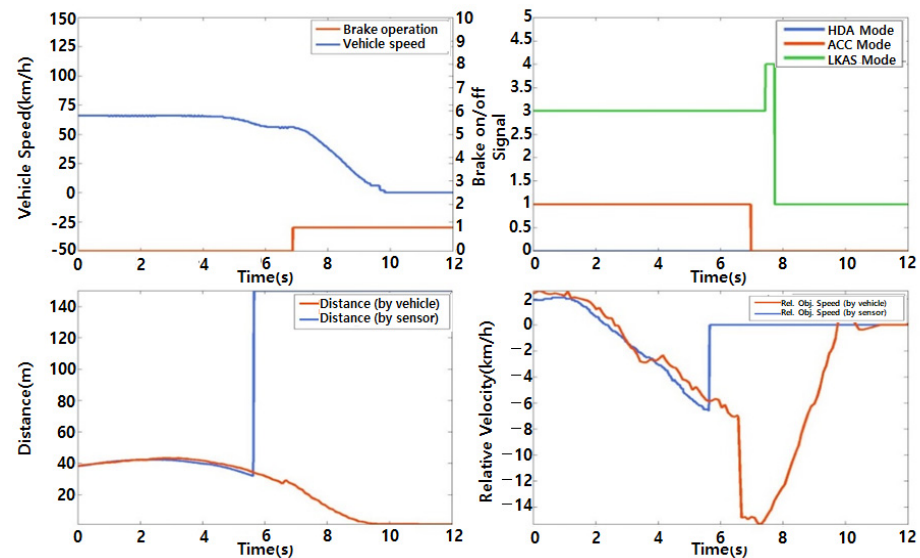


Figure 7. Preliminary data analysis for case 4.

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.

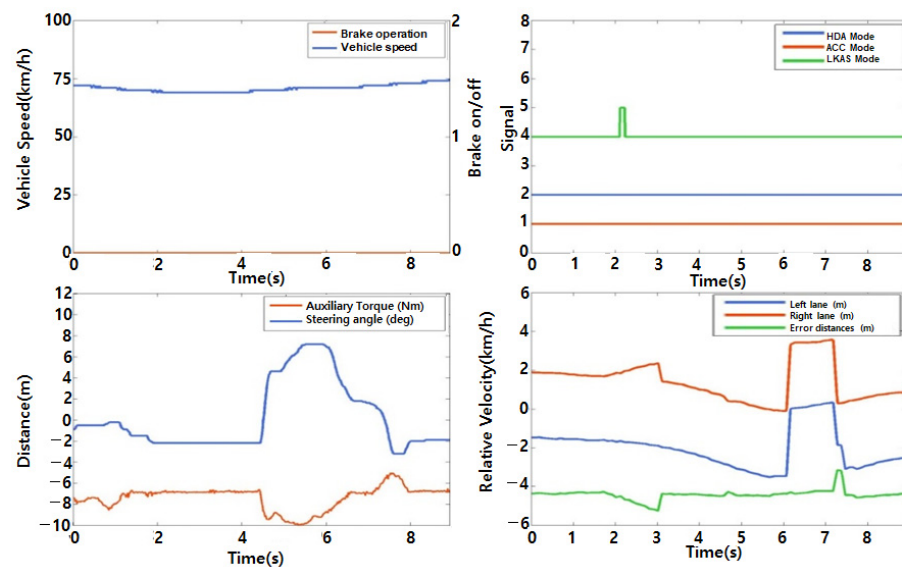
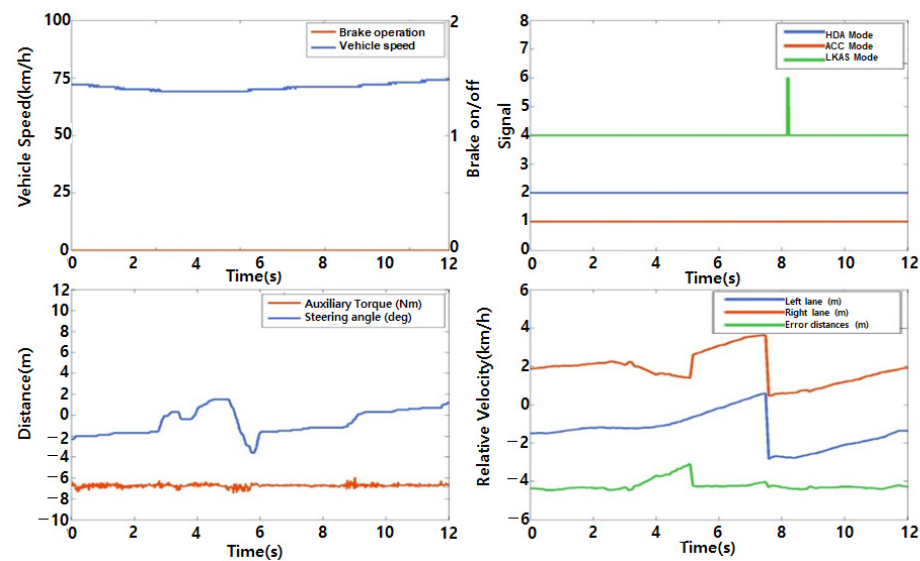


Figure 8. Preliminary data analysis for case 5.

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.



**Figure 9.** Preliminary data analysis for case 6.

The results of the analysis for the events in cases 1 to 6 confirmed that the autonomous vehicle's object and lane recognition accuracy was slower or more inaccurate than a driver's recognition accuracy depending on the slope inclination. In order to improve the recognition accuracy, information on the driving route can be obtained in advance through V2X with the corresponding infrastructure installed on the road. Additionally, an autonomous vehicle can recognize a slope through a slope value obtained from a map that includes precise information on the slope of roads. It was deemed necessary to check the possible distance and configure the controller for the autonomous vehicle so that the autonomous vehicle could safely operate.

## 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

$$y = \text{control result}$$

$$x = \text{ordinary parameters (ex : object speed)}$$

$$a_z = \text{acceleration of } z - \text{axis}$$

$$\text{Map} = \text{domestic high definition map information}$$

$y$  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.

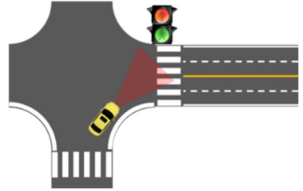
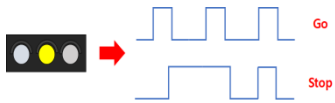
By using  $a_z$  as the control parameter, the autonomous vehicle can move more safely in case 3 (downhill after uphill situation) and 4 (curved downhill situation) events. Additionally, by using Map as the control parameter, the autonomous vehicle can detect the objects in front of it and different 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	
2	Cross road—odd cyclical signal	

**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](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 KSAE 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 KSAE Annual Conference (Autumn), 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 KSAE 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 JSAE Annual Congress (Spring), Yokohama, Japan, 24–26 May 2017.