DEVELOPMENT AND IMPLEMENTATION OF SAFETY EVALUATION SCENARIOS FOR AUTOMATED DRIVING VEHICLES ON TEST BED

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ABSTRACT

Regulation for the testing and operation of automated driving vehicles on public roadways has been recently developed all over the world. For example, the licensing standards and the evaluation technology for automated driving vehicles have been proposed in California, Nevada and EU. Like M-city, the test bed has been developed worldwide to evaluate automated driving vehicles and K-city has been developed as the test bed in Korea. The K-city has a variety of facilities such as merge, ramp, tollgate, tunnel, intersection and so on according to five road conditions: motorway, suburban road, urban road, community road and valet parking zone. Therefore, it is necessary to have automated driving evaluation scenarios that would actually be implemented in K-city. For scenario implementation as vehicle tests, automated driving vehicles are needed. The safety evaluation scenarios and criteria for level 3 and level 4 automated driving vehicles were developed in consideration of the actual driving conditions, the real road driving data, and the existed automated driving evaluation methods (ISO, NHTHA, and so on). Then, the safety evaluation scenarios were determined by considering whether the test bed could be realized, repeatable, and safety performance could be well assessed. In order to evaluate automated driving on actual test bed, vehicles as well as evaluation scenarios are needed. First of all, it needs an automated driving vehicle that is evaluated. The evaluated vehicle is called as a subject vehicle. Besides the subject vehicle, vehicles that can help evaluation are also needed and are referred to as target vehicles. Target vehicles have the ability to driving autonomously in accordance with the scenario, maintaining safety performance with the surrounding vehicles, and recognizing subject vehicle to measure safety criteria. For example, the target vehicles are used to produce a variety of situations, such as cutting in front of the subject vehicle, decelerating in front of the subject vehicle, or driving on the main road when subject vehicle is on the merge road. In the study, a subject vehicle and four target vehicles have been developed and utilized. To verify the developed evaluation scenarios, vehicle tests were conducted using subject vehicle and target vehicles. The subject vehicle has level 3 and level 4 of automated driving that have diverse functions such as lane keeping and lane change. In accordance with the scenarios, all vehicles were self-driving and the subject vehicle was checked whether it meets the evaluation criteria. Through vehicle tests, the developed evaluation scenario was verified to be feasible on the test bed and to evaluate the performance of subject vehicle well. In this paper, the vehicle test result of merge scenario is presented among various motorway scenarios.

INTRODUCTION

Evaluation technology of the automated driving is actively developed in accordance with the rapid development of automated driving system around the world [1, 2]. In the case of the advanced driver assistance system (ADAS), which is the basic technology of automated driving system, standards and evaluation techniques have been developed by organizations such as ISO, NCAP, and NHTHA [3, 4, 5]. About automated driving, research and collaboration have been conducted to create standards and evaluation criteria worldwide, including the EU and the United Nations [6, 7].

Since the automated driving system must be evaluated while driving, the driving environment is very important. For the autonomous driving, a system such as a temporary driving license for automated driving system was institutionalized [8, 9]. Initially, it was started on Nevada and California in the United States of America, and now the temporary driving license is being institutionalized in several countries around the world, including Korea. The temporary driving license system can be helpful for developing autonomous driving technology because it can travel with various vehicles on actual roads. However, it is difficult to reproduce the desired and repeated situation. Therefore, there is a great need for a test bed as well as an actual road for autonomous driving technology. M-city in the United States was built as a test bed specialized in automated driving evaluation [10]. Following M-city, many test beds specially developed for automated driving are being developed around the world, and K-city have been developed in Korea [11]. K-city simulates several driving environments such as motorway, suburban roads, urban roads, community roads and valet parking zone. In addition, facilities that can have an influence on autonomous driving are prepared such as such as V2X infra, GPS block tunnel and sensor barricade.
In this study, automated driving evaluation scenarios and criteria that can be implemented by K-city have been developed. Since the automated driving is an integrated and developed system of the existing ADAS, the existing ADAS evaluation technology was applied to the development of the automated driving evaluation technology. In addition, various evaluation criteria were developed considering actual driving data and physical characteristics of vehicles. The evaluation criteria consist of the states of the ego vehicle and the interactive states of the surrounding vehicles. To represent the interactive states of the surrounding vehicles, a variety of indices already exist such as clearance, time gap (TG), time to collision (TTC) and so on [12]. In this study, the lane keeping safety distance and lane changing safety distance are devised newly. Although various driving environments exist in K-city, only motorway scenarios are developed in this study since motorway is the closest environment to fully automated driving being realized. In the scenario verification, an automated vehicle to be evaluated and surrounding vehicles to assist in evaluation are needed. The basic automated driving function is need to the surrounding vehicles, because the vehicles is driven in accordance with the actual scenario. Using these vehicles, the evaluation scenario has been implemented and verified in K-city. In this paper, the vehicle test result of merge scenario is presented among various motorway scenarios. 3

THE CURRENT STATUS OF SAFETY EVALUATION OF ADV

Safety Evaluation Scenario and Criteria of ADAS

The automated vehicles generally is an integrated system of individual ADAS element technologies which are ACC, AEB, and LKAS. In order to evaluate the performance of the autonomous vehicle system, it is examined the evaluation scenarios and criteria of existing element systems. The test procedures are based on ISO, NHTHA and NCAP which focus the evaluation of vehicle safety system

ACC The ACC performance evaluation specified by ISO consists of straight-lane recognition performance, preceding vehicle identification performance, and preceding vehicle identification performance on curve lane. In straight-lane recognition performance test, the maximum recognition distance within 2 seconds is evaluated. In the identification performance test of the preceding vehicle, it is evaluated whether each front vehicle existing in the in-lane and the side lane in the straight road is recognized and identified. This is a test for verifying whether the ego vehicle follows the preceding vehicle on in-lane, without misrecognizing the vehicles on other lane. In the identification performance test of the preceding vehicle on curve lane, it is evaluated whether the ego vehicle can perceive and identify the preceding vehicle on curve lane. In addition, when the preceding vehicle is decelerated from the curved road, the behavior of the ego vehicle is also evaluated [3].

AEB The AEB performance assessment as defined by Euro NCAP is divided into two cases: City and Inter-Urban. For the City scenario, the AEB performance evaluation for stop targets is addressed for ego vehicle velocities of 10 to 50km/h. For the Inter-Urban scenario, the AEB performance evaluation is conducted for stop, moving, and deceleration targets for the ego vehicle velocity range of 30 to 80km/h. ISO AEB performance evaluation is based on two test scenarios . One is the case where the velocity of the preceding vehicle is 0km/h, the initial velocity of the ego vehicle is 80km/h, and the initial distance between the preceding vehicle and the ego vehicle is 120m. Second, the velocity of the preceding vehicle is 30km/h, the initial velocity of the ego vehicle is 80km/h, and the initial distance between the preceding vehicle and the ego vehicle is 120m. The criteria to be evaluated in the test scenario are as follows. It is evaluated whether the ego vehicle provides one or more warnings before 1.4seconds of automatic emergency braking, provides two or more warnings before 0.8seconds, reduces velocity of more than 10 km/h at the point of impact, and operates no emergency braking before TTC 3seconds [4].

LKAS The ISO LKAS performance test evaluates the acceleration, the operated velocity range and so on. The test is conducted within the speed range of 72km/h to 108km/h in a curved section of 800 m radius. In the scenarios defined by NHTSA, progress is made at 72km/h. Performance test is performed from a lateral speed of more 0.6m/s to a maximum speed at which the lane departure prevention performance is maintained [5].

Safety Evaluation Scenario and Criteria of automated driving system

In accordance with the rapid development of automated driving, evaluation scenarios and criteria for the automated driving system are being actively developed around the world. In this paper, large projects in the EU and UN have dealt with.

Adaptive After 2014, the EU began developing the Adaptive Self Assessment Technology project. Adaptive takes account of the reflection on legal factors and human factors. In addition, evaluation scenarios are classified into proximity scenarios such as parking lots, urban scenarios, and highway road scenarios. In evaluation, framework and methodology are focused. Assessment is done from various perspectives like technical, user related and in-traffic assessments. Also, impact analysis have also been conducted. Lastly, deployment perspective for automated driving have been presented. The project lasted about three years [6].

WP29 WP 29 means the UNECE world forum for harmonization of vehicle regulations which is a unique worldwide regulatory forum within the institutional framework of the UNECE Inland Transport Committee. UN Regulations contain provisions related to safety and environmental aspects. They include performance-oriented test requirements, as well as administrative procedures. With the development of the automated driving system world widely, WP 29 focuses on automated driving systems. WP 29 contain globally harmonized performance-related requirements and test procedures. WP 29 also provide a predictable regulatory framework for the global automotive industry, consumers and their associations. Overall, the regulatory framework developed by the World Forum WP.29 allows the market introduction of innovative vehicle technologies, while continuously improving global vehicle safety. WP 29 have two principle operating groups. One is WP29 Informal Group to provide strategic direction for automated technology. This group focuses intelligent transport systems and automated driving (ITS/AD). Another is a group which have developed the UN regulation concerning vehicle steering systems to permit certain levels of autonomy. This group is called as GRRF and the GRRF Informal Working Group. WP 29 categories automated functions as six classification [7].

ENVIROMENTS OF ADV TEST BED

For test operation of automated driving vehicles, diverse methods has been recently developed all over the world. For example, the licensing standards for automated driving vehicles have been proposed in California, Nevada and EU. Although licensing has the advantage of driving on a real road, it is necessary to use a test bed because it is difficult to repeatedly test various situations. M-city is a test bed specialized in a typical automated driving system. Like M-city, the test bed has been developed worldwide to evaluate automated driving vehicles and K-city has been developed as the test bed in Korea. The Korea Automobile Safety Institute under the Ministry of Land, Infrastructure and Transport developed a test bed for safety evaluation of automated vehicles. The test bed is called as K-city and constructed various road environments in 360,000 square meter space. K-city can be divided into five major areas. There are urban roads, community roads, motorways, suburban roads, and valet parking facilities. K-city has implemented roads, transportation and communication environments similar to actual roads consisting of signal / non-signal intersections, rotary intersections, building facades, parking facilities and child protection areas for these five roads and facilities.

Motorway

Motorway environment reproduces the exclusive road traffic environment capable of high-speed movement. This environment is composed diverse constructions which are merge, split, main road, tollgate, guardrail and tunnel. In this environment, driving test is available with wide velocity range. Functions, lane keeping, lane change and safety control with surrounding vehicles, can be tested in motorway.

Suburban Road

Suburban road environment recreates rural roads with insufficient infrastructure. This environment consists of rotary, a tree-lined street.

Urban Road

Urban road environment reproduces the road traffic environment of the city. This environment is composed diverse constructions which are signalized intersection, a bus-only lane, a bus stop and a temporary building.

Community Road

Community road environment reproduces the road traffic environment centered on pedestrians. This environment is composed diverse constructions which are a school zone, sidewalk and bicycle road.

Valet Parking Zone

Valet parking environment reproduce the parking environment where autonomous valet parking is possible. This environment consists of various shape parking spaces. Parallel, horizontal and oblique parking spaces are constructed.

Figure1. K-City Test Bed for Automated Driving System.

CRITERIA OF PERFORMANCE EVALUATION OF AUTOMATED VEHICLES

In this chapter, criteria for evaluating automated vehicles are presented. The criteria are calculated by taking into account the safety standards used in the existing ADAS, the actual road data, and the physical behavior of the vehicle. It is important to basically evaluate the state of the ego vehicle and evaluate interactive state with surrounding vehicles. Indices of safety with surrounding vehicles are clearance, time gap (TG), time to collision (TTC) and so on. In this paper, safety distance is devised as representing safety performance. In this study, since only the motorway environment is focused on, the driving situation can be largely divided into lane keeping and lane change. Different safety distances are suggested depending on the two situations.

States of Automated Vehicle

The states of the ego vehicle must be evaluated to confirm the abnormal behavior of the vehicle. Considering the existing ADAS evaluation criteria, the following state of charge is evaluated. First, it is necessary to evaluate whether the velocity of ego vehicle exceed or not in desired velocity by the scenario. And of course,
In the lane-keeping scenario, It should be evaluated whether the ego vehicle are driving inside the lane. It is important to evaluate longitudinal and lateral accelerations, which are related to abnormal behavior and ride quality. The permitted range of accelerations depends on the scenario. For example, a large area longitudinal acceleration is allowed in an emergency scenario where a front vehicle cuts in abruptly. On the other hand, a small area longitudinal acceleration is allowed in a normal driving scenario. As another example, the allowable

lateral acceleration in the lane-keeping scenario and the lane-changing scenario is different. The criteria for the states are different according to each scenario. The criterian is decided based on the existing ADAS evaluation criteria and the human driving data. The values of the specific states are given in the scenario description below.

Safety Distance in Lane Keeping Situation

Based on WP29, the safety distance in the lane keeping situation means the distance that the autonomous vehicle must proceed the safety distance control when the front vehicle is within the safety distance. For example, if the front vehicle cuts in at a distance within the safety distance, the automated vehicle must perform the safety distance control to maintain the distance over the safety distance. Safety distances are discussed internationally as in Eq. (1). The velocity of automated vehicle is multiplied by Time Gap, which means that the higher the speed, the higher the safety distance is required. The issue of how to set the time gap internationally remains an issue. In this study, the safety distance equation is presented considering the physical braking distance and actual driver driving data.

$$C_{LK} = \tau_{LK} \times V_{AV} \qquad \textbf{(1)}$$

where, τ_{LK} is time gap in lane keeping safety distance and V_{AV} is velocity of automated vehicle.

The physical braking distance can be calculated by the following parameters in consideration of the characteristics of automated vehicles that are currently being developed globally.

$$d_{brake} = (t_{sys} - {V_{AV}}\big/{2a_{\max,AV}}) \times V_{AV} \qquad \textbf{(2)}$$

where, τ_{LK} is system delay which sets 0.3 second and $a_{\max,AV}$ is maximum decelearion of automated vehicle which sets -9 m/s^2.

The actual driving data analyzed the distances when drivers were following the preceding vehicle in steady state [13]. The data were collected for 125 drivers of various age and sex. The following distance of this data is as follows.

$$c_{following} = c_0 + \tau_{following} \times V_x \qquad \textbf{(3)}$$

where, c_0 is the zero-speed clearance which sets 2m, $\tau_{following}$ is the linear coefficient, and V_x is the ego vehicle velocity.

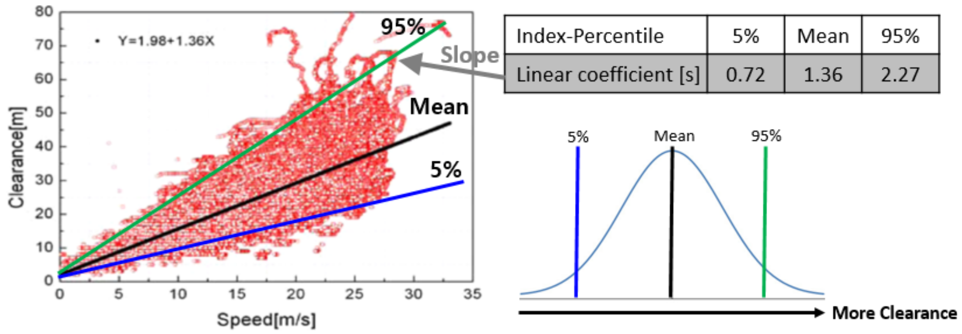


Figure2. Clearance driving data with a preceding vehicle in steady state following situation.

In pile-up accidents, the velocity of the preceding vehicle can become zero immediately without deceleration. Therefore, it need to be considered to calculate the safety distance over the braking distance in all velocity ranges. If setting the constant time gap to be discussed in WP29, time gap 2.3 second is needed to cover the braking distance of all velocity regions. This is too large in comparison with the actual driving data. And because too much safety distance is required in the low speed range, excessive and frequntely deceleration can occur. Therefore, the constant time gap is not proepr. If the time gap varies according to the velocity as Eq. (1), the safety distance is larger than the braking distance of all the velocity regions and does not largely differ from the driving data. Therefore, the safety distance in the lane keeping situation is proposed based on braking distance and driving data as Eq. (4).

$$C_{LK,proposed} = \tau_{LK,proposed}(V_{AV}) \times V_{AV} + c_0 \tag{4}$$

$$\tau_{LK,proposed} = 0.8 + ({}^{1.6\times V_{AV}}\!\big/_{36.1}) \tag{5}$$

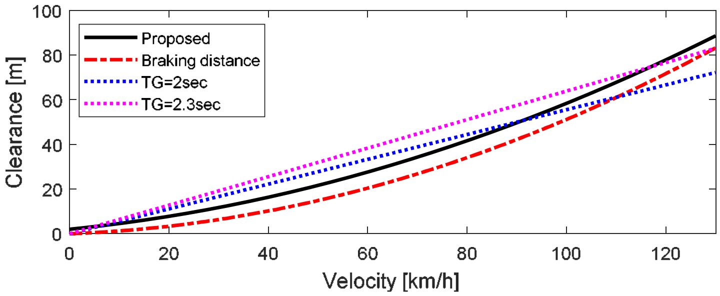


Figure3. Proposed safety distance in lane keeping.

Safety Distance in Lane Change Situation

Unlike lane keeping situation, which are important only for a preceding vehicle, all surrounding vehicles are important in lane change situation. Therefore, the lane change safety distance can be shown in Fig. 1. This distance indicates that a lane change is possible when no vehicle is present in this area. The vertical length of the area equals the lane width and the horizontal length consists of three distances which are a side, a rear and a front. The side distance is equal to the width of the ego vehicle.

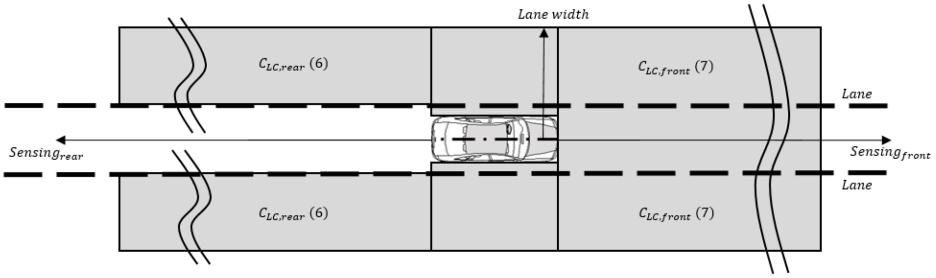


Figure4. Area by safety distance in lane change situation.

Eq. (6) indicates the rear distance which is calculated as a distance at which one second time gap is secured with a normal deceleration amount of the side-rear vehicle.

$$C_{LC,rear} = \begin{cases} (V_{rear} - V_{AV}) \times t_B + (V_{rear} - V_{AV})^2 / (2a_{rear}) + V_{rear} \times t_G & \text{If } V_{rear} \geq V_{AV} \\ V_{rear} \times t_G & \text{else} \end{cases} \tag{6}$$

where, V_{rear} is the velocity of the rear vehicle on target lane, t_B is time delay to reach target deceleration which sets 0.3second, a_{rear} is normal deceleration of the rear vehicle which sets -3 m/s^2 and t_G is time remaining between vehicles after the approaching vehicle decelerates which sets 1second.

If a front distance is applied to a rear distance, the safety distance is too large. In this case, since lane change is possible only when the vehicle does not exist in an area that is too large, it is difficult to perform lane change in practice. Therefore, the front distance is calculated by changing the parameters in consideration that the vehicle to be decelerated is an ego vehicle. Eq. (7) indicates the front distance

$$C_{LC,front} = \begin{cases} V_{AV} \times t_G & \text{If } V_{front} \geq V_{AV} \\ (V_{AV} - V_{front}) \times t_B + (V_{AV} - V_{front})^2 / (2a_{AV}) + V_{AV} \times t_G & \text{else} \end{cases} \tag{7}$$

where, V_{front} is the velocity of the front vehicle on target lane and a_{AV} is maximum decelearion of the ego vehicle which sets -9 m/s^2.

AUTOMATED DRIVING SYSTEM TEST SCENARIO

As described above, the K-city environment consists of motorway, suburban road, urban road, community road, and valet parking. In this paper, only motorway scenario is developed because the commercialization of fully autonomous driving is the closest in motorway. In the motorway, the driving function is largely divided into lane keeping and lane change, and scenarios are developed in consideration with situations that can occur according to each function. Table 1 shows test scenarios for the automated driving vehicle.

Table1.
Test scenarios for the automated driving vehicle.

Environment	Main Function	Specifics	Test No.
Motorway (+Suburban Road)	Lane Keeping	Solo Driving	M-1-1
		Preceding Vehicle	M-1-2
		Cut-in Vehicle	M-1-3
		Cut-out Vehicle	M-1-4
	Lane Change	Overtaking	M-2-1
		Merge	M-2-2
		Split	M-2-3

Motorway Lane Keeping Test (M-1)

Scenario the automated driving system should be able to keep the lane in solo driving (M-1-1). Lane keeping performance should be evaluated while varying the various velocity ranges and various curvatures within the road regulation. In addition, evaluation need to be conducted with surrounding vehicles in the vicinity. The automated driving system should be able to keep the lane as maintaining safety with a preceding vehicle (M-1-2). Along with lane keeping performance, it is necessary to evaluate whether the safety is maintained for various behaviors such as constant velocity, acceleration and deceleration of the preceding vehicle. The automated vehicle should be able to keep the lane as responding about sudden change of traffic condition such as cut-in case (M-1-3). It is necessary to evaluate the lane keeping and safety maintenance performance against the various behavior of the vehicle which performs cut-in maneuver from the adjacent lane to the in-lane. The automated vehicle should also keep the lane as responding about sudden change of traffic condition such as cut-out case (M-1-4). When a preceding vehicle is slower than the desired velocity of the automated vehicle, the automated vehicle need to follow the velocity of the preceding vehicle. It is necessary to assess whether the automated vehicle will recover the desired velocity when the preceding vehicle perform cut-out maneuver from the original lane to the adjacent lane.

Performance evaluation First, the lane keeping performance should be evaluated at various curvature and velocity conditions. And, when the surrounding vehicle exists, the maintenance of the safety with the surrounding vehicle must be evaluated. It should be assessed whether clearance with a preceding vehicle stay above a lane keeping safety distance. About the velocity, the desired velocity or the velocity of the preceding vehicle or the desired velocity recovery should be assessed depending on the scenario. Finally, in order to evaluate ride comfort and abnormal behavior, it is necessary to evaluate whether the longitudinal and lateral accelerations of the automated vehicle are maintained within a certain value.

Table2.
Performance evaluation of lane keeping situation.

Performance Index	Criteria
Lateral Position	Lane Keeping
Velocity	Desired Velocity / Velocity of Preceding vehicle
Longitudinal Acceleration (Normal Case)	$-3 \leq a_x \leq 2$

Longitudinal Acceleration (Severe Case)	-9 $\leq a_x \leq$ 2
Lateral Acceleration	-1 $\leq a_y \leq$ 1
Safety with a preceding vehicle	By lane keeping safety distance (4)

Motorway Lane Change Test (M-2)

Scenario Lane change can be classified as two cases. First, a case where a lane change is made by an influence of nearby vehicles on a normal road is referred to as a discretionary lane change (DLC). The most representative situation for DLC is overtaking situation (M-2-1). Therefore, when a preceding vehicle is slow or stopped, it should be evaluated whether the lane change is proceeding while maintaining the safety of the surrounding vehicles. Scenarios can be implemented by varying the velocity, the number and the location of the preceding vehicle and the side lane vehicles. Unlike DLC, a case where a lane change should be completed by road conditions is called a mandatory lane change (MLC). Representative situations of MLC are merge (M-2-2) and split (M-2-3). In order to perform DLC, the automated driving system should operate with the MAP. The automated vehicle must be to determine if it is located at merge or split. Then, the lane change need to be completed in limited distance and time constraints. In the merge scenario, various merge situations can be implemented by changing the position, the velocity and number of the vehicle in the target lane. In the split scenario, it is possible to implement various split situations by changing the preceding vehicle go to split lane or the preceding vehicle go straight in original lane.

Performance evaluation In a lane change scenario, the first thing to evaluate is the success of the lane change. In the case of an overtaking scenario, it is possible to perform a lane change while maintaining the safety of the surrounding vehicles, but it is also possible to maintain safety with a preceding vehicle by decelerating. In the case of merge or split scenario, the lane change must be successful while maintaining the safety of the surrounding vehicles. The lane keeping safety distance and the lane change safety distance are used for evaluation of safety with surrounding vehicles. Finally, it is necessary to evaluate whether the longitudinal and lateral accelerations of the subject vehicle are maintained within a certain area.

Table3.
Performance evaluation of lane keeping situation.

Performance Index	Criteria
Longitudinal Acceleration	-3 $\leq a_x \leq$ 2
Lateral Acceleration	-3 $\leq a_y \leq$ 3
Safety with surrounding vehicles	By lane change safety distance (6), (7)

IMPLEMENTATION OF EVALUATION SCENARIO UTILIZING AUTOMATED VEHICLES

In order to evaluate automated driving on actual test bed, vehicles as well as evaluation scenarios are needed. First of all, it needs an automated driving vehicle that is evaluated. The evaluated vehicle is called as a subject vehicle. Besides the subject vehicle, vehicles that can help evaluation are also needed and are referred to as target vehicles. Target vehicles have the ability to driving autonomously in accordance with the scenario, maintaining safety performance with the surrounding vehicles, and recognizing subject vehicle to measure safety criteria. For example, the target vehicles are used to produce a variety of situations, such as cutting in front of the subject vehicle, decelerating in front of the subject vehicle, or driving on the main road when subject vehicle is on the merge road. In the study, a subject vehicle and four target vehicles have been developed and utilized.

Subject vehicle

The subject vehicle must be capable of level 3 and 4 automated driving. The automated driving system is normally consist of localization, perception, motion planning and control functions. Localization function is achieved based on RTK GPS. In perception function, surrounding vehicles, obstacles and pedestrians are detected using six IBEO LiDARs. Lane also is detected by AVM camera and a front vision system. In motion planning function, proper motion is planned considering both a safety and a task. Safety means that automated vehicle can maintain safety with surrounding vehicles, obstacles and pedestrians. Diverse tasks, which are lane keeping, lane change and intersection driving, exist and the task is decided by the road environment. Control function determines the control input to track the planned motion. Model predictive control based automated driving algorithm is applied to merge situation, which is the vehicle test environment of this paper [14].

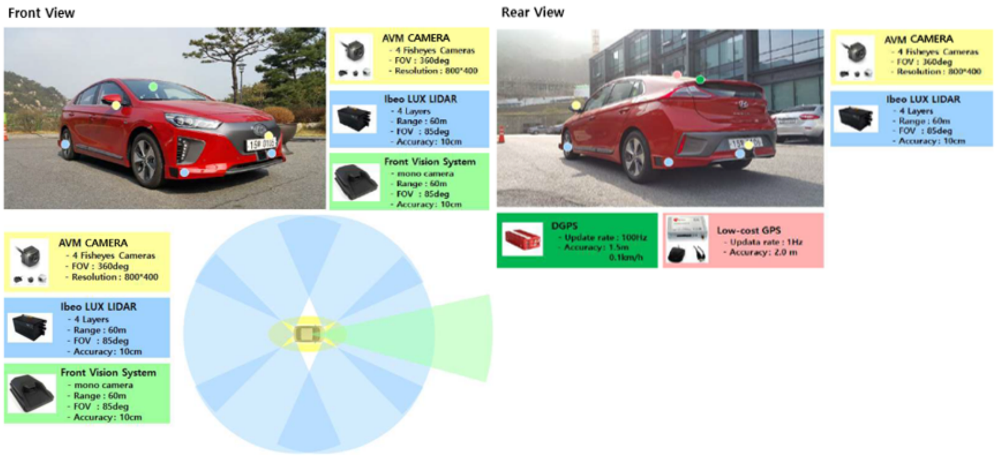


Figure5. Configuration and detection range of subject vehicle.

Target vehicle

Target vehicles have the ability to driving autonomously in accordance with the scenario, maintaining safety performance with the surrounding vehicles, and recognizing subject vehicle to measure safety criteria. Therefore, target vehicles also basic automated driving. As the subject vehicle, RTK GPS based localization function is equipped. LiDAR, Radar and Front Vision System based all-around vehicle detection can be possible to maintain safety performance with the surrounding vehicles, and to measure safety criteria of the subject vehicle. Target vehicle need to drive autonomously in accordance with a predefined scenario. For this purpose, target vehicle has a localization function using high performance RTK GPS. It also has path-generation algorithm which create a path as a predefined scenario. To decide desired steering torque as final lateral control input, path-tracking algorithm are implemented for tracking desired path [15]. Because target vehicle need to detect all-around vehicles for maintaining safety performance with the surrounding vehicles and measuring safety criteria of the subject vehicle, all-around vehicle detection module has been composed using LiDAR, radar and front vision system. For longitudinal control, two modules are considered. As first module, human driving data based ACC and AEB algorithms are equipped for safety control with surrounding vehicles [13]. As second module, scenario based velocity control algorithm is equipped. As final longitudinal control input, longitudinal acceleration is decided considering both modules. According to the above description, Fig. 6 represents algorithm structure of target vehicle. In addition, Fig. 7 shows configuration and sensor range of target vehicle.

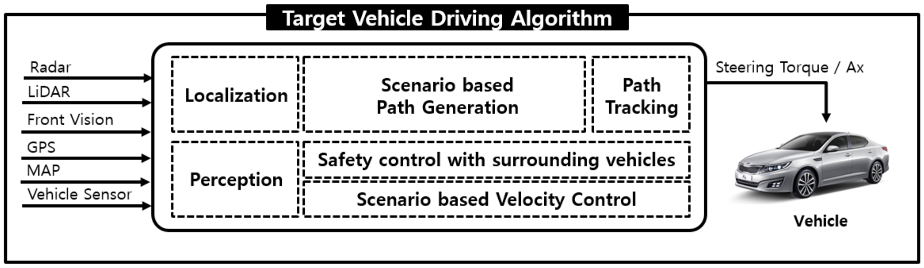


Figure6. Algorithm structure of target vehicle.

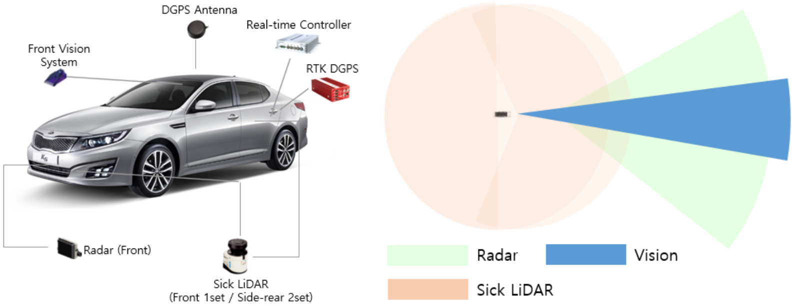


Figure7. Configuration and detection range of target vehicle.

VEHICLE TEST FOR VALIDATION OF EVAULATION SCENARIO

The actual vehicle test in K-city is carried out using the subject automated vehicle and the target vehicles which helps evaluation as mentioned earlier. Since all the scenarios cannot be shown, we present only merge scenario is presented. The merge situation is the most difficult scenario among motorway scenarios.

Test Case: Merge on Motorway

The merge scenario is shown in Fig. 8. The subject vehicle travels in merging lane, and the target vehicle which supports the evaluation travels on the target lane. Since the length of the merge lane is short as 100m in the K-city, vehicle test proceeds at a speed of 30km/h. In order to interfere with the merge of the subject vehicle, the target vehicle drives on side of the subject vehicle. Since the vehicle starts from a standstill, it must drive from the rear to meet the scenario situation. Fig. 9 represents the merge map and trajectory from the stationary state of two vehicles for the scenario situation.

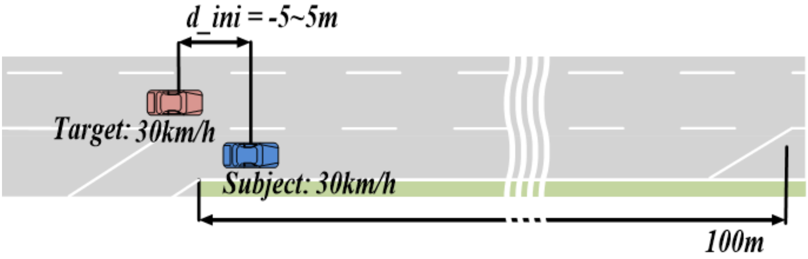


Figure8. Vehicle test condition in merge scenario.

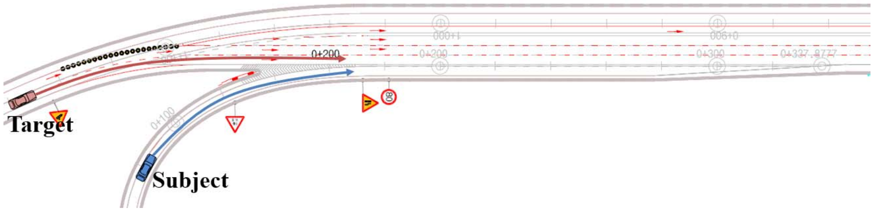
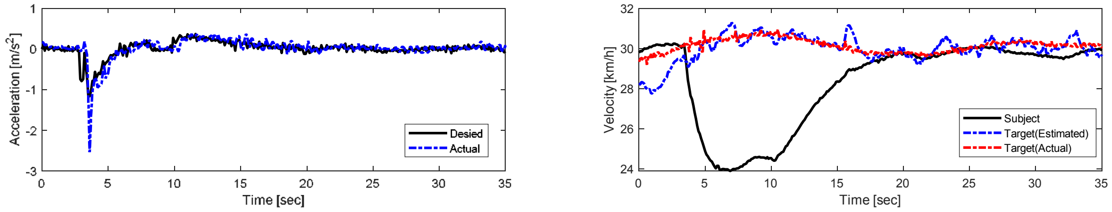
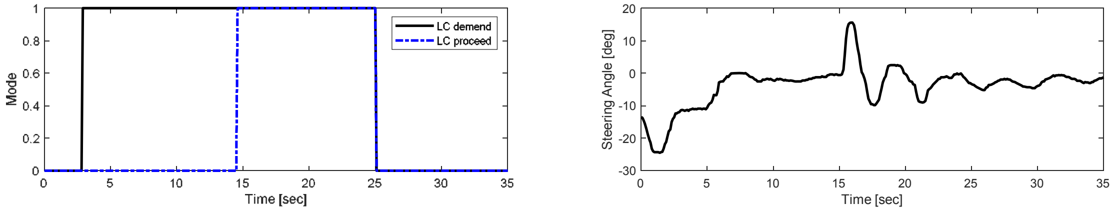


Figure9. Merge map and initial Trajectory for merge scenario condition.

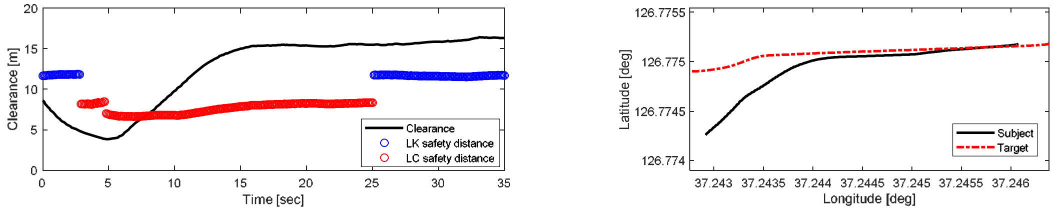
The results and sanpshots of the vehicle test are presented in Fig. 10 and 11 respectively. At 3sconds, the subject vehicle that has reached the start point of merge lane tries to make a lane change to the left, but the lane change is not possible because the target vehicle occupies on target lane. The subject vehicle judges whether to go ahead or rear of the target vehicle in consideration of the remaining distance of the merge lane and the state of the target vehicle. The subject vehicle decelerates since it decides that going rear of target vehicle is better. After the distance between the subject vehicle and the target vehicle is enough to perform lane change, the subject vehicle proceeds lane change to target lane at 14.9seconds. After the lane change is completed at 25seconds, the subject vehicle keeps a certain distance from the preceding vehicle in the lane keeping mode.



(a) Acceleration (b) Velocity of Each Vehicle



(c) Lane Change Mode (d) Steering Angle



(e) Clearance (f) Trajectory of Each Vehicle

Figure10. Vehicle test result of merge scenario.

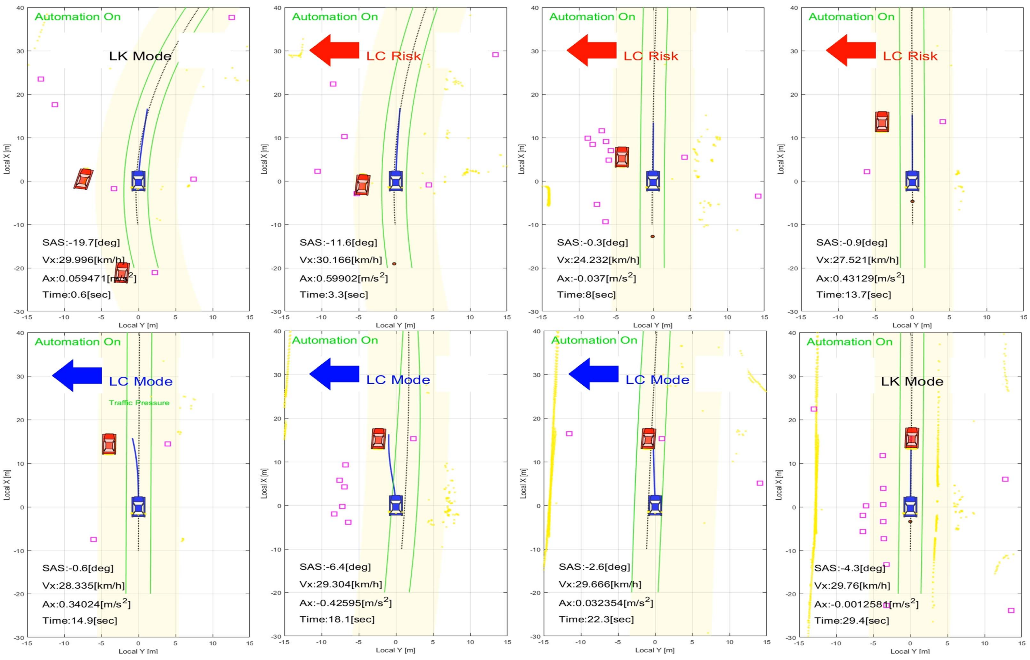


Figure11. Vehicle test snapshot of merge scenario.

CONCLUSIONS

According to the global demand for the development of evaluation technology of the automated driving system, the test bed has been developed worldwide to evaluate automated driving vehicles and K-city has been developed as the test bed in Korea. K-city simulates several driving environments such as motorway, suburban roads, urban roads, community roads and valet parking zone. In addition, facilities that can have an influence on autonomous driving are prepared such as such as V2X infra, GPS block tunnel and sensor barricade. In this study, automated driving evaluation scenarios and criteria that can be implemented by K-city have been developed. The evaluation criteria is developed considering existing ADAS evaluation criteria, driving data, and vehicle physics characteristics. The evaluation criteria consist of the states of the ego vehicle and the interactive states of the surrounding vehicles. To represent the interactive states of the surrounding vehicles, the lane keeping safety distance and lane changing safety distance are devised newly. The evaluation scenarios are developed taking into account repeatability, feasibility, and representative for driving situations. In the scenario verification, an automated vehicle to be evaluated and surrounding vehicles to assist in evaluation are needed. The basic automated driving function is need to the surrounding vehicles, because the vehicles is driven in accordance with the actual scenario. Using these vehicles, the evaluation scenario has been implemented and verified in K-city. In this paper, the vehicle test result of merge scenario is presented among various motorway scenarios. Future work requires development of evaluation scenarios and criteria for K-city remaining environments that are suburban road, urban road, community road and valet parking zone. In addition, verification would be conducted using one subject vehicle and four target vehicles.

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