Safety Assessment of Driving Support Functions as Human-machine System

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ABSTRACT
We propose an evaluation methodology to analyze the safety level of advanced driver assistance systems (ADAS) as a human-machine system in terms of comparing the increase in the safety level during normal system operation and the decrease in the safety level during a system malfunction. We propose a concept of combined error for the human-machine system and quantify this combined error by driving simulator investigations and simulation studies. First, we investigated the drivers’ behavior when avoiding rear-end collisions with a preceding vehicle when equipped with ADASs-like ACC and LKA or FCW and LDW. Then, we confirmed that the risk of collision induced by overdependence on the systems was not increased when the ADASs were mounted on the vehicle using simulation studies based on the concept of combined error for the human-machine system. We also confirmed that the decrease in collisions when the ADASs operated appropriately was much larger than the increase in collisions during a system malfunction.

Keywords: Safety Impact Assessment, Driving Support, Driving Simulator, ESK-JES Joint Session

1. Introduction
A trade-off analysis between the positive effects, i.e., the decrease in the risk of collision with the system when it is operating normally, and the negative effects, i.e., the increase in the risk induced by an overdependence on the system when it is difficult to operate, is performed, and an example of the analysis is described in this study. Specifically, we analyzed changes in the risk of a collision of a vehicle equipped with ADAS. Two approaches were adopted and combined in the analysis: one was an experiment with a driving simulator and the other was a time-series simulation of the reliability of ADAS and the driver, wherein they were modeled as a human-machine system.

2. Collision Mitigation Effectiveness Quantification Methodology
To quantify the collision mitigation effectiveness when a vehicle is equipped with the system, a situation wherein it is difficult for the system to be operational should be considered in the analysis in addition that wherein ADAS is operating normally. The former situation could occur for any reason despite the probability of such an occurrence being small. Suzuki et al. (2011) proposed a concept to estimate a driver's error when a vehicle is equipped with the system. In this concept, the reliability of the system and driver are combined, assuming that the occurrence of a situation wherein it is difficult for the system to be normally operated (hereinafter referred to as the "system error") and that wherein the driver cannot control the vehicle normally (hereinafter referred to as the "driver error") are independent. The vertical axis of Figure 1 indicates system reliability, i.e., the system's possibility of providing a driver with support, and the horizontal axis indicates the driver's reliability, i.e., the driver's possibility of driving the vehicle normally. The zones surrounded by these axes express the overall reliability. In other words, zone A in Figure 1 expresses the possible decrease in the risk of collision when the system is normally operational, and zone B expresses the possible increase in risk when it is difficult for the system to operate. In zone B, there is a fear that the risk of collision could increase due to the driver's dependence on the system. When the area of zone A is larger than that of zone B, the collision probability of the vehicle equipped with the system is lower than that of a vehicle not equipped with the system, implying that there are benefits when the system is applied in practice. Note that the reversed L-shaped zone in Figure 1 (the "total error") indicates the error probability of a vehicle controlled by a driver and system (or the combined collision probability of a vehicle equipped with the system).

In this analysis, the driving simulator test (driving test with a simulator, Figure 2) and simulations have been
combined to determine whether the increase in collision probability is distinguishable when a vehicle is equipped with ACC and LKA. The area ratio between zones A and B is also discussed. Monte Carlo simulation was applied to estimate driver and system reliabilities.

Figure 1. Combined error model to estimate driver and system reliabilities

Figure 2. Experimental scenario in the driving simulator to simulate a rear-end collision

3. Estimation of the Collision Risk

The collision probability of the normal state and that of the error state were sorted and are shown in Figure 3 and Figure 4. The collision probability is 40.3% when the system is not used under this condition, and the probability is reduced to as low as 1.16% when ACC is used. The decrease in the collision probability with the use of a system equivalent to zone A is 39.7%, and the probability increase with the use of a system equivalent to zone B is 0.557%.

Left; When the vehicle is not equipped with ADAS
Right; When the vehicle is equipped with ACC

Figure 3 Safety impact of ACC in decreasing collision probability

When a system is not used, the collision probability is 40.3%, whereas it is lowered to 1.11% when ACC and LKA are used. The collision probability decrease with the use of a system equivalent to zone A is 39.7%, and the probability increase with the use of a system equivalent to zone B is 0.457%. The driving simulator experiment and the simulation analysis reported herein indicate that the positive effect of the addition of LKA to ACC is slightly larger than the positive effect of one system only (ACC).

Figure 4 Safety impact ADASs in decreasing collision probability when LKA is installed in a vehicle equipped with ACC (LKA +ACC)

4. Conclusion

In the driver simulator experiment, when a vehicle was equipped with the combined ACC and LKA systems, drivers tended to focus on the subtask (operation of tablet PC) more than if they were driving a vehicle equipped with either ACC or LKA. However, it was confirmed that the probability of a rear-end collision with the leading vehicle did not vary. When these two functions were combined, the level of the driving load mitigation was enhanced. Drivers tended to divert their attention to other tasks while driving; however, they could still take appropriate actions against risks such as rear-end collisions.

In both cases, when a vehicle was equipped only with ACC or with both AAC and LKA, the decrease in the collision probability for the condition where the system can assist the driver, i.e., the system's normal state, was confirmed to be much higher than the increase in collision probability when it was difficult for the system to assist the driver, i.e., system error state. This was confirmed by the simulation analysis that used the driver behavior database obtained by the driving simulator experiment.

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References

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