LDWS PERFORMANCE STUDY BASED ON HUMAN FACTORS

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ABSTRACT

In order to reduce the fatality of traffic accident up to 50%, various tools are being developed for safer operation of vehicles on the road. Serious portion of accidents are believed to be the result of driving across the lane due to either negligence or drowsiness of the driver. As a prior step to lane keeping system (LKS) which enforces a vehicle to run within its current lane, lane departure warning system (LDWS) is developed to warn a driver before it moves over to next lane unintentionally and is being widely installed by a vehicle manufacturer or sold as an aftermarket product.
Even though LDWS is believed to prevent accident and reduce fatalities by 25% and 15% respectively, its effectiveness in performance is yet to be confirmed in many aspects.
LDWS is designed to issue a warning within the tolerance limits defined on both side of the lane boundary so that the driver would take evasive maneuver back to original lane securing a safe gap against vehicles moving in the adjacent lane. Since the driver may not perceive and respond properly due to human delay in recognition and in response, the warning may not be triggered early enough.
In this study, the vehicle lateral locations relative to warning zone envelop (earliest and latest warning zone defined in International Organization for Standardization (ISO) standard, Economic Commission for Europe (ECE) and National Highway Traffic Safety Administration (NHTSA) regulations) are compared with respect to various factors including delays, vehicle velocity, vehicle heading angle with respect to the lane.
Since LDWS is designed to be activated at the velocity over 60 km/h, vehicle velocity range for the study is set to be from 60 to 100 km/h.
The vehicle heading angle (yaw angle) is set to be up to 5 degree away from the lane (abrupt lane change) considering standard for lane change test using double lane-change test specification.
There are no solid guideline for human perception and response delay for imminent accident. Tentative delay up to 2.0 second is found from emergency braking case study for accident perception while 0.54 to 0.73 second range actuation delay is necessary.
Even though further study may follow as for the assessment for human delays in more systematic approach, preliminary study still suggests that LDWS might not be sufficient enough to issue a proper warning for drivers. Thorough knowledge of human factors to the system is needed in order to understand the limit of LDWS and to facilitate the technology like LKS.

INTRODUCTION

The most of vehicle accident occurs due to carelessness of driver. Therefore, concept of active safety technologies to perform evasive action prior to hazardous environment different from passive safety technologies that lessen the aftermath of the crash is being developed aiming at reducing traffic accidents and ensuring the safety of vehicle. The earlier version of active safety technology as ADAS(Advanced Driving Assistance Systems) facilitating the minimal safety tactics eliminating unsafe factors has been introduced with the aids of sensors to improve safety and convenience of the vehicle driving environment. Gradually, the proportion of these support devices is expected to increase. Among various ADAS, the readily developed ones which can effectively prevent vehicle accidents are being actively commercialized and corresponding regulations and standards are widely discussed. These systems can be categorized with the longitudinal and the lateral control system depending on the orientation of the control activity applied to the corresponding vehicle maneuvering[1].

Longitudinal control system includes Adaptive Cruse Control (ACC), Advanced Emergency Brake Systems (AEBS) and Front Collision Warning System (FCWS). The systems which assist the lateral control of the vehicle are Lane Departure Warning System (LDWS) and Lane Keeping Assist System (LKAS). LDWS is designed to detect the unintentional lane departure possibly from drowsiness or inadvertently leaving the lane while driving and alert the driver through various ways including alarming. LDWS currently is being installed in commercial vehicles and its convenience in use and effectiveness in alerting driver against possible danger due to monotonous driving environment is reported. In addition, there have been many discussions on international standards leading to the finalized agreement[2].

In the process of ensuring the product quality and enhancing the performance of the controller, more thorough studies were made in the perspective of various factors affecting the outcome of the system including roadway environment, hardware specification and driver characteristics. In recent studies, the human factors in ADAS warning system such as LDWS or ACC were the most actively discussed ones which could alter the performance of the system[3].

Thiffault and Bergeron studied steering behavior data on the monotony road environment using the simulator[4]. The analysis result shows that as the driver's fatigue level increases the steering angles become large (from 6 to 10°) and extreme (more than 10°) values.

Sleepiness ratings and reaction time increase along with driving time. The research on driver fatigue on highway driving using simulator[5].

Suzuki studied changes of the vehicle driver's steering behavior depending on 4 types of lane-departure warning system when vehicles depart from lane using a driving simulator[6]. As for the form of warning, if the driver has the prior knowledge of the warning, the sound beep was more effective in reducing the response time compared to that with other types of warning. However, without the prior information given to the driver against the upcoming warning, the alert delivered through the vibration with the steering wheel was most effective.

Type of the lane departure warning is classified as early and last warning. The first or early warning is given when the vehicle is confronting the first stage of entering the lane departure mode which could be developed into the accrual crash of the vehicle with the one move in the adjacent lane. The last warning is occurred when the vehicle is still in a dangerous situation after the early warning possibly from the driver negligence against the first warning. The visual type of warning aid provide as the first warning signal is not effective enough and often triggers more second or last warning delivered in the more alarming type of signal as beep. In comparing the performance between a visual and an auditory warning method, the auditory warning appears be better compared to the visual warnings in terms of maximum deviation distance and recovery time[7].

In determining the performance of the vehicle active safety system, the reaction time is found to the most importance factor. The reaction time, often referred as response delay is defined to be the lapse until it takes to the driver to recognize objects and perform appropriate actuation against the detected situation. It becomes the crucial criteria in deciding how fast the driver recognizes and reacts to the given incidents. Reaction time varies depending on individual characteristics and the way situation is perceived. In addition, the reaction time can be reduced through the driver's prior knowledge or alertness of the upcoming danger. The driver's react time in ACC and LDWS appears to be different depending on various aspects like alert type, alert methods, driver control actions and the surrounding environment during driving.

In order to find the effect of preventing accidents in US, the field test was performed to analyze a reduction in accidents rate during 10,000 miles driving on each cargo vehicle. As a result, LDWS equipped vehicle showed better enhanced results with reduction rate of 25% in vehicle accidents and 15% in accident severity[8].

Unlike field test research, few results were found in simulating the effectiveness of active safety system since it is difficult to determine the key factors altering the performance of the system especially human induced parameters like response delay. In the process of estimating the human factors, it is hardly possible to observe human reaction since it is difficult to construct similar situation with actual driving environment without informing the driver against the test environment. If the driver acknowledge the empirical environment, it is difficult to induce natural lane departure situation from the driver's drowses or unknown mistakes and identify to source of the lane departure.

In this study, the reaction time among human factors will be considered for the simulation. It is also studied to confirm how reaction time affects accident probability after LDWS alert is triggered. A single reaction time is assessed to estimate the possibility leading to the catastrophe. Distributed reaction time with Gaussian distribution is introduced to facilitate the variation of the actual driver.

LANE DEPARTURE WARNING SYSTEM (LDWS)

LDWS consists of sensing module detecting lanes and additional portion determining the vehicle location with respect to relevant lanes, warning function to the driver if necessary, visual aid to be displayed in front of the driver (Figure 1)[9]. LDWS takes images of traveling direction using camera, recognizes current lane and determines the location of vehicles on the road. Considering the velocity of a moving vehicle and vehicle departure angle, LDWS determines whether the vehicle leaves off the lane and endangers adjacent vehicles. Various types of alarming method are executed to deliver the imminent environment effectively to the driver.

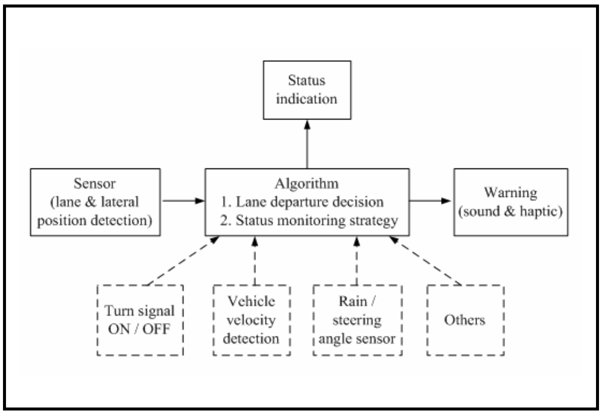


Figure 1. Functional elements of LDWS

SIMULATION

Simulation Factors

<u>Assumption</u> Following assumptions are introduced for the simulation:

1) Roadway is 3.5 m-wide two-lane straight road
2) No malfunction in LDWS device operation
3) Both the subject vehicle in the current lane and the target one in the adjacent lane run in the same velocity
4) Both vehicles are commercially operated ones

In order to simulate the accident due to the inadvertent lane change along with the vehicle running in the lane next, two lane roadways are necessary. The assumption of commercially operated vehicle might play better role in the curvature road.

<u>Selection of factors</u> Key parameters used for LDWS simulation to evaluate its benefit in terms of reducing traffic accident are as follows:

1) The vehicle velocity range is 60~100 km/h.
2) Yaw angle range involved in the lane departure of the subject vehicle is 1~10 degrees.
3) The reaction time is between 0.38 and 1.5 seconds.

Since the operating range of the most LDWS device is 60-100 km/h, same velocity condition is selected in the simulation. In simulating lane departure involved accident, fictitious vehicle as target one is assumed to exist in the adjacent lane.
The vehicle yaw angle is 1~5 degree for mild lane departure while that would be extended up to 10 degrees in the abrupt change[10]. Human reaction delay includes time it would take to perceive the imminent danger from the warning alarm and actuate the steering wheel in order to maneuver back to the original lane. This type of delay range is found to be between 0.38 and 1.5 seconds.

Simulation Procedures

The subject vehicle leaves the current line due to drowsiness or inattention. LDWS detect the lane departure and warning is issued. The hardware delay is neglected. The driver recognizes the warning and turns the steering wheel back towards to original driving lane after the designated response delay. The subject vehicle’s maneuvering distance (lateral distance) from the initial location which is the middle of two lane boundary until the last position where it returns would be calculated. Either the leftmost or the rightmost location of the subject vehicle would decide the collision between the subject vehicle and the target one. Depending on the level of delay, the subject vehicle might be exposed to accident with the target vehicle or safely return to the initial lane. The reaction time of driver is different depending on various conditions (driver's age, driving conditions, environmental conditions, etc.).

The human reaction delay is the most difficult and uncertain factor to apply. A fixed value and distributed ones with Gaussian distribution are assumed for the simulation. The simulation process calculated the lateral distance using factors including reaction time with a Gaussian distribution and yaw angle. Three exclusive zones as safe, transient and accident zone are defined depending on the vehicle's last location in the roadway relative to each lane before it moves back to its original position (Figure 2). The transient zone is introduced since the subject vehicle might impose threat to the target vehicle's operation due to close distance in between even though there would not be any accident.

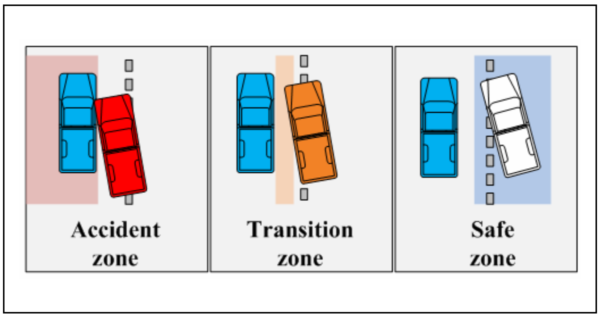


Figure 2. Schematic diagram of three zones

RESULTS

Figure 3 shows the yaw angle defining three characteristic zones for specific fixed reaction delay of 0.38 second with respect to vehicle velocity variation. The upper boundary separates accident zone from transient one while the lower one

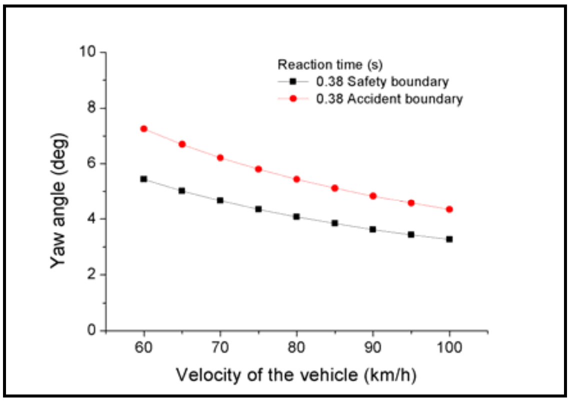


Figure 3. Yaw angle for three zones (reaction delay of 0.38 second)

classifies transient zone from the safe one. As the vehicle runs faster, it reaches easily to transient and accident zone.

Figure 4 shows yaw angle boundaries among three zones revealing for various driver's reaction time. As the reaction delay becomes larger accident zone increases. Generally, the yaw angle is inversely proportional to the vehicle velocity. The slope gets steeper for smaller reaction time, thereby the yaw angle variation becomes insensitive for larger reaction delay.

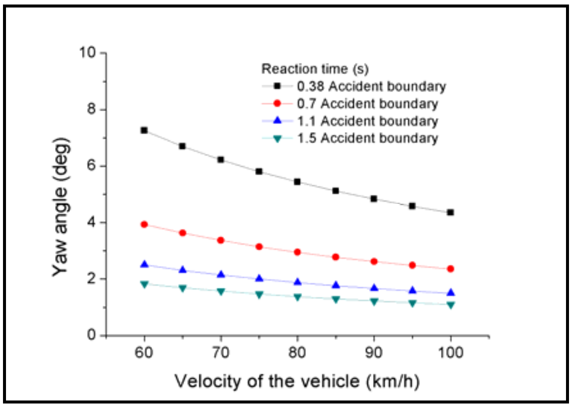
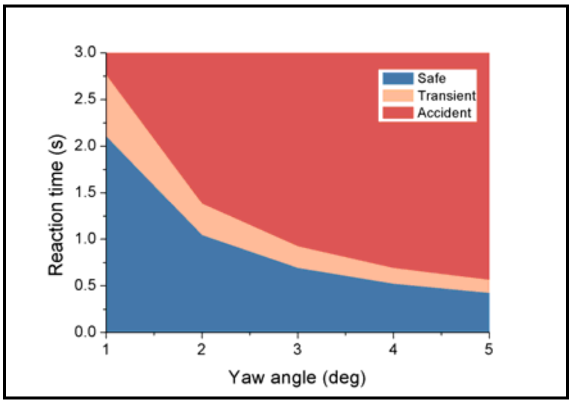


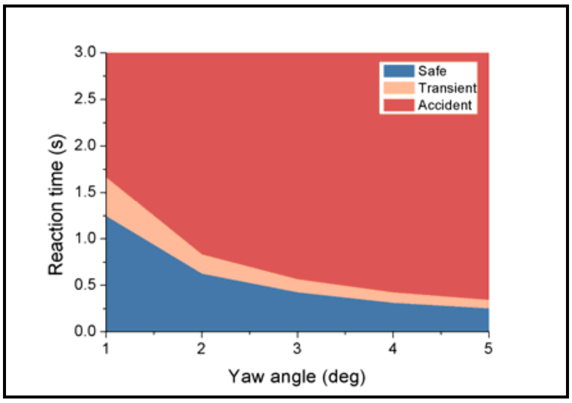
Figure 4. Accident zone variation for reaction time

Figure 5 compares boundaries of three zones for two different vehicle velocities. As velocity becomes higher accident zone increases.

Figures 6 and 7 show collaborated comparisons and trends displayed for various velocity and delay times. Similar trends are observed as in previous figures.



(a) Velocity of the vehicle : 60 km/h



(b) Velocity of the vehicle : 100 km/h

Figure 5. Boundary comparison(V=60, 100 km/h)

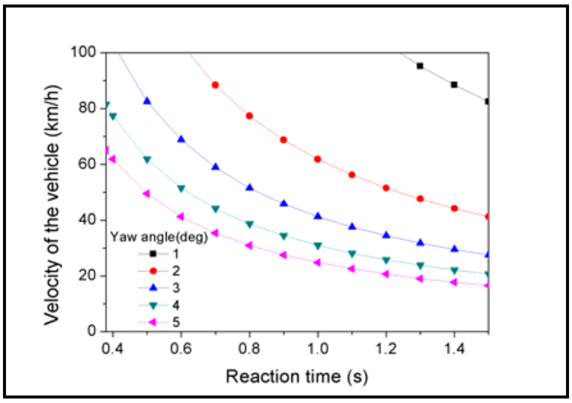


Figure 6. Safety boundary trend

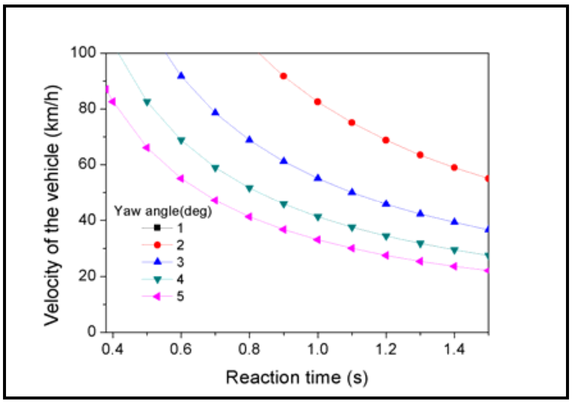
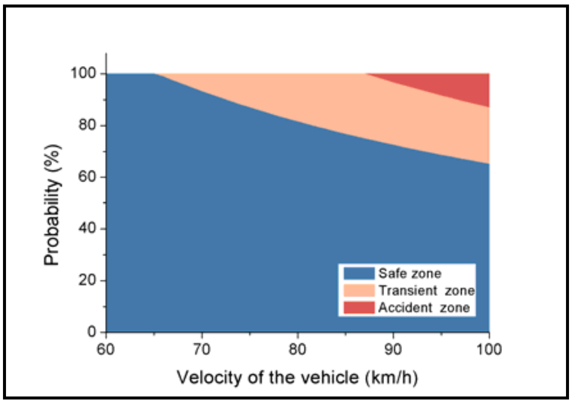
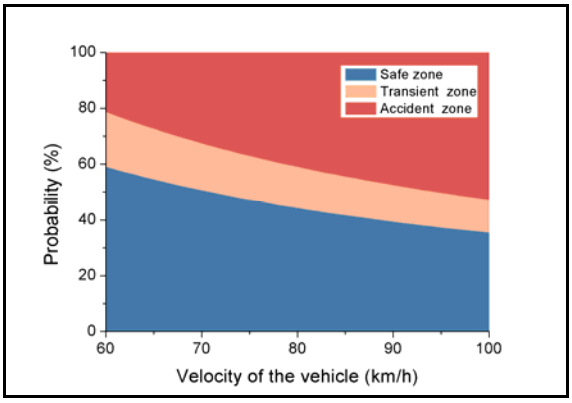


Figure 7. Accident boundary trend

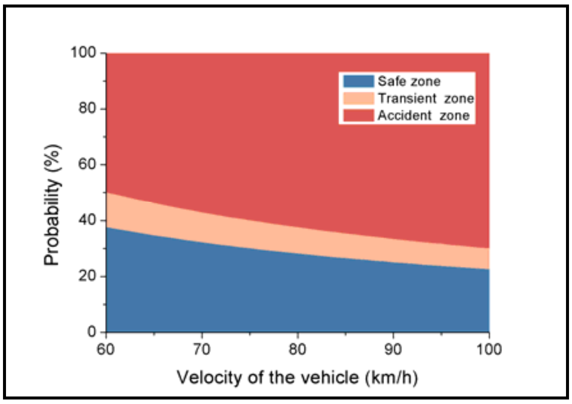
Figure 8 shows the probability of vehicle reaching three zones as safe, transient and accident region accounted for yaw angles ranging from 1 to 5 degrees as mild lane change. As the reaction delay increases, safe and transient zones decrease along with their decreasing rate trend.



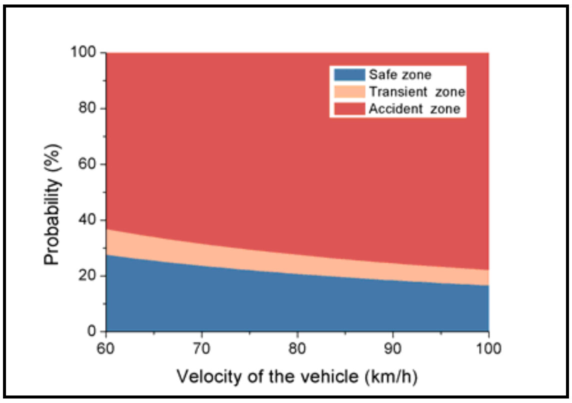
(a) Reaction time : 0.38 second



(b) Reaction time : 0.7 second



(c) Reaction time : 1.1 second



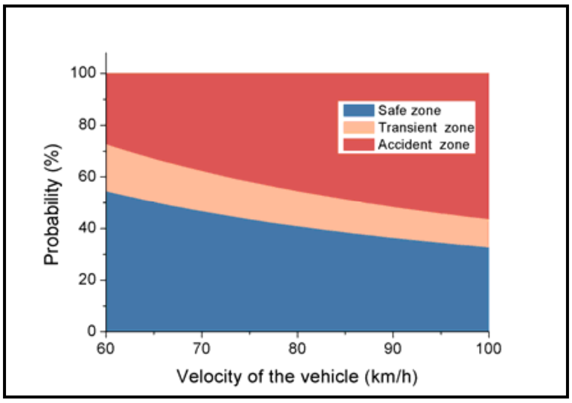
(d) Reaction time : 1.5 second

Figure 8. Accident probability trend variation (mild lane change)

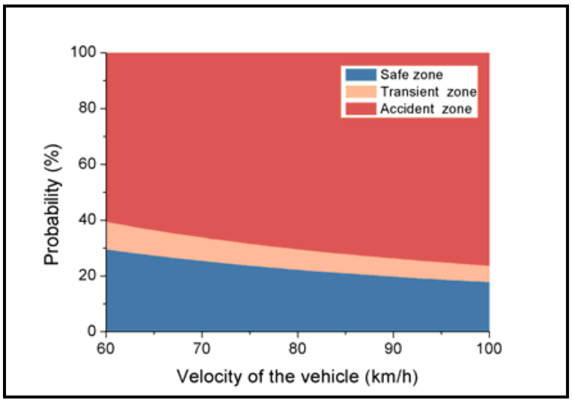
Figure 9 shows the probability of accidents due to vehicle velocity, vehicle angle 1~10 degrees is a result of simulation. When compared to Figure 8 there are big differences in accident area. The reason for this difference is because of vehicle's angle (larger than 5 degrees) due to the sudden departure. Only accident zone can be found with reaction time of 0.7 seconds and angle larger than 5 degrees in figures 8 and 9

Figure 10 shows the probability of vehicle reaching three zones. Results are also from the accumulated simulation outcomes accounted for yaw angles ranging from 1 to 10 degrees which include abrupt lane change.

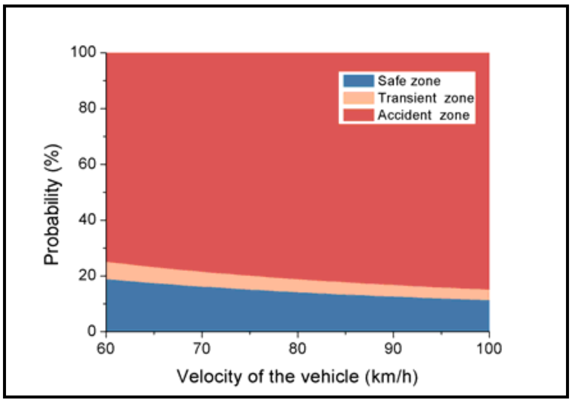
It can be naturally confirmed that incidents including the abrupt lane change display more unsafe region. For example, probability of safe zone for mild steering is 80% while that of wider steering range is 40% for vehicle velocity of 80 km/h and



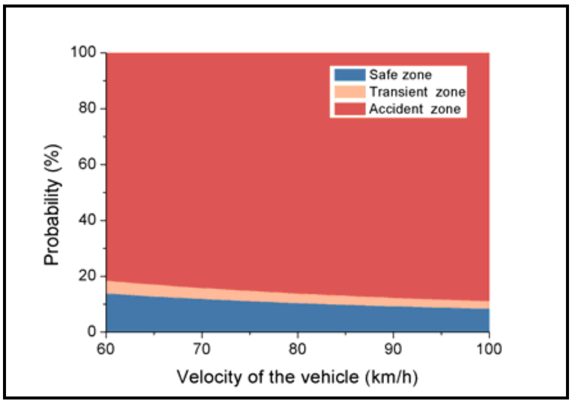
(a) Reaction time : 0.38 second



(b) Reaction time : 0.7 second



(c) Reaction time : 1.1 second



(d) Reaction time : 1.5 second

Figure 9. Accident probability trend variation by velocity of the vehicle (1~10 degree)

minimal reaction delay of 0.38 s (Figures 8 and 9). This can be explained from different perspective as in Figure 10. For mild lane change, as reaction time delay increases, hazardous results are obtained.

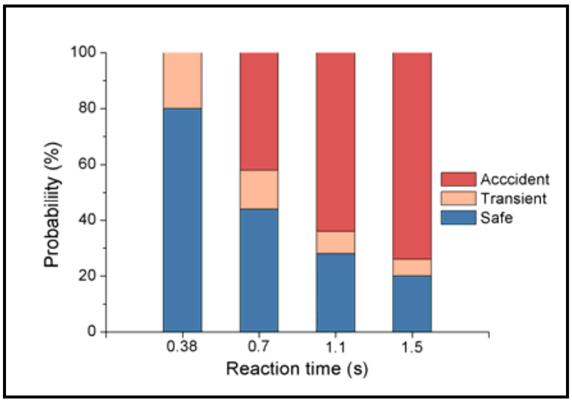


Figure 10. Probability variation by reaction time (mild lane change)

Figure 11 is a probability graph accumulated for all velocity range(60~100 km/h) and yaw angles designating mild lane changes.

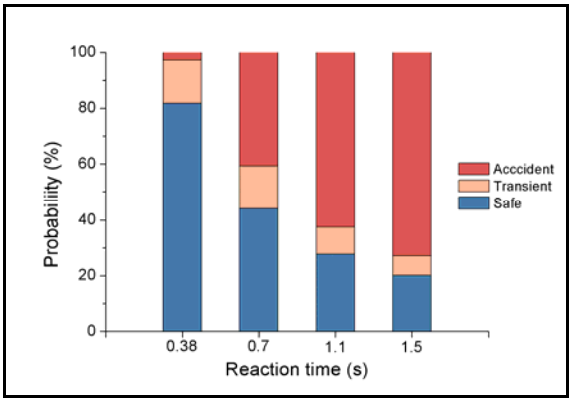


Figure 11. Accident probability variation by reaction time(yaw angle : 1~5 degree, velocity of the vehicle : 60~100 km/h)

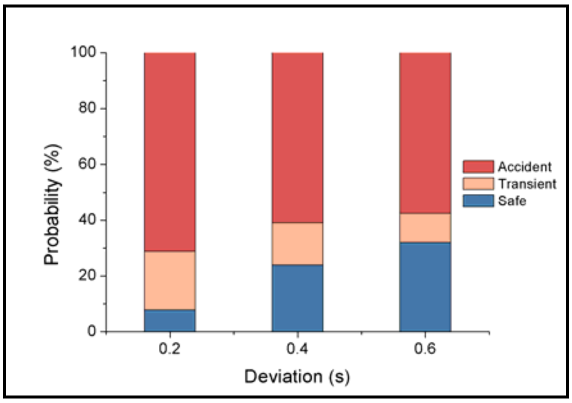
RESULT OF GAUSSIAN DISTRIBUTION REACTION TIME

Unlike the results observed in the previous section, driver’s characteristics are different and varying depending on various sorts of factors. In this study, drivers with different reaction time are all considered by collaborating results. The probability of an accident was estimated using Gaussian distribution reaction time. Since the consequence of the lane departure is decided by the level of the specific reaction delay as has been observed in the previous section, the probability of the three zones would be decided by the area under the distribution function within each specific interval that classify each regions.

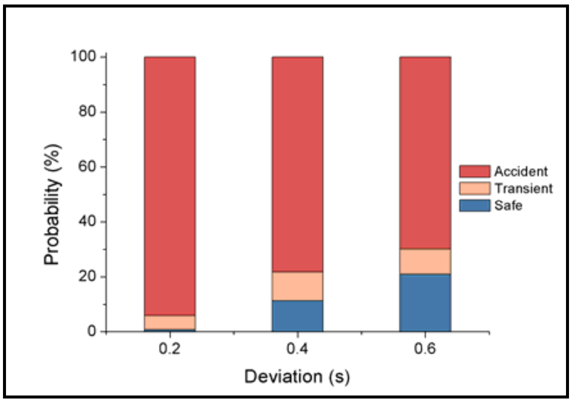
Figure 12 shows the result of simulation when vehicle's velocity and yaw angle are 80 km/h and 3 degree using Gaussian distribution assumption for driver’s reaction delay.

The result has been estimated, using mean of various reaction time distribution and relevant deviation. The higher deviation decreases the probability of an accident. As the deviation gets smaller, it displays similar feature with that from a fixed reaction delay at the very mean value.

In figure 12, as deviation becomes smaller, the accident zone gets larger. It can be naturally decided that the mean value of the distribution contributes more to cause accident as can be observed in smaller deviation results.



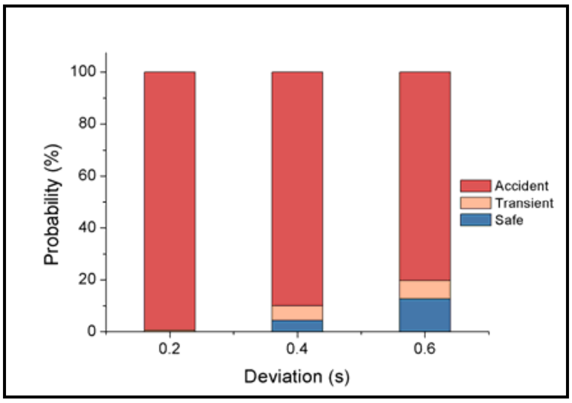
(a) Mean of reaction time : 0.8 second



(b) Mean of reaction time : 1.0 second

CONCLUSIONS

Through this study, the effect of driver’s perception reaction time with various types at lane departure affecting the performance of the system is studied.



(c) Mean of reaction time : 1.2 second

Figure 12. Probability trend for varying mean and deviation in Gaussian distribution(yaw angle : 3 degree, velocity of the vehicle : 80 km/h)

1. Specific reaction delay is identified to specify safe, transient and accident zone. The level of accident probability is also evaluated through driver's reaction time and vehicle condition at lane departure.

2. It is found that faster reaction time is needed to properly respond to the accident for larger vehicle deviation angle and velocity as vehicle departs current lanes.

3. The possibility of accident occurrence probability increases as vehicle velocity and deviation angle increases.

4. The accident probability rapidly increases up to 1 second of reaction delay and the rate of increase would subside afterwards.

5. Gaussian reaction time distribution is effectively used to approximate the general behavior of the driver against predicting the accident probability for LDWS equipped vehicle maneuver.

A thorough and detailed work will follow regarding the effect of roadway curvature. Other characteristics including vehicle dimension, steering characteristics and LDWS hardware specifications related to the commercially operated vehicle would be more thoroughly studies.

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