Impact assessment of enhanced longitudinal safety by Advanced Cruise Control Systems

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ABSTRACT

This paper presents an impact assessment of enhanced safety by Advanced Cruise Control (ACC) systems. The objective of our study is to assess of the enhancement of the driving safety between with and without the ACC system. For the impact assessment of the ACC system, the system performance test data as well as the usual driving data should be used to assess direct and indirect safety impacts.

Therefore the proposed methodologies were developed by using the collected data from the Field Operational Test (FOT) and the evaluation scenario based test for conducting the safety impact assessment of the ACC system.

First, 5 vehicles equipped with ACC system will take part in the field operational test so that we can make the FOT database. By using the collected database, Changes of crash risk between with and without ACC system are used to quantify the impact of the ACC system.

Second, to make up for the missed the FOT data, test scenario based ACC performance test was conducted. From the scenario based test, system's physical performance in the specific driving situations can be evaluated.

Finally, impact assessment of the ACC system can be obtained by combining FOT based analysis and scenario based test results. By using the proposed assessment methods, the impact assessment with respect to impacts on safety by the ACC system can be assessed scientifically.

INTRODUCTION

Road safety is a major concern in most countries and the attention is turning towards active safety system that is not only developed to reduce the consequences of accidents but also to reduce the number of driver errors and thereby the number of accidents. In case of Korea, there is the unenviable record being one of the highest traffic accidents and fatality rates. In 2009, there were 5,838 fatalities on the road.[1] Therefore, a new and systematic approach to safety system is necessary to reduce traffic casualties.

In this point of view, an Adaptive Cruise Control (ACC) system for the passenger vehicle had entered the market to mitigate the consequences of an accident and to reduce the number of fatalities among car occupants.

As market of such various new technology entries goes, research about effectiveness and necessity by new system are conducted. Also, estimating the benefits of advanced safety systems before introducing to markets is useful to develop and enhance systems effectively.

A research of safety effect by an integrated vehicle-based crash warning system was developed and tested under the Integrated Vehicle-Based Safety System (IVBSS) initiative of the United States Department of Transportation's (U.S. DOT) Intelligent Transportation System program [2][3].

In case of Europe, SEiSS(Socio-Economic Impact of intelligent Safety Systems)[4] project and euroFOT project[5] are conducted to develop harmonized and standardized assessment procedures as well as to improve related tools for commercially available pre-crash sensing system.

General research method to assess the safety effect of the system is using an accident data which is relative to safety system. From the accident data, we can simulate the safety system's performance in a same driving situation to determine whether accidents could have been avoided with the system or not. The problem of this method is that it cannot represent every relative situation of the system. Besides, it is difficult to obtain cases with detailed kinetic information for the simulation.[6]

Another approach is using of a Field Operational Test (FOT) data. By using the test vehicles equipped with the safety system, driving data was collected by 'with' and 'without' the safety system. From the analysis of the collected data, safety enhancement can be assessed as change of the crash rate 'with' and 'without' safety system. In case of FOT based approach, it also has a problem that accidents seldom occur in actual traffic.

Therefore, in this paper, assessment of enhanced longitudinal safety of the ACC system is conducted by using not only the FOT data based, but also test scenario based. First, by using the collected FOT database, the assessed safety impact of the ACC system is conducted. Next, by using the scenario based test result, expected safety effect of the ACC system can be assessed in selected driving scenarios.

Finally, impact assessment of the ACC system can be obtained by combining FOT based analysis and scenario based test results. By using the proposed assessment methods, the impact assessment with respect to impacts on safety by the ACC system can be assessd scientifically.

FIELD OPERATIONAL TEST DATA BASED SAFETY IMPACT ASSESSMENT

To assess the safety impact of the ACC system on real driving condition in Korea, Field Operational Test data based safety impact assessment was conducted.

1. System Definition

Test vehicles equipped with ACC system will take part in the field operational test so that we can make the FOT database. The FOT data was collected using a test vehicle equipped with various sensors, e.g., a laser-radar sensor, a CCD camera, a three axis inertial sensor, and a GPS.

By using the test vehicles, control input of ACC system and driver's inputs (steering, throttle, brake) are collected. Also, vehicle's driving information (velocity, longitudinal and lateral acceleration, yaw rate, etc.) and information of preceding vehicle (relative speed, clearance) are stored with GPS data.

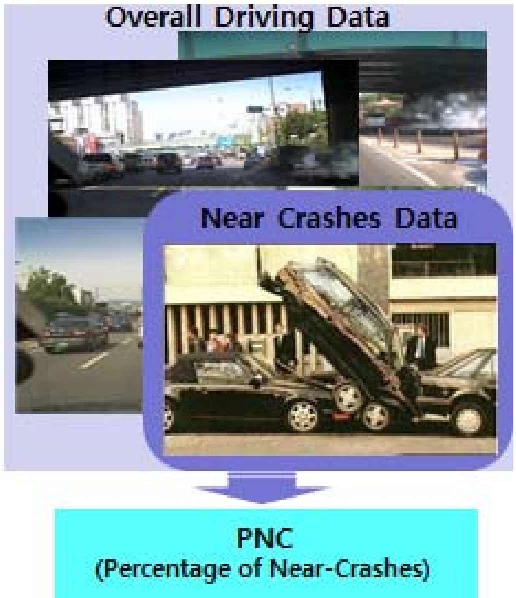

Fig.1 Overview about FOT based safety impact assessment

2. Manual FOT data base

The field test was conducted in April 2012. The test was implemented for two test conditions over a period of 1 month. During the first condition, drivers drove the instrumented vehicle for about 1 week with the ACC system turned off. In the second condition drivers drove the vehicle for about 3 weeks with the ACC system enabled. The driving road type is mix of urban and non-urban roads around the city of Seoul (Korea).

Throughout the course of the field test, drivers accumulated over 6604 km of driving – 21% by manual driving and 79% by ACC system were operated.

Table.1 Field Operational Test Data Overview

No	ACC		Manual	
	Time (sec)	Distance (km)	Time (sec)	Distance (km)
1	103271.6	667.2	12552.5	111.0
2	72229.9	825.9	26691.7	226.3
3	37241.6	697.2	13791.3	220.2
4	103060.5	1356.6	33920.7	318.2
5	177686.5	1961.7	39905.4	219.4
Total	493489.8	5508.6	126861.5	1095.1
Portion	79.6%	83.4%	20.4%	16.6%

3. Near Crashes Definition

To evaluate whether ACC system increases the safety, near-crash thresholds were selected. Threshold values consist of 3 parameters: Time To Collision (TTC) and minimum clearance between subject and target vehicle and longitudinal deceleration of the subject vehicle. If all of these three values of the FOT data are over each value's threshold, it is considered as near-crash driving situation. Near-crash thresholds were determined using distributions of intensity measures recorded in the field test.

Time To Collision(TTC)

TTC means time that is expected to collide when present relative speed and distance are kept.

By using the ECE regulation No.48 (Rear end collision Alert Signal)[7] and driver's reaction delay (1.0sec), , TTC threshold can be determined as follow:

$$TTC_{NearCrash} = \begin{cases} 1.0\ \text{sec} & if\ \ V_{rel} < 12.5kph \\ \dfrac{2.4}{30_{[kph]}} \cdot V_{rel} & if\ \ 12.5kph < V_{rel} < 30kph \\ 2.4\,\text{sec} & if\ \ 30kph < Vrel \end{cases} \quad (1)$$

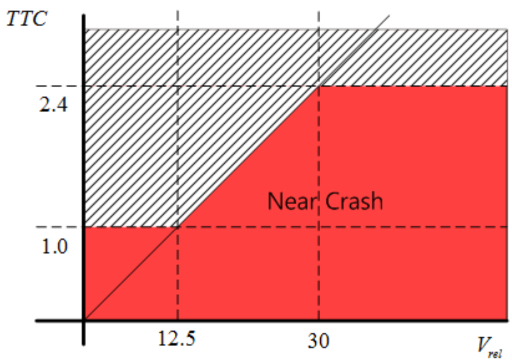

Fig.2 Threshold of the TTC

Minimum Clearance

From the experimental test data, we confirm that vehicles clearance about preceding vehicle had tended to maintain linear combination of velocity and normal time-gap.

$$c = c_0 + \tau \cdot v_p \quad (2)$$

Where, C0 means minimum clearance and τ is the linear coefficient.

By analysis of the manual driving data in normal car-following situation, the linear coefficient can be obtained as Table.2

From the under 5 percentile's linear coefficient, Table.3 Near crash rates of the FOT database the threshold value of the minimum clearance can be obtained as:

$$c_{\min} = 0.7 \cdot v_s + 1.0 \quad (3)$$

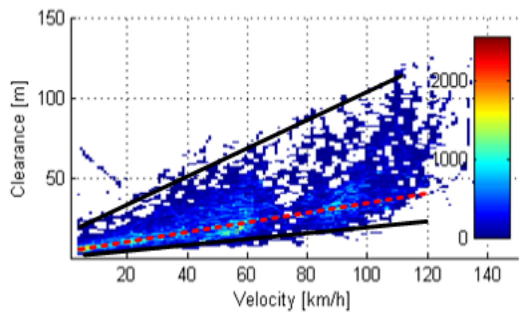

Fig.3 Clearance and Velocity relation in car-following situation

Table.2 Linear coefficient of the Time gap in Car following situation

Following-Data (15 person, 342min)					
Index-Percentile	5%	25%	Mean	75%	95%
Linear coefficient [s]	0.72	1.07	1.36	1.69	2.27

Longitudinal Deceleration

As shown in Fig.4, mainly uses area of the longitudinal accelerations were close to zero, which means that the majority of the motion occurred at nearly uniform speed. About 90% of acceleration and decelerations occurred within –2.0 and 2.0 m/s2.

Therefore, values that driver seldom used area (under -2.0m/s) are mainly selected as threshold values of longitudinal deceleration.

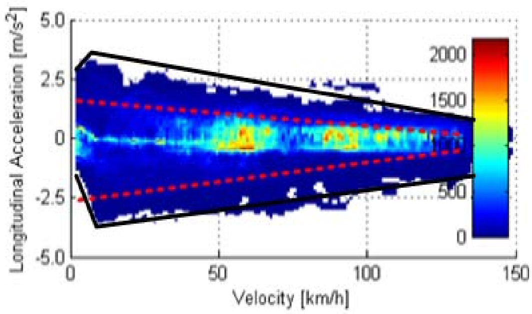

Fig. 4 Longitudinal Acceleration and Velocity Relation

4. Test Results

The exposure to near crashes in the manual and ACC driving periods provides a measure to assess the

No.	ACC				Manual			
	Distance (km)	Near Crash			Distance (km)	Near Crash		
		Total	Deceleration	Cut In		Total	Deceleration	Cut In
1	667.2	2	1	1	111.0	0	0	0
2	825.9	2	1	1	226.3	1	0	1
3	697.2	1	0	1	220.2	0	0	0
4	1356.6	7	1	6	318.2	1	1	0
5	1961.7	2	1	1	219.4	3	1	2
Total	5508.6	14	4	8	1095.1	5	2	3
Near Crash Rate (No./100km)	0.25/100km				0.46/100km			

potential safety benefits of the ACC system. By using the collected database, changing of crash risk between with and without ACC system is used to quantify the impact of the ACC system.

The number of near crash per 100 km in the manual driving period is 0.46 and in the ACC case was 0.25. In case of three vehicles (number 1, 3 and 4), the near crash rate are increased in ACC driving period. As shown in Table 3, it is caused by other vehicle's cut in. It means that the ACC system cannot guarantee the vehicle's safety in case of cut in case as much as in case of deceleration case. However, average of the near crash rates decreased during the ACC driving period.

Safety impact of the ACC can be assessed based on driver exposure to near crashes with and without the ACC system by using equation (4) [2]

$$E(S_i) = 1 - \frac{PNC_w(S_i)}{PNC_{wo}(S_i)} \qquad (4)$$

$$where,\ PNC_w(S_i) = Near\ crash\ rate\ with\ System$$

$$PNC_{wo}(S_i) = Near\ crash\ rate\ without\ System$$

From the result of the near crash rate of the manual and ACC driving case with equation (1), expected safety benefit of the ACC system in the Korean road condition is that 45% of longitudinal crash can be reduced by the ACC system.

TEST SCENARIO BASED SAFETY IMPACT ASSESSMENT

To make up for the missed FOT data, test scenario based ACC performance test was conducted. From the scenario based test, system's physical performance in the specific driving situations can be evaluated. By using the scenario based test result, expected safety effect of the ACC system can be assessed in selected driving scenarios.

1. Scenario Definition

To construct the test scenario, important component of the system should be defined first. In this research, the main component of the ACC system are defined as 'Detection', 'Decision' and 'Control'.

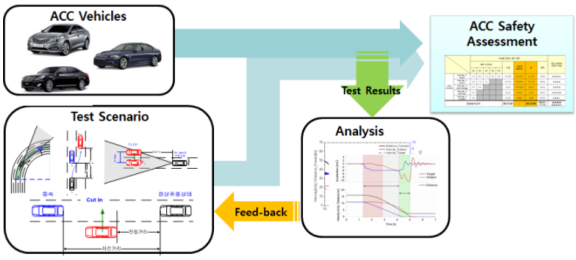

Fig. 5 Overview of the Scenario based Safety Assessment

From the main component of the ACC system, the test scenario is composed to represent ACC related accident situation which are mainly occurred in daily driving situation, i.e. subject vehicle's lane-change, cut-in or sudden decelerations of the target vehicle.

Table.4 Main component of the ACC system

Performance Factors	Assessment Elements
Detection	In-lane Vehicle Detection
	Side-lane Vehicle Detection
	Mult-vehicle Detection
Decision	Following Performance: Curved Road
	Following Performance: Multi-Vehicle
	Following Performance: In-path Vehicle
Control	Control Performance: Deceleration
	Control Performance: Cut-In Vehicle
	Control Performance: Lane Change

Tabel.5 Test Scenario for Assessment of the ACC system

Driving Situation		Scenario	
Curved Road	Entrance	In-path Vehicle (No.1-1)	Side-lane Vehicle (No.1-2)
	Following	In-path Vehicle (No.1-3)	Side-lane Vehicle (No 1-4)
Cut In		Straight Road (No.2-1)	Curved Road (No.2-2)
Lane Change		Subject Vehicle's Lane Change (No.3)	
Straight Road		Detection Range (No.4)	Distance Control (No.5)

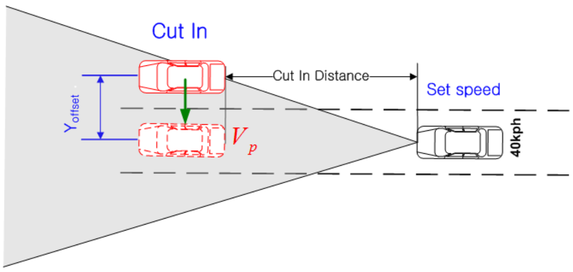

Fig. 6 Test Scenario: No.2-1, Straight Road Case

Table.6 Test Condition of Scenario No.2-1

V_s (Set Speed)	Vp (Cut In Vehicle)	Cut In Distance	Cut In Speed
40 kph	40 kph	8 (m)	Slow (4sec)
			Fast (2sec)
	35 kph	8 (m)	Slow (4sec)
			Fast (2sec)

2. Test System Definition and Test Results

To evaluate the ACC system's safety performance on the test scenario, test vehicles construct by preceding vehicle and subject vehicle. The following measuring instruments were used during the experiment: DAQ system, CCD camera, three axis inertial sensor, and a GPS.

In order to warranty sufficient safety and the repeatability of the test results, Steering and Throttle/Brake robot were selected to perform the preceding vehicle.

In case of the subject vehicle, 4 kinds of passenger vehicles (which are included the ACC system) were used.

By using the test system, each vehicle's driving information (velocity, steering, acceleration and Driver's input) and relative motion (clearance, lateral offset, relative velocity, etc.) can be collected simultaneously.

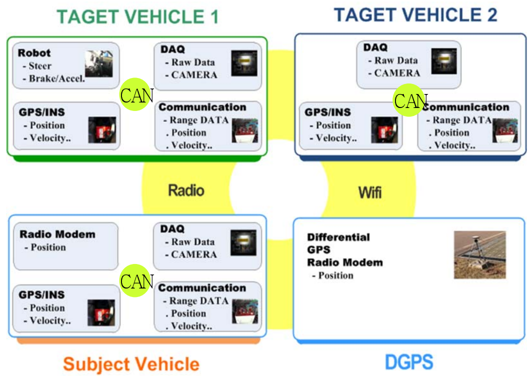

Fig. 7 Test System composition for the scenario based safety assessment

3. Safety Grade Definition

Safety level of the ACC system can be determined from the test result. To grade the performance quality of the ACC system, it should evaluate its main component which defined in previous chapter, such as detection, decision and control. Also, the longitudinal safety index (equation 5) [8] which was proposed in our previous research is used to evaluate the safety level of the ACC system's control performance.

$$I_{longitudinal} = \max\left(\frac{|x_{\max} - x|}{|x_{\max} - x_{th}|}, \frac{|TTC^{-1}|}{|TTC_{th}^{-1}|} \right) \quad (5)$$

Therefore, every scenario has an appraisal standard to make an objective evaluation. For instance, in case of 'Cut-in scenario in the straight road', the appraisal standard is composed as follow:

1) Detection component

- A point of the time to target selection

- Lateral offset between subject vehicle and cut-in vehicle when the preceding vehicle was selected as the target

2) Decision component

- Delay time of the warning signal

(If the driving came to near crash situation)

3) Control component

- Minimum clearance during preceding vehicle's

cut-in motion
- Clearance control after cut-in
- Safety index during overall driving

4. Test Results

From the scenario based test, the ACC system's safety grade can be obtained as Table.7. As shown in the Table.7, all of vehicles got over 80% of grade in total point. Especially, all of ACC system had a greate score in detection range test. Even though test vehicles had different system and control algorithm, test result was very similar to each other. However, in case of cut in test scenario, grade of some ACC system is little lower than other case.

The effect of the ACC system can be assessed by using the test result with real accident data. In this research, we referred the Pre-crash scenario from NTHSA. [9] By matching between the longitudinal related pre-crash scenario and test scenario of the ACC system, reduction rate of accidents can be estimated as Table.8. From the estimation, it is expected that 35% of the accidents can be reduced by the ACC system based on safety assessment by using the test scenario.

Table.7 Test Result of 'Test scenario based safety assessment of the ACC system'

Test Result : Test Scenario based Safety Assessment of the ACC system						
	Test No. 1 Curved Road	**Test No. 2 Cut In**	**Test No. 3 Lane Change**	**Test No. 4 Detection Range**	**Test No. 5 Distance Control**	**Sum**
Vehicle A	13.8/15	21.2/24	9.75/15	5.64/6	30/40	80.4/100
Vehicle B	11.5/15	17.3/24	11.55/15	5.8/6	36.4/40	82.5/100
Vehicle C	12.3/15	17.4/24	13.5/15	5.8/6	33.6/40	82.6/100
Vehicle D	12.3/15	15.7/24	12.9/15	5/6	36.2/40	82.1/100
Average	12.5/15 (0.83)	17.9/24 (0.75)	11.9/15 (0.80)	5.6/6 (0.93)	34.1/40 (0.85)	81.9/100 (0.82)

Table.8 Safety Assessment based on Scenario test

Pre-crash Scenario (Longitudinal related Case)	**Rate**	**Matching Scenario**	**Test Result**	**Estimated Reduction Rate of Accidents**
Following Vehicle Approaching a Decelerating Lead Vehicle	7.2%	Distance Control (No.5)	0.85	6.1
Following Vehicle Approaching Lead Vehicle Moving at Lower Constant Speed	3.5%			3.0
Following Vehicle Approaching an Accelerating Lead Vehicle	0.3%			2.6
Following Vehicle Approaching a Stopped Lead Vehicle	16.4%			13.9
Vehicle Taking Evasive Action Without Prior Vehicle Maneuver	0.95%			0.8
Vehicle(s) Changing Lanes – Vehicles Traveling in Same Direction	5.7%	Cut In (No.2)	0.75	4.3
Vehicle Taking Evasive Action With Prior Vehicle Maneuver	0.2%			0.1
Vehicle(s) Turning – Vehicles Traveling in Same Direction	3.7%			2.8
Following Vehicle Making a Maneuver and Approaching Lead Vehicle	1.4%	Lane Change (No.3)	0.80	1.1
Vehicle(s) Parking – Vehicles Traveling in Same Direction	0.8%	None (Low Speed Case)	-	-
Total	40.15%			34.9%

CONCLUSIONS

In this paper, the impact assessment method of enhanced safety by Advanced Cruise Control (ACC) system was proposed. For the impact assessment, the scenario based system performance tests as well as the usual FOT data were used to assess direct and indirect safety impacts.

By using the FOT data, expected safety impact of the ACC system can be obtained from changing of near crash rate between with and without ACC system. Based on the reduction of near crashes, the integrated system could help prevent from near crashes approximately 45%.

Test scenario based ACC performance test was conducted to make up for the missed case in the FOT data. From the scenario based test, system's physical performance in the specific driving situations can be evaluated. Finally, impact assessment of the ACC system can be obtained by combining real accidents data and scenario based test results. By using the proposed assessment methods, the impact assessment with respect to impacts on safety by the ACC system can be assessed scientifically. From the estimation result, the ACC system can reduce the accident by 35%.

As a conclusion, the ACC system can reduce the car accidents significant in car following near crashes when the system was enabled. However, in case of the cut in of other vehicle, the system cannot be guaranteed the safety as well as other case.

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