공학석사학위논문

Implementing Surrogate Safety Measures to Driving Simulator and its Applicability

Driving Simulator내 적용가능한 Surrogate Safety Measures의 선정

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Abstract

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Since 93% of all traffic accidents are related to human factors, the prevention of human factors is important for reducing the number of traffic accidents, and safe-driving education can contribute to this goal. Thus, a many safe-driving education programs using driving simulators (DSs) have been developed to reduce crashes that occur due to human factors. However, DS-based education has several limitations to be fully utilized, such as risk-free decision making, simulator sickness, and the lack of reality. Of special concern is that DS-based education generally is conducted without considering the interaction between the vehicle represented by the DS and surrounding vehicles. Thus, the goal of this study was to determine whether a driver's aggressive driving can be evaluated by considering his or her interaction with surrounding vehicles in comparison to the surrogate safety measures (SSMs) currently used in driver's education using DSs. Thus we used a traffic flow model to realistically represent the movement of vehicles surrounding the DS. After reviewing the literature, we used various SSMs as indicators to identify aggressive driving, and the usefulness and applicability of the the SSMs were reviewed through an experimental study. The results showed that 20 of the SSMs were significant measures that could be used in DS-based education. An additional study is needed to evaluate the effects of driving education based on the SSMs proposed in this research and to develop a scoring system that integrates several SSMs into a comprehensive index for evaluating the safety effects of drivers' education.

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Chapter 1. Introduction

INTRODUCTION

Generally, the 3E policy, i.e., enforcement, education, and engineering, has been presented as a measure to reduce traffic accidents and improve traffic safety *(1)*. Since 93% of traffic accidents have been found to be related to human factors *(2)*, the prevention of human factors is very important because doing so would result in a significant reduction in the number of traffic accidents, and reducing drivers' errors can be addressed to a certain degree through safe-driving education. For instance, the Nevada Department of Transportation implemented safety education called "The Aggressive Safety Program Targeting Drivers" to address the various problems associated with traffic accidents. As a result, fatalities caused by drivers' errors decreased by approximately 40%, i.e., from 431 to 258 *(3)*. Also, the results of another study showed that safety education targeting bus drivers had the effect of reducing abnormal behaviors related to deceleration and steering *(4)*.

Since safe-driving education is related very closely to improvements in traffic safety, this education is provided through various programs, and many of the safe-driving education programs use a driving simulator (DS) *(3, 5)*. According to a survey targeting people subject to safe driving education in Nevada, approximately 53% of survey respondents selected DS education as being the most useful among all programs in safe-driving education, which indicated its significant usefulness *(3)*. Also, the Algemene Nederlandse Wielrijders Bond (ANWB), an automobile association in Holland, has been conducting safety education since 2002 in which initial and advanced drivers are targeted, and 19 DSs allow each participant to have 20 minutes of DS training *(5)*. In addition, in the TRAINER program conducted under the sponsorship of the EU, a driver training curriculum using DS was developed as a part of the efforts to reduce traffic accidents *(6)*.

Education using the DS has become an important part of safe driving education, and the usefulness of the education using the DS has been acknowledged. As indicated in a study conducted by Fisher, D. et al. (2007), DS trained group showed higher eye fixation ratio about risky information than DS untrained group *(7)*. However, there are some limitations that DSs are fully utilized as an alternative for real driving. *(8, 9)*. First, actual risks based on drivers' decisions do not exist in the DS environment, risk-free decision making occurs, which makes the DS less practical. Second, drivers who use the DS may suffer from physical or mental discomfort due to a simulator sickness. Third, since the algorithms that are used to simulate the movement of surrounding vehicles have narrow ranges and fewer variations, it is difficult to mimic realistic circumstances around the vehicle. Fourth, aggressive driving is influenced by various factors, so it is necessary to prepare reliable training courses that consider such factors in order to evaluate drivers accurately. If the limitations of DSs are improved, it is expected that they will be used more extensively for safe-driving education. This study was conducted to improve the third and fourth limitations among the four limitations mentioned above.

As described more precisely in the Methodology section, the literature review indicated that speed, lane position, steering angle, and acceleration are the main variables used as measures for evaluating a driver in a DS. It also was indicated that most of the measures tend to focus on the behavior of a subject vehicle without considering its relationship to surrounding vehicles. This indicates that a driving behavior that requires interaction with surrounding vehicles, such as changing lanes, cannot be properly evaluated in a DS. If the evaluation of a driver is properly done in a DS by considering the interaction between the subject vehicle and surrounding vehicles, it is expected that the usefulness of DSs could be improved significantly, and they could be used extensively to train drivers.

The intent of this study was to review whether it is possible to evaluate a driver's aggressive driving by considering the interaction with surrounding vehicles targeting the surrogate safety measures (SSMs) currently used in drivers' education using DS. To do this, various traffic flow models for realistically describing the movement of surrounding vehicles were implemented in the DS. After reviewing the literature, various SSMs were implemented that have been used as indicators for identifying aggressive driving, and the usefulness and applicability of the implemented SSMs were investigated through an experimental study. In an experimental study, the DS scenario includes several road types such as freeway, urban and rural road. The applicability of implemented SSMs was analyzed in the whole sections integrating all road types in scenario and can be further analyzed regarding each road type in future research. Currently, drivers' education using DSs has been conducted in various ways throughout the world. If the evaluation indicators presented in the results of this study can be applied appropriately to DSs in the future, it is expected that the reliability of DS will be enhanced, and utilization of DSs will be increased.

Chapter 2. Methodology

METHODOLOGY

For this research, numerous prior studies were reviewed to identify the measures that have been used to date to evaluate driving behaviors in DSs, and it was confirmed that the number of measures that could explain the interrelationship between vehicles is very limited. In addition, the SSMs were scrutinized to identify implementable SSMs that were judged to be applicable to the evaluation of aggressive driving behaviors. Next, we developed a new DS in which the movement of surrounding vehicles was implemented based on traffic flow models. With the newly-developed DS, an experiment was designed to collect data on the behaviors of a variety of drivers. During the experiment, individual drivers were instructed to conduct normal, conservative, and aggressive driving. Then, several statistical analyses were conducted to investigate which SSMs could be applicable to DS.

Review of the Driving Behavior Evaluation Measures Used in DS

Numerous prior studies were reviewed to identify the measures that had been used to date in DS to evaluate driving behaviors. Figure 1 shows that, in most of the literature references, drivers' driving behaviors were evaluated with several indicators, including speed *(10, 11)*, lane position *(11-13)*, steering angle *(14)*, and acceleration *(15)*. In addition, several indicators related to traffic violations *(12)* also were used. However, as mentioned earlier, the effects of interaction with surrounding vehicles rarely are considered in the current DSs, even though an individual driver's driving behavior is significantly influenced by the surrounding vehicles.

According to the analysis of Moridpour et al., lane-changing behavior varied according to the types of the surrounding vehicles *(16)*. Also, El-Shawarby et al. indicated that the influence of surrounding traffic flow varied according to the rate of deceleration of the vehicle *(17)*. However, indicators considering the relationship with surrounding vehicles in lane-changing situation were not applied to DSs, and the indicators that were applied that considered the relationship with leading and following vehicles were limited to Time to Collision *(18, 19)*, Time Headway *(20)*, and Distance Headway *(21*). Therefore, it is necessary to determine whether indicators that consider the relationship with surrounding vehicles can be applicable to the driver's education using DSs.

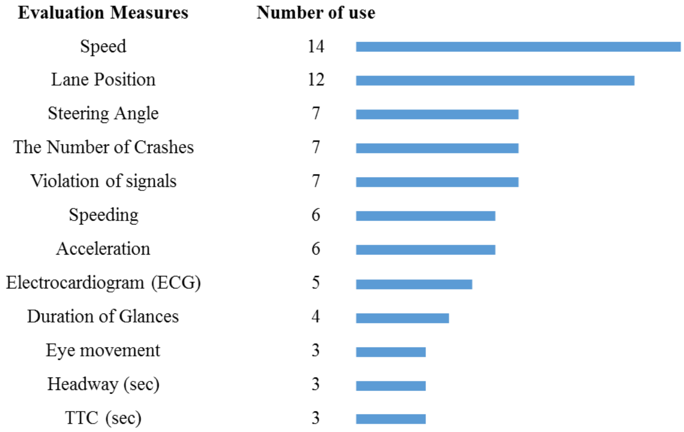


FIGURE 1 List of the evaluation measures applied in DSs

Survey of Implementable SSMs in DSs

In order to identify indicators applicable to DSs, we reviewed the literature regarding SSMs. SSM is an indicator that can reflect the safety of a facility or at least the probability of higher-than-average accident rates for a facility *(22)*, and it is known that the frequency and severity of accidents can be captured with the value of the relevant indicator, so it is used in various fields *(23)*.

Initially, SSMs were used as measures for the analysis of highway safety. Gao et al. used "time to collision" (TTC) and deceleration rate to avoid crash (DRAC) as indicators for judging the safety of a work zone on the highway *(24)*. Moreno et al. used accumulated speed uniformity and accumulated speeding as the indicators to evaluate the effectiveness of traffic calming measures (*25)*.

SSMs also are used as measures to evaluate drivers' behaviors, and time to collision (TTC) and post-encroachment time (PET) are used as indicators to evaluate the driver's safe driving *(26)*. Hallmark et al. compared countermeasures to determine which countermeasure was effective for preventing lane departures that occur on the curved sections of rural, two-lane roads, and they analyzed the driver's behavior by comparing the access gap time of drivers at the left-turn lanes of the intersection according to the type of offset *(27)*. Also, the Modified TTC (MTTC) and Crash Index (CI) were presented as indicators for evaluating the risk of collision *(28)*.

Previous studies have attempted to apply SSMs to DSs. TTC was used as an indicator to judge the effectiveness of Advanced Driver Assistance Systems (ADAS) designed for supporting older drivers in the DS *(19)*. However, other than those, only limited studies have applied other SSMs to DSs, and the aim of most of those studies was to compare the driver's behavior in specific conditions rather than to evaluate the overall driving performance. SSMs are used as indicators to evaluate the degree of risk on a specific road section or to evaluate drivers' aggressive driving.

However, the use of SSMs in DSs has been very limited. Therefore, it is necessary to use the literature to investigate applicable SSMs.

In this study, the evaluation indicators were classified into “Individual Vehicle” and “Relating to Surrounding Vehicle,” and various aggressive driving types that caused aggressive driving were selected. Then, after the literature review, the SSMs that were judged to be applicable to each type of aggressive driving were selected as implementable SSMs. Applicability was judged by two possibilities, i.e., (a) the possibility of computation in DS and (b) the possibility of analyzing aggressive driving with the values of the indicators.

TABLE 1 Definition of Implementable SSMs

1st Criterion	2nd Criterion	No.	SSM	Units	Definition
Indivi-dual Vehicle	Speeding	1	Accumulated Speeding (AS)	*kph*	Sum of areas (absolute values) bounded between the speed profile and the speed limit divided by length of the driving segment
	Inconsistent-Speed Driving	2	Speed Uniformity (SU)	*kph*	Sum of areas (absolute values) bounded between the speed profile and the average speed divided by length of the driving segment
		3	Speed Variation (SV)	*kph*	The standard deviation of the operating speeds
	Rapid Acceleration/ Deceleration	4	Acceleration	m/s^2	Acceleration of subject vehicle
		5	Deceleration	m/s^2	Deceleration of subject vehicle
		6	Acceleration Noise (AN)	m/s^2	The standard deviation of the operating accelerations.
	Rapid Handle Manipulation	7	Lane Position	*M*	Standard deviation of Lane position during driving
		8	Yaw Rate	*°/sec*	Vehicle's angular velocity around its vertical axis
		9	Lane Change	-	The number of lane chane during driving
Relating to Surround-ing Vehicle	Non-compliance of Safe Distance	10	Gap Distance (GD)	*m*	Distance between the vehicles
		11	Proportion of Stopping Distance (PSD)	-	Ratio of distance available to maneuver to the distance remaining to the projected location of collision.
		12	Time to Collision (TTC)	*sec*	Expected time for two vehicles to collide if they remain at their present speed and on the same path
		13	Modified TTC (MTTC)	*sec*	Time to Collision considering deceleration of vehicles
		14	Deceleration Rate to Avoid Crash (DRAC)	m/s^2	Rate at which crossing vehicle must decelerate to avoid collision
	Unsafe Lane – Changing	15	Front GD	*m*	GD (Gap Distance) with leading vehicle of current lane in Lane Change situation
		16	Lag GD	*m*	GD (Gap Distance) with following vehicle of target lane in Lane Change situation
		17	Lead GD	*m*	GD (Gap Distance) with leading vehicle of target lane in Lane Change situation
		18	Front TTC	*sec*	TTC(Time to Collision) with leading vehicle of current lane in Lane Change situation
		19	Lag TTC	*sec*	TTC(Time to Collision) with following vehicle of target lane in Lane Change situation
		20	Lead TTC	*sec*	TTC(Time to Collision) with leading vehicle of target lane in Lane Change situation
		21	Max Yaw Rate	*°/sec*	Maximum value of yaw rate in collision course
		22	Min TTC	*sec*	Minimum value of TTC(Time to Collsion) in collision course
	Fatal Crash Risk	23	Braking Reaction Times (BRTs)	*sec*	Reaction time of subject vehicle in collision course
		24	Max S	*kph*	Maximum speed of the vehicle in collision course
		25	Min Deceleration	m/s^2	Minimum value of deceleration in collision course
		26	Deceleration Rate (DR)	m/s^2	Initial deceleration rate in collision course
		27	Crash Index (CI)	m^2/s^3	Kinetics to describe the influence of speed on kinetic energy involved in collisions

Development of A New Driving Simulator

The DS developed in this study was equipped with vehicle dynamics based on a real vehicle and a physics engine which is a software related to graphic system was installed in the DS, and it provides driving environments similar to actual driving environments. The DS consists of the cabin where the driver sits, an electric motion platform, and an operating console for equipment operation and data management.

■ **Equipment Specifications**

- Model : 1/4 of vehicle (1 Seat Type)
- Instrument panel : ramp and gauge
- Steering wheel handle and Active Steering Wheel System
- Max torque Rating : 38 Nm @12 V
- Signal Interface : CAN (500 Kbit/s)
- Power Supply : 12 VDC (60 A max)
- min 38 Nm @300˚/sec, min 20 Nm @ 600˚/sec

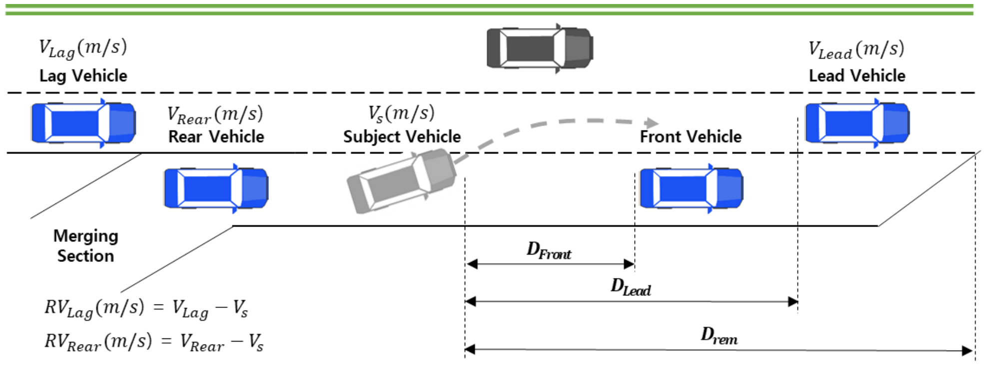
■ **Visual System**

- Panel Type : 42-inch LCD
- Screen ratio : 16:9
- Viewing Angle : 178˚
- Resolution : 1920 x 1080
- PC Interface : HDMI. D-SUB
- Power : AC 220 V, 190 W
- Weight : 16 kg/1 ea
- Operating Environment : 0 – 50℃

FIGURE 2 Components of the Driving Simulator

The movement of surrounding vehicles should be realistic in order to use an indicator that can consider the relationship with them as an indicator to judge safe driving. Techniques which have been used to describe the movement of surrounding vehicles are State machines, Rule-based models and Mathematical or probabilistic models. However, Rule-based model is hard to reflect the various movement since the model is deterministic, Therefore, we applied mathematical or probabilistic models in DS which can apply various variables and stochastic model. The traffic flow models used included car-following, lane-changing with merging, and gap-acceptance (left-turn, right-turn, roundabout). A linear car-following model and a generalized GM model were applied to car-following, and a logit model and the critical gap model were applied to lane-changing and gap-acceptance.

In this study, the parameters of the models were calibrated separately for normal times and when it was raining. The parameters that were estimated through field observations were set as the reference values for the movement of surrounding vehicles, and the parameters were implemented differently according to the weather indicated in the DS scenario.



Variable Definition of Binary Logit Model

1st Category	2nd Category	3rd Category	Parameter	
			Normal	Rainy
Car-Following Model	Car-Following	* Generalized GM Model	λ : 0.40, m : 0.91, ℓ : 1.19	λ : 0.22, m : 1.44, ℓ : 1.39
		* GM's Linear Model	λ : 0.14, T : 2.09(sec)	λ : 0.22, T : 2.46(sec)
Lane-Changing Model	Merging Line	** Critical Gap (m)	51.73(m)	56.52(m)
		** Critical Gap (sec)	9.43(m)	13.24(m)
		* Binary Logit	D_{Lead} : 0.01, D_{rem} : 0.05 V_s : -0.21, RV_{Lag} : -0.15	-
	Main Line	** Critical Gap (m)	88.60(m)	45.30(m)
		** Critical Gap (sec)	4.55(m)	8.65(m)
		* Binary Logit	D_{Front} : 0.12, D_{Lead} : -0.01 RV_{Rear} : 0.12, RV_{Lag} : 0.04	-
Gap-Acceptance Model	Unprotected Left-Turn	* Binary Logit	Time Gap : -1.33, Car-Type : 2.35	Time Gap : 0.99, Conflicting Flow : -0.27 Number of Conflicting Lane : -1.51
		** Critical Gap (sec)	4.5(sec)	4.80(sec)
	Unprotected Right Turn	* Binary Logit	Time Gap1) : -2.62, Q_1stlane2) : 0.01	Time Gap1) : 1.80 Q_1stlane2) : -0.21
		** Critical Gap	3.75(sec)	4.10(sec)
	Roundabout	* Binary Logit	Time Gap1) : -1.48, tFollowing-up 3) : 0.01	Time Gap1) : 1.76 Waiting Time : -0.20
		** Critical Gap (sec)	3.5(sec)	4.40(sec)

* : Mathematical or probabilistic models , ** : Rule-based model
1) Time Gap : Time gap between the subject vehicle and mainlane vehicles (sec)
2) Q_1stlane : Traffic volume on the first lane of the major Street (vph)
3) tFollowing-up : Time gap between the subject vehicle and front vehicle (sec)

Figure 3 Traffic Flow Models and Parameters Implemented in the DS

In order to analyze and evaluate the applicability of the indicators selected as implementable SSMs to judge whether drivers were driving safely, the indicators must be implemented on the DS. To do this, the input variables required for the calculation of each SSM were defined, and modules that could calculate SSMs were implemented. Also, a 'traffic violation' item was implemented on the DS for safe driving education. Since the purpose of this study was to analyze the applicability of SSMs in DS, traffic violation indicators were excluded from the analysis.

Experimental Design

Experimental data were collected in order to analyze whether each SSM was applicable to DS. The purpose of the instruction was to analyze whether SSMs applied to the DS could capture the differences between the types of driving. therefore, we instructed each participant to drive three different driving type; Normal, Conservative, Aggressive driving. Same experimental instruction was implemented in another study to compare fuel consumption *(29)* and 'Normal' driving means driving as usual, and 'conservative' driving means maintaining a significant distance from the leading vehicle, avoiding rapid acceleration and deceleration, and driving at or below the speed limit. Also, in order to obtain data related to ‘aggressive’ driving, each driver was instructed to drive the entire section within 10 minutes and to maintain a narrow distance between her or his vehicle and the leading vehicle. The instruction was focused on ‘safe distance’, ‘speed’, ‘acceleration and deceleration’ not to confuse participants by information overload.

The intent of the study was to set eight risk events in three types of roads, including a freeway, a rural road, and an urban road, and to evaluate the driver's driving behavior under the various scenarios. The whole driving section was approximately 6.2 miles (freeway: 1.4 miles, urban road: 3.7 miles, rural road: 1.1 miles), and it took approximately 20 minutes to drive the whole section (Figure 4). The experiment was conducted for approximately two months, from February 2017 to November 2017, and 41 drivers (29 male drivers and 12 female drivers) participated in the experiment. The ages of the test subjects ranged from the 20s to the 40s, and the test subjects who were in their 20s and 30s accounted for 39% of the total number of participants. Concerning the driving experience, drivers with 0-5 years of driving experience accounted for the largest portion, i.e., 31%.

No.	Risk Event Description	No.	Risk Event Description
1	Rear-end collision situation by rapid deceleration of leading vehicle	5	Right-angle collision by vehicle going straight from left side during left-turn in signal intersection
2	Crash situation by passing pedestrian in crosswalk	6	Right-angle collision by vehicle going straight from left side during left-turn in signal intersection
3	Crash situation by passing pedestrian in midway of the road	7	Crash situation by passing pedestrian(Bicycle) in crosswalk
4	Right-angle collision by surrounding vehicle in lane-changing situation	8	Crash situation by passing pedestrian in crosswalk during right-turn

FIGURE 4 Experimental design

Chapter 3. Results OF The ANALYSES

The purpose of this study is to review SSMs applicable to DSs. As mentioned in the experimental design, DS data of 41 people were analyzed in order to judge the applicability of each SSM in the DS. Each driver performed three types of driving, i.e., normal, conservative, and aggressive driving during the experiment.

In this study, statistical analyses were performed to evaluate whether the indicators included in the candidate group of evaluation indicators had the ability to properly capture the differences between the types of driving. The overall analysis process is presented in Figure 5.

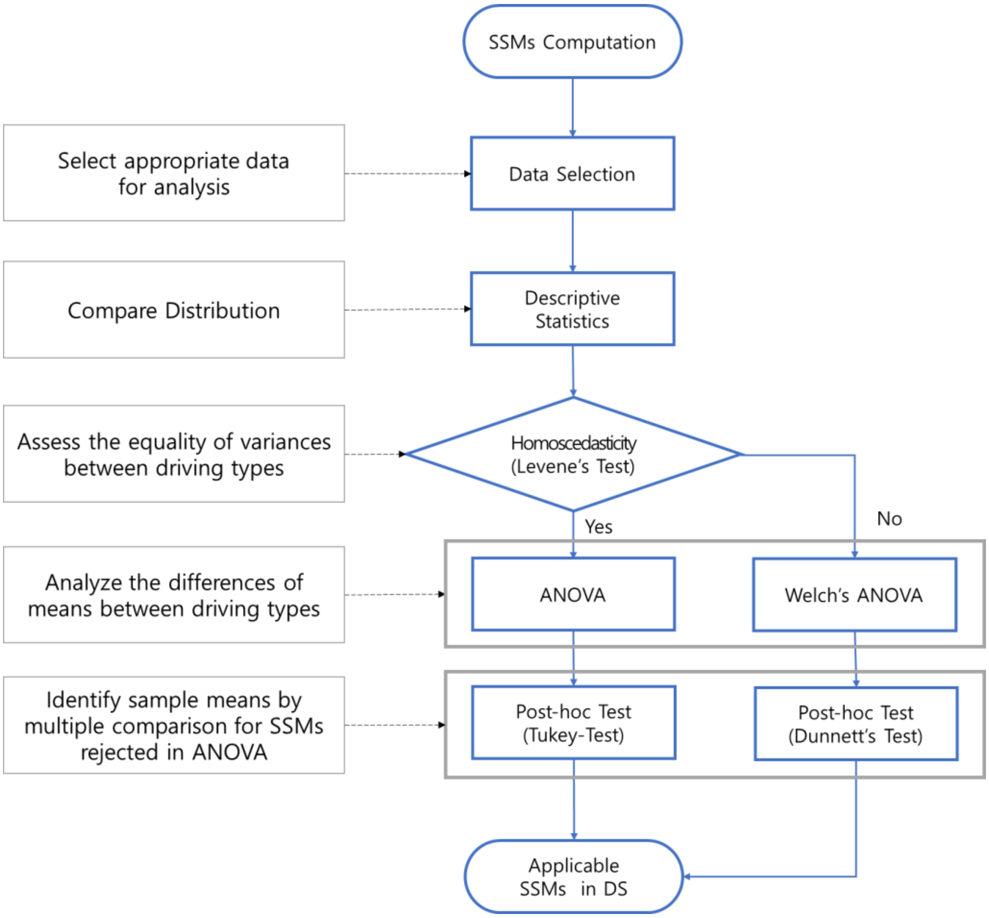
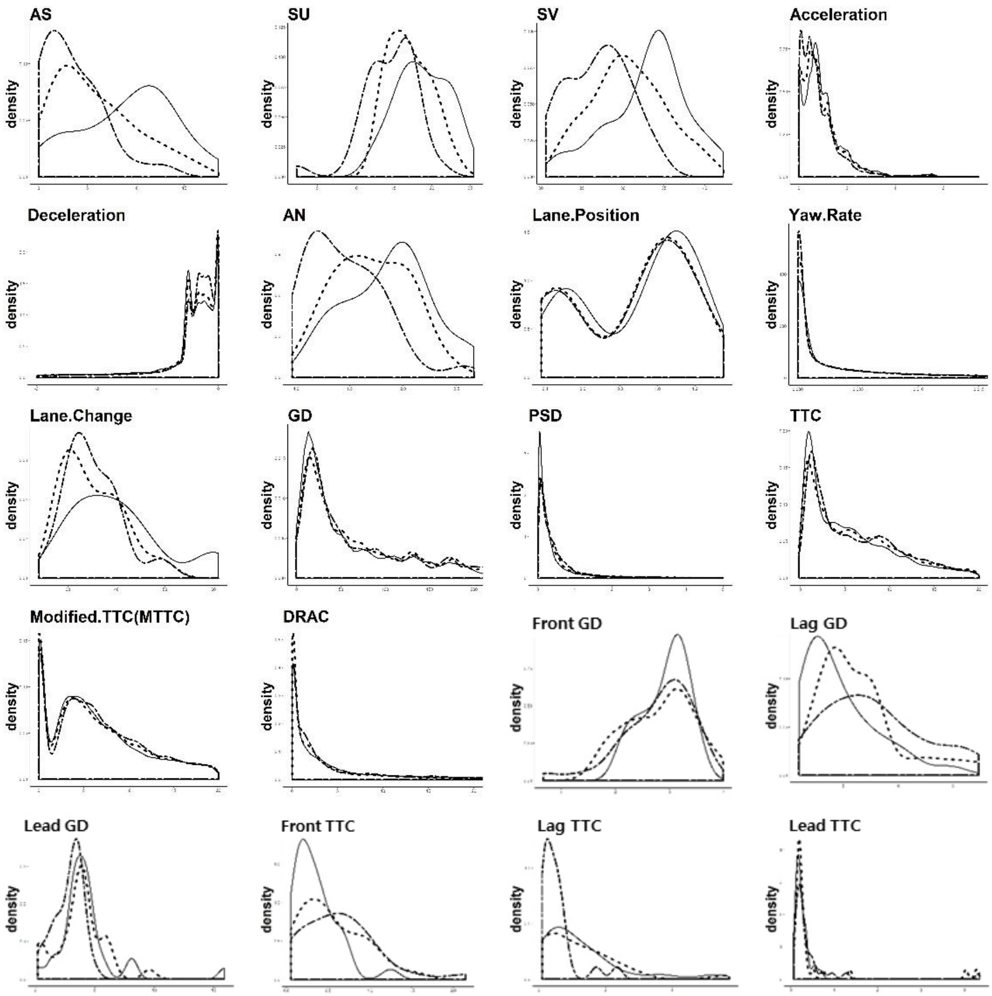


FIGURE 5 Process of statistically analyzing applicable SSMs in the DS

Data Selection
Before analyzing measures which showed significant difference between driving type (Conservative vs Aggressive), each participant's data set should be reliable. To select reliable data, we set average as representative value. If the gap of average between driving type shows same direction as we intended, the experiment can be seen as appropriate for the purpose of experiment. In this research, we set 13(50%) as minimum number to satisfy standard among 27 measures. Therefore, we selected 31 participants' data set which satisfied minimum standard (50%), and rest of 10 participants' data were excluded.

Distribution Comparison
Prior to the statistical analysis, the distribution of drivers' recorded driving behaviors was compared by driving type and reviewed for each SSM. If the distribution by driving type varies for a certain SSM, it can be considered that the relevant SSM shows a significant difference by driving type and that such an SSM is appropriate as an evaluation indicator.



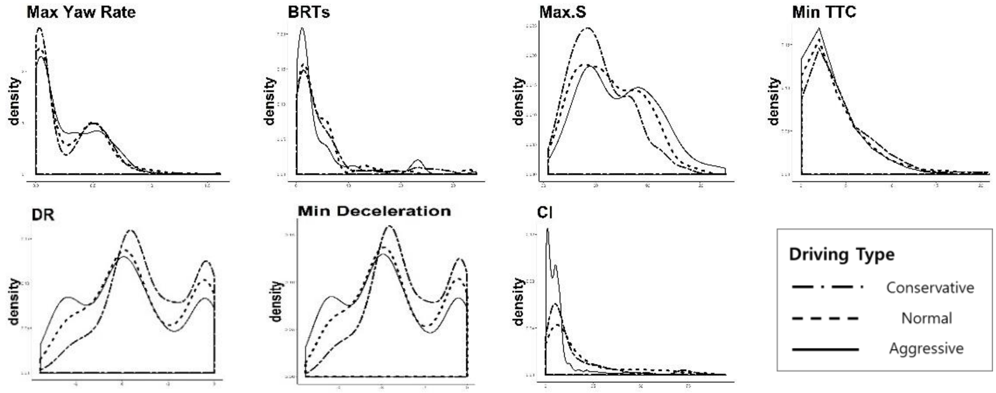


Figure 6 Results of distribution comparison

After comparing the distribution of SSMs, it was found that the distribution by driving type varies in most SSMs, as shown in Figure 6. However, Lead GD and CI showed a difference in the distribution by driving type, but the conservative type had a more aggressive distribution than the aggressive type, indicating a slight difference from the expected results. In addition, the distributions of most evaluation indicators were asymmetrical to the left and right. Asymmetry is created by a few outliers or extreme values that fall abnormally out of the distribution, and it can be interpreted that such outliers or extreme values were created by aggressive driving. Thus, the possibility of capturing values of aggressive driving was confirmed to a certain degree through the distribution of the SSMs.

ANOVA and Post-hoc Test

One-way ANOVA was conducted in order to analyze a significant difference by driving type. In order to conduct ANOVA, normality and homoscedasticity should be satisfied. If the number of data is enough, the average of each measure can be seen as normal distribution by Central Limit Theorem(C.L.T.). Since we used 31 participants' data, normality can be seen as satisfactory. After that, the Levene's Test was conducted for each SSM to judge homoscedasticity by determining whether the level of distribution by driving type was the same, as shown in Figure 5. ANOVA or Welch's ANOVA was conducted according to whether or not homoscedasticity was satisfied. As a result of conducting the ANOVA analysis at the 95% confidence level, 22 out of 27 SSMs were statistically significant, as indicated in Table 2. This indicated that the average values of three driving types, which are classified based on the criteria of the relevant indicators, are different from each other for 22 SSMs.

TABLE 2 Results of ANOVA

1st Criteria	2nd Criteria	No.	SSM	F-statistics	p-value
Individual Vehicle	Speeding	1	**AS	24.02	0.00
	Inconsistent - Speed Driving	2	*SU	22.32	0.00
		3	*SV	24.61	0.00
	Rapid Acceleration/ Deceleration	4	**Acceleration	5563.43	0.00
		5	**Deceleration	1516.05	0.00
		6	*AN	27.08	0.00
	Rapid Handle Manipulation	7	*Lane Position	0.29	0.75
		8	**Yaw Rate	559.47	0.00
		9	*LaneChange	4.64	0.01
Relating to Surround ing Vehicle	Non-compilance with Safe Distance	10	**GD	2907.93	0.00
		11	*PSD	3326.10	0.00
		12	**TTC	1069.32	0.00
		13	**MTTC	418.79	0.00
		14	**DRAC	3551.18	0.00
	Unsafe Lane -Changing	15	**Front_GD	0.67	0.51
		16	**Lag_GD	4.04	0.02
		17	**Lead_GD	0.14	0.87
		18	**Front_TTC	6.87	0.00
		19	**Lag_TTC	3.51	0.04
		20	**Lead_TTC	4.41	0.02
	Fatal Crash Risk	21	**Max YawRate	2.09	0.12
		22	*BRTs	1.52	0.22
		23	**Max S	36.83	0.00
		24	*Min TTC	3.47	0.03
		25	**DR	6.08	0.00
		26	**Min Deceleration	14.06	0.00
		27	**CI	5.57	0.00

* : ANOVA, ** : Welch's ANOVA

Since the ANOVA analysis is a test to evaluate whether there is a difference in the average between three or more groups, it has the disadvantage that it cannot determine the groups between which a difference exists, even if the null hypothesis is rejected. Therefore, a post-hoc test was conducted for the 22 SSMs that were found to be significant in order to identify the driving types between which a difference existed. A similar type may be displayed according to the driver's tendency without a significant difference between normal driving and conservative driving and between normal driving and aggressive driving. Therefore, the comparison and review were conducted in the post-hoc test to determine whether there was a significant difference between aggressive driving and conservative driving that would allow the characteristics of the two types of driving to be relatively contrasted.

TABLE 3 Results of the Post-hoc Test

1st Criteria	2nd Criteria	No.	SSM	Conservative		Normal		Aggressive		p-value	
				μ	σ^2	μ	σ^2	μ	σ^2	C vs A	N vs A
Individual Vehicle	Speeding	1	AS	1.56	3.02	4.53	20.18	7.02	19.04	0.00	0.02
	Inconsistent-Speed Driving	2	SU	13.78	8.88	16.95	6.73	18.47	8.26	0.00	0.09
		3	SV	25.13	8.60	29.22	27.90	31.64	20.18	0.00	0.06
	Rapid Acceleration / Deceleration	4	Acceleration	0.69	0.40	0.82	0.53	0.98	0.70	0.00	0.00
		5	Deceleration	-0.75	1.71	-0.95	2.49	-1.13	3.09	0.00	0.00
		6	AN	1.27	0.06	1.61	0.12	1.86	0.17	0.00	0.01
	Rapid Handle Manipulation	8	Yaw Rate	0.03	0.01	0.03	0.01	0.04	0.01	0.00	0.00
		9	Lane Change	33.42	40.85	34.74	39.40	38.48	58.06	0.01	0.08
Relating to Surrounding Vehicle	Non-compilance with Safe Distance	10	GD	62.74	2781.7	62.11	2752.3	52.55	2525.8	0.00	0.00
		11	PSD	0.85	1.85	0.86	2.09	0.58	1.36	0.00	0.00
		12	TTC	9.33	82.54	9.19	86.13	7.99	80.47	0.00	0.00
		13	MTTC	11.42	130.40	10.48	122.87	9.83	117.54	0.00	0.00
		14	DRAC	3.94	52.33	4.72	89.14	6.68	144.20	0.00	0.00
	Unsafe Lane -Changing	16	Lag_GD	8.31	20.46	7.95	22.48	5.52	10.04	0.03	0.06
		18	Front_TTC	0.74	0.25	0.66	0.20	0.42	0.06	0.01	0.05
		19	Lag TTC	1.08	0.87	1.37	2.14	2.28	5.55	0.01	0.07
		20	Lead TTC	1.15	2.97	0.67	0.99	0.36	0.07	0.02	0.46
	Fatal Crash Risk	23	Max S	58.51	173.77	65.37	339.21	71.83	377.72	0.00	0.00
		24	Min TTC	5.30	107.26	4.84	113.49	3.28	13.68	0.03	0.13
		25	DR	-0.10	0.12	-0.10	0.19	-0.40	1.13	0.00	0.00
		26	Min Deceleration	-4.15	6.81	-5.21	8.87	-5.52	9.89	0.00	0.49
		27	CI	13.25	346.3	31.49	3546.7	24.62	1032.0	0.13	0.49

Discussion

As shown in Table 3, the results of the analysis indicated that all evaluation indicators, except for CI, showed a significant difference. While Lag TTC showed a significant difference between two driving types, there was an inversion where the average of safe driving had a larger value than the average of aggressive driving, and thus, these two indicators were judged to be inappropriate for evaluating a driver. Therefore, it was analyzed that 20 out of 27 SSMs reviewed in this study could evaluate the driver's independent driving behavior and properly represented the driver's driving behavior during interaction with surrounding vehicles, and thus, these SSMs could be applicable as the evaluation indicators that judge safe driving.

Conversely, seven out of the 27 implementable SSMs reviewed in this study were not analyzed as indicators that could properly capture aggressive driving; those ten SSMs were Lane Position, Lead GD, Front GD, Lag TTC, Max YawRate, BRTs, and CI. Lane position was used mainly as an indicator to analyze drivers' behaviors in special conditions, such as a critical event *(30)* or vehicle tracking *(31)* in most of the literature. Such use of lane position may be due to the fact that, while the lane position may be significant according to the driver's behavior in certain circumstances, it may not be significant to evaluate the driver's behavior in normal driving situations.

Lead GD and Front GD did not show a significant difference in comparison to Lag GD. Thus, it can be explained that in lane-changing, aggressive driving is decided by the distance from a following vehicle rather than the distance from a leading vehicle. Also, in the case of Lag TTC, as the speed of the main vehicle generally is faster than the speed of a following vehicle in the target lane, the condition for calculating TTC $(v_{following} > v_{leading})$ is not met, thus it is difficult to compare the difference between driving types.

Max Yaw Rate, BRTs, and CI are indicators that are evaluated in a risk event situation, and risk events occur when the main vehicle passes a certain position and the trigger operates. However, the time at which a risk event occurs may vary depending on the speed of the main vehicle. This is considered as a limitation of the DS scenario, and since the time of the occurrence of the risk event varies by the driver, it may be difficult to compare the difference between driving types.

It was analyzed that the TTC *(18, 19)* and Gap Distance which was similar to Distance Headway *(20)* used in the previous literature, also could be applicable as an evaluation indicator, so the appropriateness of the SSMs presented in previous studies was confirmed in this study.

Chapter 4. Conclusions

Since traffic accidents that occur due to human factors account for approximately 93% of all traffic accidents, safety education courses aimed at reducing human error among drivers is being conducted. Among those courses, traffic safety using DSs has been conducted actively, and the effectiveness of such education has been proven to be effective to a certain degree. However, the education using DSs has limitations, and one typical limitation is that the driving environments implemented in DSs are not very realistic. Since most indicators focus only on the behavior of the main vehicle, such as speeding without considering its relationship with surrounding vehicles, these indicators cannot properly capture the driving behavior that occurs in the interaction with surrounding vehicles. Therefore, in this study, we used a traffic flow model in the DS to make the driving environments more realistic, and it was reviewed to identify which SSM could be applicable as an indicator to capture the driving behavior that occurred during the interaction with surrounding vehicles.

Besides the indicators used previously, we used a literature review to select and review 27 indicators for capturing aggressive driving. The experimental environment using the DS was established for the analysis, and the experiment was conducted with 41 drivers. Based on the scenario in which eight predefined critical events were implemented, each test subject was instructed to drive normally, conservatively, and aggressively.

By conducting an ANOVA analysis based on the data that were collected, it was found that 20 out of 27 SSMs were indicators that could properly capture a difference in the driving behavior, and in the post-hoc test in which those 20 SSMs were targeted, it was determined that all of the SSMs could distinguish between safe driving and aggressive driving. These 20 SSMs also include SSMs that were used previously in addition to the newly-evaluated indicators in this study. Thus, the results of this study confirmed that the SSMs presented in previous studies were indicators that could evaluate safe driving and aggressive driving.

Various driving education approaches using DSs currently are being conduct throughout the world. Since the SSMs presented in the results of this study can evaluate safe driving based on driving behavior observed during interaction with surrounding vehicles, it is possible to reliably evaluate the driver's driving behavior. It also was confirmed that the implementation of evaluation indicators on the DS presented in the results of this study could widen the area that could be captured by the DS. Therefore, it is expected that more useful driver's education could be made available by improving the current DSs and applying the results of this study.

In this study, a risk event in the scenario may occur at different times according to the driver's traveling speed. This is considered as a limitation of the trigger that creates a risk event, and, since the time of its occurrence varies by the driver, it may be difficult to compare the difference between driving types.

It is necessary to develop a system that generally scores the degree of improvement before and after the education by performing empirical analysis to determine what difference is made by the education of each indicator and expressing these driving indicators as one integrated indicator. Also, applicability of SSMs can be further analyzed depending on the type of roads to apply the indicators in different DS scenarios.

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국문초록

Driving Simulator내 적용가능한 Surrogate Safety Measures의 선정

Alicandri, E (1995)에서는 모든 교통사고 요인의 93%가 인적요인(human factors)과 관련이 있음을 제시하였다. 따라서 human factors에 의한 사고를 감소시키는 것이 전체교통사고 감소에 큰 부분을 차지하며, 이는 운전교육을 통해 감소할 수 있다.
안전운전 교육에서는 Driving Simulator(DS)를 이용한 사례가 많으며, 하지만 DS에는 다양한 위험요소를 평가할 수 있는 평가지표들의 수가 적다는 한계점이 존재한다.
기존 문헌고찰 결과, DS에는 Speed, acceleration와 같이 기본적인 지표들만 적용하여 운전자를 평가하고 있다. 특히, 대부분의 지표들이 주변차량과의 관계를 고려하지 않고, 본차량의 행태에만 집중된 측면이 있다. 따라서, 본 연구에서는 DS를 이용한 운전자 교육에서 위험운전을 평가하기 위한 지표들을 DS에 반영(implement)하고, DS에서의 적용가능성을 검토하는 것이 목적이다.
위험운전을 평가하기 위한 지표로써, 기존 DS에서 활용된 지표들 외에 다양한 SSMs들이 문헌검토를 통해 DS에 반영되었다. 또한, 주변차량과의 관계를 고려한 지표를 적용하기 위해서 주변차량의 움직임을 교통류 모형에 근거해 DS에 반영하였다. 다음, experimental study를 통해 통계적으로 유용한 SSMs(applicable SSMs)들이 검토되었다.
그 결과, 20개의 SSMs들이 통계적으로 유의한 평가지표로 검토되었다. 해당 평가지표들이 DS에 적용되면 운전자의 다양한 운전행태를 평가할 수 있다. 즉, ‘Violation of Safe Distance’, ‘Unsafe Lane Change’와 같이 본 연구에서 설정한 모든 위험 운전유형들이 applicable SSMs들에 의해 평가될 수 있다.
향후에는 각 지표들의 교육전후로 어떤 차이가 나는지 실증적인 분석을 하고, 하나의 종합지표로 표현함으로써 교육전후의 개선 정도를 총체(종합)적으로 평가하는 점수체계를 개발해 볼 수 있다. 또한, 도로구간별로 각 평가지표의 적용 가능성을 검토하여 운전자의 도로구간별 안전운전 정도를 평가해볼 수 있다.