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ANALYSIS OF DRIVER VEHICLE INTERACTION IN A STUDY ON ASSESSMENT METHODS OF DRIVER ACCEPTANCE OF AUTOMATIC LANE CHANGE SYSTEMS

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ABSTRACT – In recent years, with increased interest in high levels of automated driving assistance systems such as automatic lane change systems, the need for a reliable assessment tool for driver acceptance has arisen. Because acceptance depends on individuals, it can only be based on an individual's personal attitudes, expectations, and experiences. Accordingly, only subjective evaluation methods have been utilized for assessing drivers' acceptance of newly developed driver assistance systems. In this paper, an investigation of the effect of vehicle dynamic behavior and the traffic environment on drivers' acceptance is described in consideration of a study on a reliable solution for the objective evaluation of drivers' acceptance of an automatic lane change system. In order to conduct the investigation, a specific test program is designed and a massive database including information on drivers, vehicles, and traffic environments is constructed with a selected group of 19 drivers. Then, some possibilities for the development of an objective evaluation method are shown as results of the subjective acceptance; results are then compared and discussed with respect to behavioral parameters of drivers and vehicles. The results of this investigation can be not only the basis for the development of an objective evaluation method for drivers' acceptance, but can also be used to suggest design criteria for control strategies for any automated driving assistance systems.

TECHNICAL PAPER –

INTRODUCTION

In the last decade, with increased interest in the technologies of autonomous vehicles, several types of advanced driver assistance systems have been developed and commercialized. Most of these systems are focused on active safety and highly automated driving, such as an adaptive cruise control system (ACC) for autonomous longitudinal control, a lane keeping assistance system (LKAS), an automated parking assist system for semi-autonomous lateral control, etc. Recently, considerable efforts have been invested in the development of an automated lane change system as one of a group of semi-automated driving technologies being developed by car manufacturers in advance of the commercialization of fully autonomous vehicles. In (1) - (5), various studies on lane change assistance have been carried out to solve practical issues such as traffic situation assessment, decision making, generation of effective steering commands, etc.

However, for technologies such as automatic lane change systems, critical issues must still be solved, including safety, reliability, and acceptance. In particular, assessment of drivers' acceptance is recognized as one of the most important issues. Even if a proposed system satisfies all requirements related to safety and reliability, it will be valueless if drivers do not use the system, because the aforementioned technologies are being developed not only for safety, but also for convenience. Accordingly, the need for a reliable assessment tool for driver acceptance has arisen with the increased interest in high level automated driving assistance systems. Several studies have tried to evaluate drivers' acceptance of advanced driver assistant systems; these studies found that this characteristic is highly dependent on individual emotional factors (6) - (11). Thus, a number of studies on user acceptance of vehicle technologies have been conducted over the past decades. A standardized checklist for assessment of the level of acceptance of a new vehicle technology was proposed in (12). The idea of technology acceptance was defined in terms of usefulness, ease of use, effectiveness, affordability and social acceptance in (13). Gender differences in technology adoption were studied in (14). The technology acceptance model (TAM) was suggested to measure user acceptance in (15).

The need for a practical and objective assessment method for user acceptance of in-vehicle driver assistance systems has appeared in previous studies. The purpose of this paper is to investigate the effect of vehicle dynamic behavior and traffic environments on the drivers' acceptance, as part of a study on a reliable and objective method for the evaluation of drivers' acceptance of an automatic lane change system currently being developed. In order to investigate and discuss the effect, a specific experimental program is designed, and a massive database including information on drivers, vehicle dynamic behavior, and traffic environments is constructed with information of a group of 19 selected drivers. The database includes not only objectively measured data but also subjective results submitted by all of the participants. The subjective evaluation results on acceptance are partly compared and discussed in regard to the objective measured data and the behavioral parameters of the drivers and vehicles. This research considers the idea that human drivers' acceptance of automated driving assistant systems may be quantified according to both vehicle dynamic behavior and traffic environments. The results of this investigation can be not only the basis for the development of an objective evaluation method for drivers' acceptance, but can also be used to suggest design criteria for control strategies for any automated driving assistance systems.

CONSTRUCTION OF THE DATABASE

Experimental Design

To secure significant information and data on the interactions between drivers, vehicles, and traffic, and considering the development and assessment of the automatic lane change system, a specific test environment is designed to simulate situations in which a driver is supposed to be operating a vehicle equipped with an automatic lane change system. For the configuration of the test environments, 1 driver and 2 passengers are employed, as shown in Figure 1. The roles of each driver and passenger are as follows. The driver, subject #1, is regarded as the controller of the automatic lane change system. The driver is supposed to conduct lane changes according to both self-decisions and the tester's orders while driving. One of the passengers, subject #2, is regarded as a driver who monitors the driving situations during each lane change. A small monitor is installed to provide the same view as the driver's. The other passenger, the experimenter, is regarded as a real passenger. The experimenter not only monitors all situations, but also gives lane change commands to the driver during the test.

Figure 1: Configuration of test environments for passengers

A test course is designed including driving on a highway with a proper density of traffic, a speed of approximately 90kph on average, and the expectation of a moderate number of lane changing events. A 160km-long course is designed for a round trip journey, allowing an 80km long one-way trip as well. To achieve the purposes of this test program, a few basic conditions are needed, such as that the driver, subject #1, should try to be safe and comfortable, and should perform all actions as quickly as possible during the entire test. Subject #1, the driver, should not only drive, but also make any lane changes by self-decision following the basic conditions while proceeding to the halfway point. Then, when driving during the other one-way trip, the driver must make lane changes only according to the experimenter's commands. The purpose of the test program is basically to investigate several features: how the drivers drive in traffic, what their patterns are when making lane changes, what things make the passengers comfortable or uncomfortable, etc. General and natural driving characteristics of the drivers are expected to be shown in the first one-way trip; specific characteristics on how the drivers make lane changes when asked to by the experimenter are expected to be obtained as well.

In terms of subjective information, the drivers take time to answer a questionnaire before the test. All of the passengers including the driver also answer questionnaires specially designed after the vehicle test. Immediately after completing the questionnaires, all passengers evaluate each lane change event that occurred during the test by reviewing the recorded video data. Details of the questionnaire are provided in the following section.

Classification of The Subjects

The subjects are classified into two groups, experts and novices. The conditions of each group are as follows: more than 3 years of work experience as a chauffeur in regular employ and less than 1 month of driving experience with their own vehicles. The expert group is expected to show easy and safe lane changes made with comparably higher acceptance from passengers. Their lane change performance is also expected to be an important reference for the controller of the automatic lane change system. The novice group is expected to show difficult and dangerous lane changes conducted with comparably lower acceptance from passengers. It is also expected that possible dangerous situations will be identified in practice.

Design of Questionnaires

A subjective evaluation process is needed to secure a subjective database because several studies have been conducted to assess driver acceptance (15) - (18). To obtain the information, 4 questionnaires are developed: 1 questionnaire including 48 questions for a pre-test, and 3 questionnaires including 14 questions each for a post-test. The questionnaire for the pre-test is to be answered only by the drivers, and is designed to show drivers' general characteristics. The other questionnaires for the post-test is to be answered by all of the passengers. The purposes of the questionnaires for the post-test are not only to assess the lane change characteristics of subject #1, but also to compare all the assessment results of passengers.

For the review process, 4 common indexes for all and 1 additional index for all passengers except the driver are proposed. All of the test participants answer the post-questionnaires while looking at the recorded video that shows selected driving situations. In-depth evaluations of each lane-change case will be conducted through the review process.

Configuration of Test Environments

A specific test vehicle for driver vehicle interactions is configured as shown in Figure. 2. The test vehicle includes measurement systems for various human factors and behaviors as follows: steering, accelerating, and braking behaviors are measured by vehicle CAN and pressure sensors on the pedals; human factors are measured by electroencephalogram (EEG), electrocardiography (ECG), galvanic skin reflex (GSR), and respiration (RESP) using a polyG-I system; drivers' heading and gaging information are measured with an eye tracking system. The configuration of the vehicle and traffic conditions can also be seen in Figure 2.: vehicle dynamic behavior is measured by vehicle CAN, a gyro system, D-GPS, etc.; various traffic information and relative vehicle behavior in traffic determined by Mobile-Eye and 5-Lidar systems.

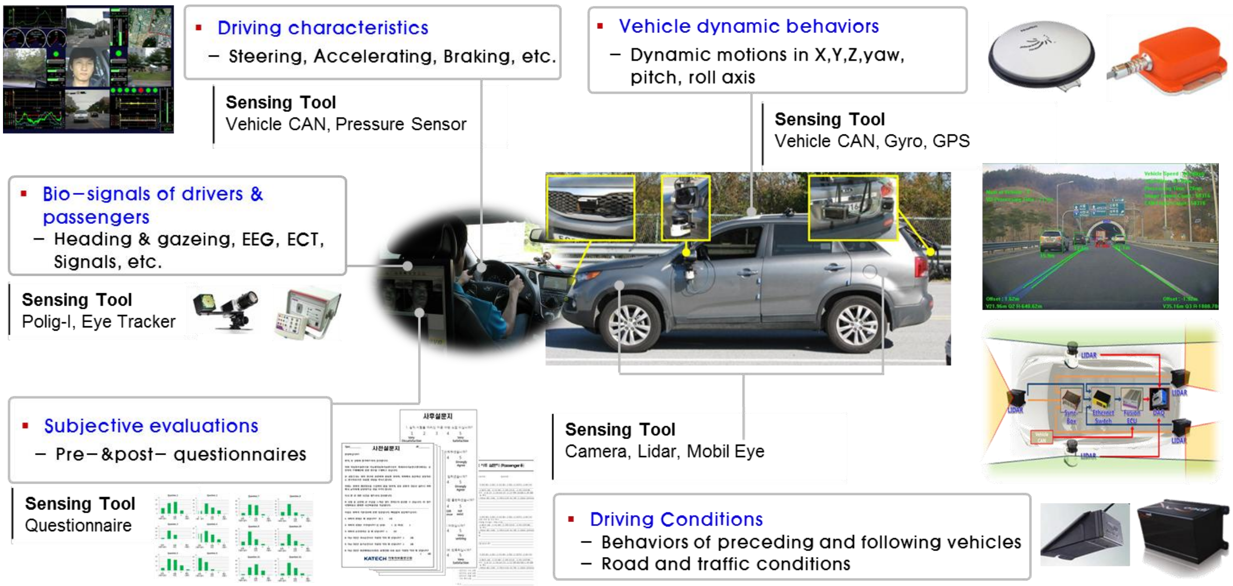
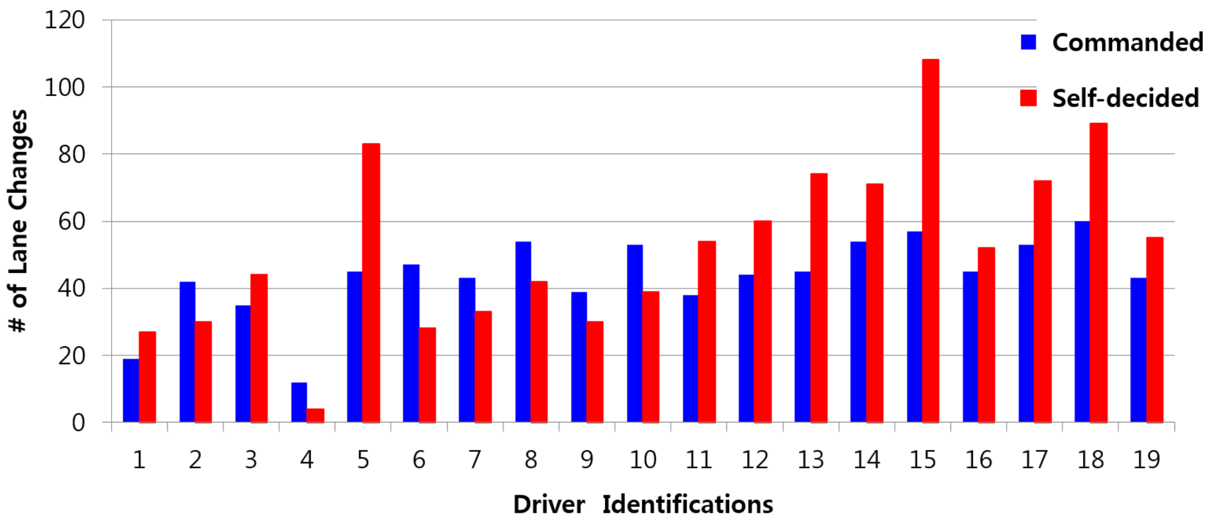


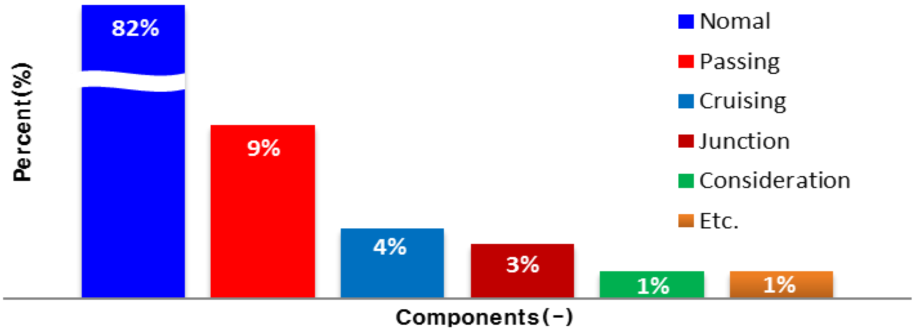
Figure 2: Configurations of the test vehicle for driver, vehicle, and traffic environments

Overview of The Constructed Database

A database on interactions between driver, vehicle, and traffic has been constructed in this research. The database contains a massive amount of information with respect to subjective and objective evaluations of the lane change situations on the expressway. Nineteen drivers participated in this research. Ten of them are considered expert drivers, selected by specific classification criteria. The other nine drivers are considered novice drivers. As can be seen in Figure 3, 1,823 cases of lane change are secured to be analyzed; 45% of all cases are made at the experimenter's command; the other cases are conducted according to the drivers' own decisions. 82% of all cases are regarded as normal cases; the other cases are considered abnormal cases of lane change. The abnormal cases have specific purposes: 9% for passing, 4% for maintaining cruising speed, 3% for junctions, 1% in consideration of other vehicles, etc.



(a)



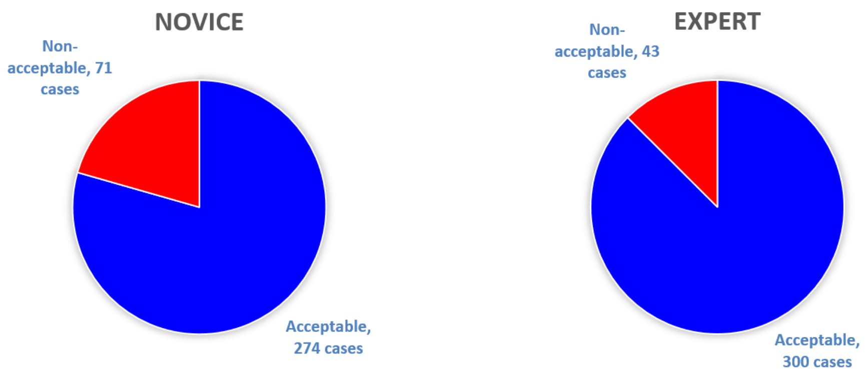
(b)

Figure 3: Component ratios of the constructed database: (a) outlines of the constructed database, (b) component ratios regarding purposes

RESULTS AND DISCUSSIONS

Although thousands of lane change cases are secured for the research object as described above, only limited parts of the database are subjected to analysis in this paper: several representative vehicle parameters and passengers' subjective evaluation results are compared and discussed to allow an investigation of possible vehicle parameters that can be used to represent drivers' acceptance.

The ratios of acceptable lane change cases for each participant group are shown in Figure 4. As was expected, the number of acceptable cases of the expert group is larger than that of the novice group. Figure 5 shows numbers of non-acceptable reasons related to each lateral and longitudinal behavior based on subjective assessment. Among the entire set of un-acceptable cases, about 81% for the expert group and 77% for the novice group are related to the vehicle's longitudinal motion. It can be expected that the acceptance level is dependent on the vehicle longitudinal behavior.



(a) (b)

Figure 4: Subjective acceptance ratios between groups: (a) Novice group, (b) expert group

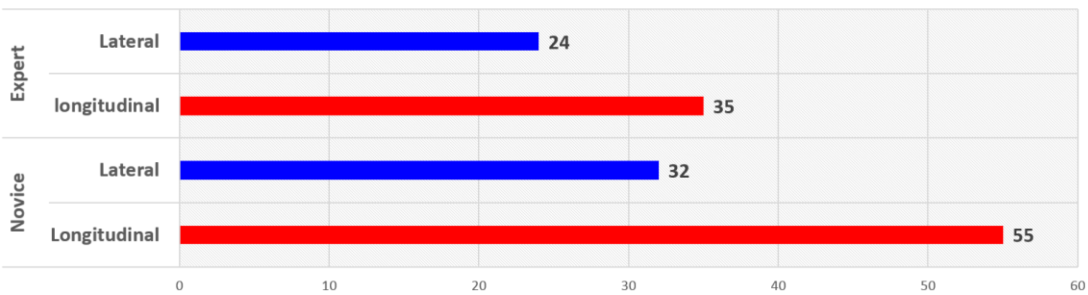


Figure 5: Subjective evaluation results of the non-acceptable causes related in lateral and longitudinal behaviors

Several vehicle and driver parameters representing both longitudinal and lateral behaviors are compared with the level of subjective acceptance, as can be seen in Table 1. The parameters are classified into average value, maximum value, and variation range. As can be seen in Figure 6 a radar chart is also utilized to look into the relatedness between the subjective acceptance and the vehicle behavioral parameters. The differences of each values with respect to the subjective acceptance are compared in terms of the percent ratio by assuming that all of the parameter values of the acceptable cases are standard (=100%). Larger differences in the parameters related to the longitudinal behavior appear with a consideration of the subjective acceptance. It is also found in comparisons of the variation range that the percent ratios of most of the parameters are consistently larger than the values of the acceptable cases, while those percent ratios are partly smaller and partly larger than the acceptable values in comparisons of the average and maximum values.

Table. 1: Comparison of vehicle behavioral values with subjective acceptance

Parameters		**unit**	**Acceptable**	**Non-Acceptable**	**Acceptable**	**Non-Acceptable**	**Acceptable**	**Non-Acceptable**
			Average value		**Maximum value**		**Variation range**	
Longitudinal	Velocity	m/s	28.89	27.22	29.64	28.20	1.53	1.97
	Acceleration	m/s^2	0.29	0.40	0.53	0.69	0.59	0.76
	Deceleration	m/s^2	0.24	0.38	0.40	0.61	0.45	0.63
	Gas pedal input	%	26.58	27.78	35.81	41.15	19.59	26.78
Lateral	Steering wheel input	deg	3.41	3.34	4.17	4.13	5.50	6.10
	Velocity	m/s	0.19	0.18	0.29	0.30	0.21	0.23
	Acceleration	m/s^2	0.43	0.39	1.03	1.04	1.02	1.03
	Yaw-rate	deg/sec	0.02	0.02	0.04	0.04	0.04	0.04

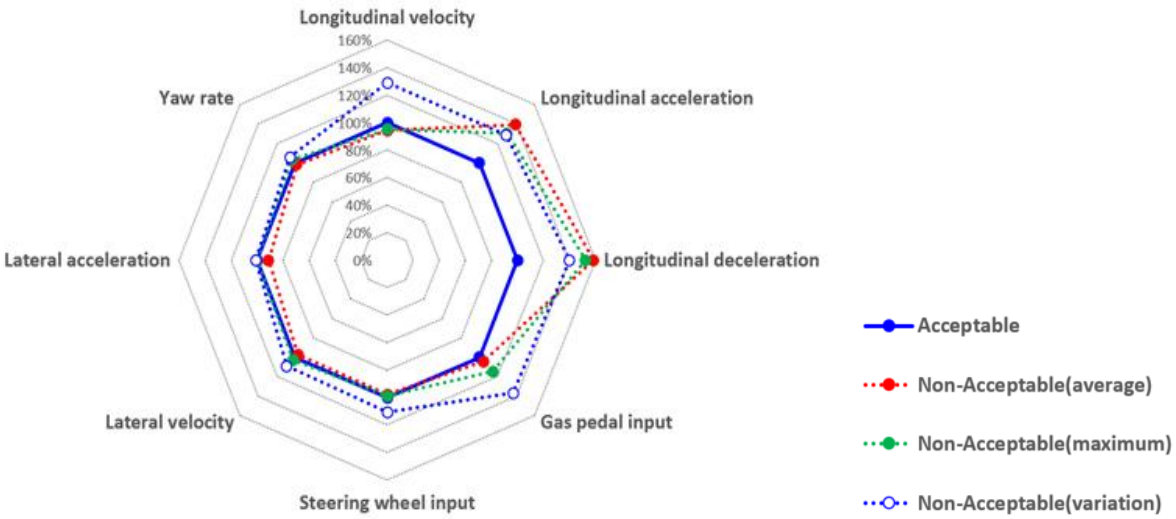


Figure. 6: Radar chart comparison of vehicle behavioral values with subjective acceptance

The vehicle and driver parameter values with respect to the subjective acceptance, based on levels of the longitudinal acceleration and deceleration, are shown in Table 2; variation ranges are compared using a radar chart, as can be seen in Figure 7. The non-acceptable cases are classified by subjective assessment. As can be seen, comparably strong relatedness between the subjective acceptance and the vehicle longitudinal behaviors is shown; for the non-acceptable cases classified as 'high deceleration', the subjective acceptance is expected to be correlated with the longitudinal velocity, acceleration, and deceleration; for cases classified as 'low deceleration', the acceptance is expected to be correlated with the longitudinal velocity and acceleration; for cases classified as 'high acceleration', the acceptance is expected to be correlated with the longitudinal velocity, deceleration, and gas pedal input; for cases classified as 'low acceleration', the acceptance is expected to be correlated with the longitudinal deceleration, and gas pedal input.

Table 2: Comparison of vehicle behavioral values subjective acceptance related to the longitudinal motion

Parameters		Unit	Acceptable	Non-Acceptable			
				Deceleration		acceleration	
				High	Low	High	low
Average value							
Longitudinal	Velocity	m/s	28.89	26.78	27.05	28.41	26.59
	Acceleration	m/s^2	0.29	0.54	0.37	0.42	0.27
	Deceleration	m/s^2	0.24	0.27	0.33	0.49	0.36
	Gas pedal input	%	26.58	14.04	29.03	36.02	32.17
Lateral	Steering wheel input	deg	3.41	2.71	4.51	3.01	3.40
	Velocity	m/s	0.19	0.18	0.17	0.19	0.18
	Acceleration	m/s^2	0.43	0.34	0.46	0.37	0.37
	Yaw-rate	deg/sec	0.02	0.01	0.02	0.02	0.02
Maximum value							
Longitudinal	Velocity	m/s	29.64	27.94	27.68	29.40	27.47
	Acceleration	m/s^2	0.53	0.94	0.75	0.66	0.49
	Deceleration	m/s^2	0.40	0.47	0.54	0.77	0.58
	Gas pedal input	%	35.81	26.46	38.93	46.23	51.50
Lateral	Steering wheel input	Deg	4.17	4.38	6.33	4.19	2.30
	Velocity	m/s	0.29	0.29	0.28	0.30	0.28
	Acceleration	m/s^2	1.03	1.03	1.14	0.98	0.95
	Yaw-rate	deg/sec	0.04	0.04	0.05	0.04	0.04
Variation range							
Longitudinal	Velocity	m/s	1.53	2.22	1.11	2.18	1.72
	Acceleration	m/s^2	0.59	0.95	0.72	0.67	0.63
	Deceleration	m/s^2	0.45	0.80	0.43	0.72	0.57
	Gas pedal input	%	19.59	22.12	19.01	31.72	30.04
Lateral	Steering wheel input	Deg	5.50	5.96	6.33	6.08	5.81
	Velocity	m/s	0.21	0.23	0.22	0.23	0.23
	Acceleration	m/s^2	1.02	1.03	1.14	0.94	0.98
	Yaw-rate	deg/sec	0.04	0.04	0.04	0.04	0.04

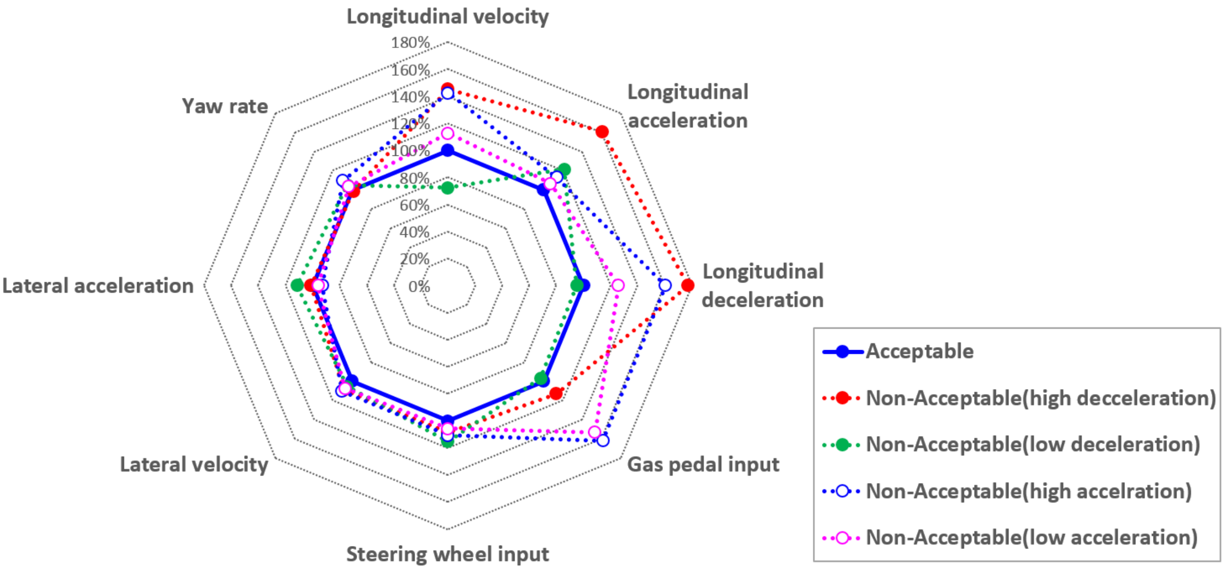


Figure 7: Radar chart comparison of variation range of vehicle behavioral values with subjective acceptance related to longitudinal motion

The vehicle and driver parameter values with respect to subjective acceptance, based on levels of the lateral motion, are shown in Table 3; variation ranges are compared using a radar chart, as can be seen in Figure 8. The non-acceptable cases are classified by subjective evaluation as well. As can be seen, comparably strong relativeness between the subjective acceptance and the vehicle longitudinal behavior is also shown with respect to several parameters: for the non-acceptable cases classified as ‘too slow’, the subjective acceptance is expected to be correlated with the longitudinal acceleration, driver’s gas pedal input, in small part the steering wheel input; for cases classified as ‘too fast’, the acceptance is expected to be correlated with almost all of the parameters at similar levels, and with the longitudinal deceleration at a lightly higher level.

Table 3: Comparison of vehicle behavioral values with subjective causes related to lateral motion, among non-acceptable cases

Parameters		unit	Acceptable	Non-Acceptable	
				too slow	too fast
Average value					
Longitudinal	Velocity	m/s	28.89	27.71	26.44
	Acceleration	m/s^2	0.29	0.28	0.43
	Deceleration	m/s^2	0.24	0.23	0.37
	Gas pedal input	%	26.58	28.90	28.00
Lateral	Steering wheel input	deg	3.41	2.55	3.87
	Velocity	kph	0.67	0.60	0.71
	Acceleration	m/s^2	0.43	0.30	0.45
	Yaw-rate	deg/sec	0.02	0.01	0.02
Maximum value					
Longitudinal	Velocity	m/s	29.64	28.33	27.34
	Acceleration	m/s^2	0.53	0.65	0.66
	Deceleration	m/s^2	0.40	0.39	0.60
	Gas pedal input	%	35.81	41.56	39.43
Lateral	Steering wheel input	deg	4.17	5.08	4.26
	Velocity	kph	1.04	0.98	1.21
	Acceleration	m/s^2	1.03	0.89	1.14
	Yaw-rate	deg/sec	0.04	0.03	0.05
Variation range					
Longitudinal	Velocity	m/s	1.53	1.17	1.79
	Acceleration	m/s^2	0.59	1.00	0.67
	Deceleration	m/s^2	0.45	0.49	0.60
	Gas pedal input	%	19.59	26.87	23.32
Lateral	Steering wheel input	deg	5.50	4.08	6.76
	Velocity	kph	0.76	0.73	0.89
	Acceleration	m/s^2	1.02	0.89	1.12
	Yaw-rate	deg/sec	0.04	0.03	0.04

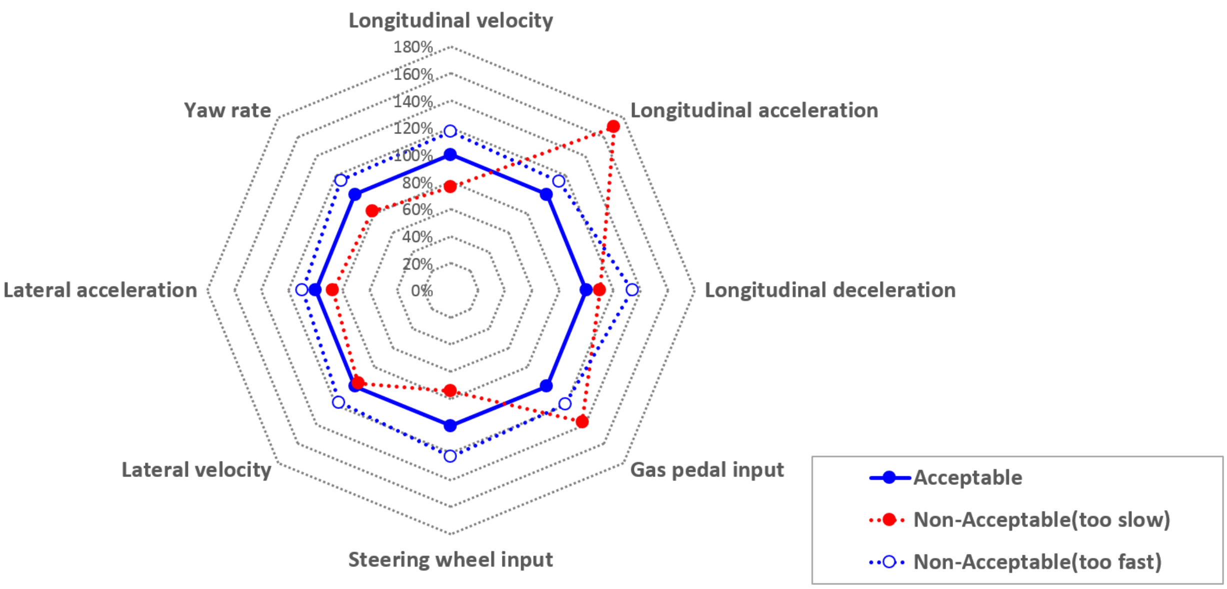


Figure 8: Radar chart of comparison of variation range of vehicle behavioral values with subjective acceptance, related to longitudinal motion

By comparing vehicle and driver parameters with respect to the subjective acceptance, a few clear aspects can be found, as follows. Passengers’ subjective acceptance is mostly dependent on the longitudinal behavior, although lane changing is believed to be highly dependent on lateral behavior. The existence of correlations between subjective acceptance and objective parameters representing vehicle behaviors is identified: the subjective acceptance is something that it is possible to objectively evaluate.

CONCLUSIONS

Through this study, a database including a massive amount of information on drivers, vehicles, and traffic interactions is constructed in consideration of the development and assessment of an automatic lane change system. For the construction of the database, a specific test program including several questionnaires and information on the vehicle test environment is designed. In the database, 1,823 cases of lane change events with the 19 selected drivers are secured. Abundant information from an objective evaluation and a subjective evaluation for each lane change case is also included in the database.

In this paper, using certain parts of the constructed database, the effects of vehicle dynamic behavior on drivers' acceptance are investigated. By comparing several parameters representing vehicle dynamic behavior and passengers' subjective assessment results, it is found that the differences appear to be small in numerical terms; especially, the percent ratios of the variation range show a certain level of consistency with respect to the subjective acceptance, and that the measured objective parameters can be used to represent subjective acceptance. A few meaningful aspects to consider for this study, the development of an evaluation method for an automatic lane change system, are also found, as follows. Passengers' subjective acceptance is mostly dependent on longitudinal behavior, even though lane changing is believed to be highly dependent on lateral behavior. The existence of correlations between the subjective acceptance and the objective parameters representing vehicle behaviors are identified, and it is found that subjective acceptance can be objectively evaluated. Although only limited parts of the massive database are used for the investigation, this study shows the possibility that passengers' subjective evaluation can be represented using objective values of vehicle dynamic motion.

Therefore, it is clear that the effects of traffic environments on acceptance need to be investigated in further research. It is expected that a reliable driver acceptance model and a method for implementing an automatic lane change system can be suggested and verified by further in-depth correlation analysis using information on drivers, vehicles, and traffic. The suggested model and methods will be extended to other ADAS based on autonomous driving systems because lane changing includes almost all of the important issues related to autonomous driving technology.

REFERENCES

[1] R. Schubert, K. Schulze, and G. Awnielik, "Situation Assessment for Automatic Lane-Change Maneuvers", IEEE Transactions on Intelligent Transportation Systems, 2010, 11, 607-616
[2] J. D. Alonso, E. Ros Vidal, M. Muhlenberg, "Lane-Change Decision Aid System Based on Motion-Driven Vehicle Tracking", IEEE Transactions on Vehicular Technology, 2008, 57, 2736-2746
[3] J. E. Naranjo, C. Conzlez, R. Garcia, T. de Pedro, "Lane-Change Fuzzy Control in Autonmous Vehicles for the Overtaking Maneuver", IEEE Transactions on Intelligent Transportation Systems, 2008, 9, 438-450
[4] C. Hatipoglu, U. Ozguner, K. A. Redmill, "Automated Lane Change Controller Design", IEEE Transactions on Intelligent Transportation Systems, 2003, 4, 3-22
[5] Hidehisa Yoshida, Shuntaro Shinohara, Masao Nagai, "Lane Change Steering Maneuver using Model Predictive Control Theory", Vehicle System Dynamics, 2008, 46, 669-681
[6] E. Adell, "Driver Experience and Acceptance of Driver Support Systems – a case of speed adaptation", PhD Dissertation, Lund University, 2009

[7] E. Adell, A. Varhelyi, “Driver comprehension and Acceptance of the Active Accelerator Pedal after Long-term Use”, Transportation Research Part F, 2008, 11 (1), 37-51
[8] H. Katteler, “Driver Acceptance of Mandatory Intelligent Speed Adaptation”, European Journal of Transport and Infrastructure Research, 2007, 5 (4), 317-336
[9] F. Saad, C. Dionisio, “Pre-evaluation of the “mandatory active” LAVIA: Assessment of Usability, Utility and Acceptance”, Proceedings of 14^{th} World Congress and Exhibition of Intelligent Transport Systems and Services, Beijing, China, 2007
[10] F. Saad, “Behavioral Adaptations to New Support Systems – Some Critical Issues”, Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics, 2004, 288-293
[11] V. Venkatesh, M. G. Morris, G. B. Davis, F. D. Davis, “User Acceptance of Information Technology: Toward a Unified View”, MIS Quarterly(MISQ), 2003, 27 (3), 425-478
[12] Van der Laan, J. D., Heino, A., and De Waard, D., “A simple procedure for the assessment of acceptance of advanced transport telematics” Transportation Research Part C, 1997, 5(1), 1-10
[13] Regan, M., Mitsopoulos, E., Haworth, N., and Young, K. “Acceptability of in-vehicle intelligence traport systems to Victorian car drivers” 2002, Monash University Accident Research Centre.
[14] Venkatesh, V., And Morris, M. G. “Why don’t men ever stop to ask for directions? Gender, social influence, and their role in technology acceptance and usage behavior” 2000, MIS Quarterly, 115-139
[15] Davis, F. D., Bagozzi, R. P., and Warshaw, P. R. “User acceptance of computer technology: A comparison of two theoretical models” 1989, Management Science, 35(8), 982-1003
[16] G. Sandra Hart, and Lowell E. Staveland, “Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research”, Advances in psychology, 1988, 52, 139-183
[17] A. Pauzi, “A Method to Assess the Driver Mental Workload - The Driving Activity Load Index (DALI)”, IET Intelligent Transport Systems, 2008, 2 (4), 315-322
[18] J. Yeon Kim, and Yong Gu Ji, “A Comparison of Subjective Mental Workload Measures in Driving Contexts”, Journal of the Ergonomics Society of Korea, 2013, 32 (2), 167-177