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# INVESTIGATION OF OBJECTIVE PARAMETERS FOR ACCEPTANCE EVALUATION OF AUTOMATIC LANE CHANGE SYSTEM

Chulwoo Moon[1, 2], Youngseok Lee[2], Chang-Hyun Jeong[2] and Seibum Choi[1)*]

[1)]School of Mechanical, Aerospace & System Engineering, KAIST, Daejeon 34141, Korea
[2)]Driving & Safety System R&D Center, Korea Automotive Technology Institute, 303 Pungse-ro, Pungse-myeon, Dongnam-gu, Cheonan-si, Chungnam 31214, Korea

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**ABSTRACT**−Recently, with increased interest in high levels of automated driving systems such as automatic lane change system, the need for reliable assessment methods of driver acceptance has arisen. Because the acceptance depends on the individual, the assessment of the acceptance can only be based on an individual's personal attitude, expectations, and experiences. Accordingly, subjective evaluation methods have mostly been utilized to assess the acceptance of newly developed advanced driver assistance systems. In this study, an investigation of the effects of vehicle dynamic behavior and the traffic environment on driver acceptance is conducted to provide an objective evaluation method of driver acceptance for an automatic lane change system. In order to conduct the investigation, a specific experimental program is designed and a massive database, including information on interaction behaviors between drivers, a vehicle and the traffic environment is constructed with a selected group of 19 drivers. Then, 21 parameters and their descriptive statistics for an objective evaluation index are presented to illustrate the analysis results. The results of this research can be important not only for an objective evaluation of the acceptance, but can also be expanded to suggest design criteria for control of advanced and automated driving assistance systems.

**KEY WORDS** : Driver/Passenger acceptance, Acceptance evaluation, Objectification, ADAS (Advanced Driver Assistant System), Automatic lane change system

## NOMENCLATURE

$A$ : accelerations, m/s$^2$
$D$ : distance to target vehicles, m
$J$ : derivative of accelerations, m/s$^3$
$V$ : velocity, m/s
$Q$ : quartile value of a ranked set
TPS : throttle positions sensor value, -
TTC : time to collision, s
relV : relative velocity between vehicles, m/s
SWA($\delta$) : steering wheel angle, deg
SWV($\dot{\delta}$) : steering wheel angular velocity, deg/s
$\psi$ : vehicle yaw angle, deg
$\phi$ : vehicle roll angle, deg

## SUBSCRIPTS

1,2,3,4 : $n_{th}$ quartiles of a ranked set
A,B,C : identifications of target vehicles
min : set of minimum values
max : set of maximum values
median : set of median values
mean : set of mean values
sd : set of standard deviation values
x : element in longitudinal vector
y : element in lateral vector

*Corresponding author.* e-mail: sbchoi@kaist.ac.kr

## 1. INTRODUCTION

In the last decade, with increased interest in the technologies of autonomous vehicles, several types of advanced driver assistant systems have been developed and commercialized. The systems being developed are focused on the enhancement of traffic safety and passenger comfort. Advanced Driver Assistance Systems (ADAS) such as Adaptive Cruise Control (ACC), Lane Keeping Aid (LKA), and Automatic Emergency Brake (AEB) have been shown to have a positive impact on traffic safety (Neale *et al*., 2005). It is expected that further development of ADAS, and eventually highly automated driving, will continue to increase traffic safety by reducing the impact of human error (Peden *et al*., 2004).

In recent years, in advance of the commercialization of fully autonomous vehicles, considerable efforts have been invested in the development of automated lane change systems as part of a group of semi-autonomous driving systems. However, for highly automated driving technologies such as an automatic lane change systems, critical issues must still be solved, including safety, reliability, and acceptance. In particular, assessment of driver acceptance is recognized as one of the most important issues (Adell, 2010; Regan *et al*., 2002). Future technologies will be valueless if drivers do not use a proposed system even when the system satisfies all requirements related to safety and reliability. It is the driver who makes the decision to use or not use a system. Since acceptance is individual, it can only be based on an individual's personal attitudes, expectations, experiences, and subjective evaluation of the system and the effects of using it (Schade and Baum, 2007; Adell, 2010), because the aforementioned technologies are being developed not only for safety, but also for convenience. Accordingly, various studies on lane change assistance have been carried out to enhance driver acceptance (Nishiwaki *et al*., 2008; Yao *et al*., 2013; Butakov and Ioannou, 2015; Gindele *et al*., 2015; Nobukawa *et al*., 2016).

In accordance with the increased interest in higher levels of automated driving technologies, the need for a reliable assessment tool for driver acceptance has arisen. In addition, several studies found that the acceptance is highly dependent on individual emotional factors. A number of studies on user acceptance of vehicle technologies have been conducted over the past decades. Van Der Laan *et al*. (1997) proposed a standardized checklist for assessment of the level of acceptance of a new vehicle technology. Regan *et al*. (2002) defined the idea of technology acceptance in terms of usefulness, ease of use, effectiveness, affordability, and social acceptance. Venkatesh and Morris (2000) studied gender differences in technology adoption. Davis *et al*. (1989) suggested a technology acceptance model to measure user acceptance. Adell and Varhelyi (2008) investigated driver experiences and acceptance of Intelligent Speed Adaptation (ISA). Kim (2008, 2011) studied the objectification of steering feel of a vehicle. The need for a practical and objective assessment method for driver acceptance of in-vehicle driver assistance systems has appeared in previous studies because user acceptance have been mostly evaluated by subjective methods.

In this paper, relationship between passengers' subjective acceptance and observed data of vehicle dynamic behaviors and driving environments are investigated to determine representative parameters of driver/passenger acceptance evaluation for an automatic lane change system. In order to investigate the relativeness, in Section 2, a methodology of the investigation is described such as a specific experimental program, and methodology of parameter analysis. Through the experiment, a database including massive information on drivers, vehicle dynamic behaviors, and driving environments is constructed with 19 selected drivers. The database includes not only objectively measured data, but also subjectively evaluated information submitted by all of the participants. In Section 3, analysis results are presented by conducting the suggested method. Then, in Section 4, several parameters with their descriptive statistics are suggested and discussed as the objective evaluation index of acceptance evaluation for an automatic lane change system.

## 2. METHODOLOGY OF INVESTIGATION

In order to investigate the objective factors for driver acceptance, an experimental program is not only designed, but also a specific methodology for analysis is suggedsted in this section.

### 2.1. Definition of Driver Acceptance

As Regan *et al*. (2002) asserted that there is no consistency across studies as to what acceptability is, in this study, the acceptance is defined and suggested in considerations of the target system and main objective of this study as following definition (1).

'Acceptance is the degree to which
an individual intends to use the system (1)
in his / her driving if the system is incorporated.'

This suggested definition of acceptance has the advantages of focusing on the individual perspective, both

Table 1. Configurations and roles of each passenger for the experiment.

| | Role (Assumed) | Seat position | Description |
|---|---|---|---|
| Subject #1 | Driver (Lane change system) | Driver's seat | - Drive and make lane changes as comfortable as possible<br>- Make any lane changes as ordered<br>- Follow the experimenter's instruction |
| Subject #2 | Co-driver (Driver operating the system) | Front passenger seat | - Observe and evaluate driver's lane change performance with respect to the traffic<br>- Provide bio-signals |
| Experimenter | Co-driver (Passenger) | Back seat | - Observe and control all the exmperiment environment<br>- Observe and evaluate driver's lane change performance with respect to the traffic<br>- Make lane change commands to the driver |

regarding the subjective evaluation of the system and the gains of using the system. This also provides the potential of realizing the expected effects of the system.

## 2.2. Experimental Program Design

### 2.2.1. Outline of experimental program

An experimental program is designed to look into several features: how drivers drive in traffic, what their patterns are during lane changes, what makes passengers comfortable or uncomfortable, etc. To secure, significant information and data with regard to the interactions between driver, vehicle, and traffic, a specific driving environment is set to simulate situations in which a driver is operating a vehicle equipped with an automatic lane change system; one driver and two passengers are employed as described in Table 1.

A driving route is designed on a highway with a proper density of traffic, with vehicle speeds from 80 kph to 90 kph on average, in expectation of a moderate number of lane change events. As shown in Figure 1, a 160 km-long course is suggested for a round trip journey, allowing an 80 km-long one-way trip as well. To achieve the purposes of this experimental program, a few basic conditions must be met, as follows. The driver should make any lane changes by self-decision while driving to the first halfway point. Then, the driver has to make lane changes only according to the experimenter's commands for the other one-way trip. The experimenter commands for lane change when a certain interested situation occurs based on Table 2 and Figure 5. General and natural driving patterns of the drivers

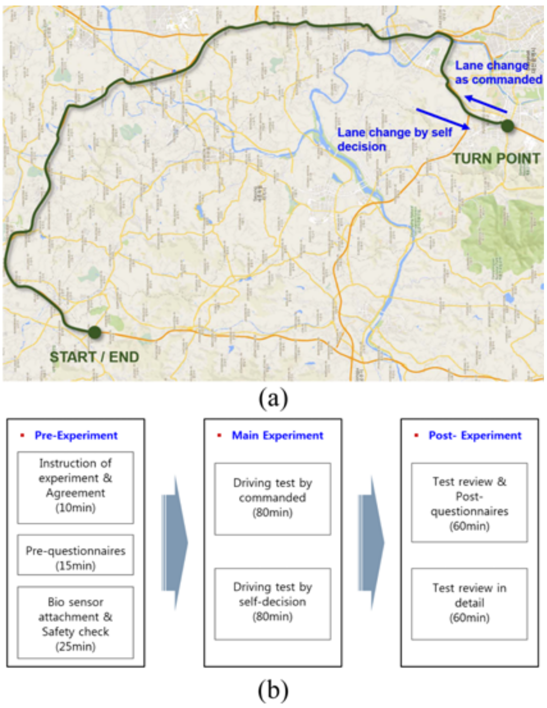



Figure 1. Outline of the designed experimental program: (a) Driving route; (b) Overall procedure.

Table 2. Classification of lane change situations.

| Category | | Sub category | |
|---|---|---|---|
| Situations | Existing vehicles | | |
| Situation 1 | Ego alone | N/A | |
| Situation 2 | Ego, B | 2.1 | $V_{Ego} > V_B$ |
| | | 2.2 | $V_{Ego} = V_B$ |
| | | 2.3 | $V_{Ego} < V_B$ |
| Situation 3 | Ego, C | 3.1 | $V_{Ego} > V_C$ |
| | | 3.2 | $V_{Ego} = V_C$ |
| | | 3.3 | $V_{Ego} < V_C$ |
| Situation 4 | Ego, B, C | 4.1 | $V_{Ego} > V_B(=V_C)$ |
| | | 4.2 | $V_{Ego} = V_B(=V_C)$ |
| | | 4.3 | $V_{Ego} < V_B(=V_C)$ |

are expected to be shown for the first one-way trip, and specific characteristics on how the drivers make lane changes when directed by the experimenter are expected to be obtained as well.

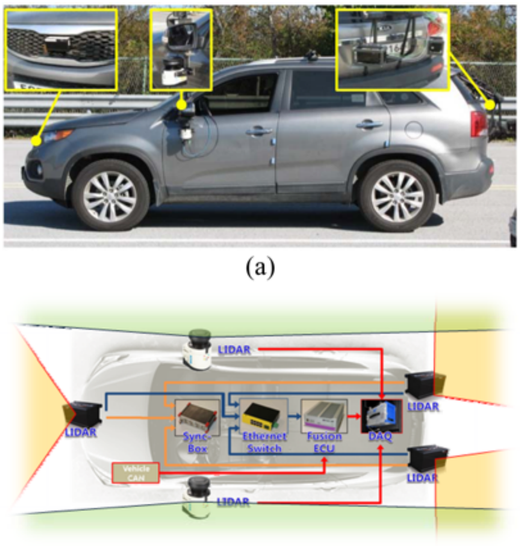
In order to identify participant's general characteristics, the drivers take time to answer a questionnaire at the beginning of the experiment. All of the passengers including the driver also answer questionnaires after the experiment. At the end of each experiment, all passengers evaluate each lane change event by reviewing recorded video data.

### 2.2.2. Subject groups

The subjects are classified into two groups, expert and novice. The conditions of each group are, respectively, as follows: more than three years of work experience as a regular chauffeur and less than one 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 supposed 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 can be identified in practice. In this experiment Nineteen drivers participated: 10 of them are considered expert drivers, selected by specific criteria; the other nine drivers are considered novice drivers.

### 2.2.3. Questionnaires

To obtain information of subjective evaluation in various ways about lane change events, four questionnaires are developed: one questionnaire including 87 questions for the pre-experiment, and three questionnaires including 14 questions for the post-experiment. The questionnaire for




(a)

(b)

Figure 2. Traffic environment measurement: (a) View of a vehicle for the experiment; (b) Schematic diagram of measurement systems.

the pre-experiment is answered only by drivers, and is designed to show drivers' general characteristics. This questionnaire was also conducted through online, and a part of the pre-questionnaire was analyzed in order to select the adequate participants for this experiment. The other questionnaire for the post-experiment is answered by all of the passengers. The purposes of the questionnaires for the post-experiment are not only to assess driving characteristics of subject #1, but also to compare all the assessment results. Four common indexes for all and one additional index for passengers except the driver are proposed for a review process. Subjective driver acceptance for every lane change situations was simply assessed between '*Accepted*' and '*Rejected*' based on the definition in (1) during the experiment in real itme, and manually recorded by the experimenter. All of the participants undergo a review process involving the indexes by reviewing recorded video that shows selected driving situations. In-depth analyses of each case of lane change are conducted through the review process.

### 2.2.4. Experimental environments

An experimental environment for driver vehicle interaction is configured. Equipment is configured for various human factors and behaviors: Vehicle CAN and pressure sensors on pedals for driver's inputs, and the polyG-I system for bio-signals. A high precision gyro-platform, GPS and CAN are used for measuring vehicle dynamic behaviors. As shown in Figure 2, a vehicle for the experiment is configured with laser scanning systems for traffic environment measurement: there are three laser scanner sensors for front and rear traffic, and two laser scanner sensors for traffic on both sides, all incorporated using a data fusion systems.

### 2.3. Identification of Vehicle Relations

The orad and lane characteristics are very important for accurate identifications of relations between vehicles. However, there are significant limitations to identify such relations based on road and lane characteristics: Limited access to geographic information system (GIS) of the driving route, and limited use of Differential Global Positioning System (D-GPS).

In this research, accurate relations between vehicles are identified by following process: the measured information of driving route from a general global positioning system (GPS) in geographical coordinates ($\phi$, $\lambda$, $\eta$) is transformed into geocentric Cartesian coordinate ($X$, $Y$, $Z$), and the geocentric coordinate is coverted into topocentric coordinate ($X_{\text{East}}$, $Y_{\text{North}}$, $Z_{\text{Up}}$); the converted data in cartesian coordinate is described in linear curve function by using Newton's third order interpolation method; a map of the entire route is filly determined by taking median values of the fitted curves for all of the experiment cases; and, then, other lanes on the driving route are generated on the estimated map. Thus, relations between vehicles are corrently identified by processing data fusion between measured data from five laser sensors and road characteristics.

### 2.4. Methodology of Parameter Analysis

Each lane change case is described with various measurable, objective parameters. Each data set of observed parameters consists of information from the starting point of the lane change to the finishing point. To derive an evaluation index, a significance test is performed on the parameters measured in relation to the acceptance/rejection of drivers and passengers during lane changes. The null hypothesis and alternative hypothesis are presented as shown in Equation (1) and tested. X and Y are the sets of all parameters observed for accepted and rejected cases during lane changes, and E[X] and E[Y] are the expected statistical values of each set.

$$\text{Hypothesis}\begin{cases} H_0(null) & : \mathrm{E[X]} = \mathrm{E[Y]} \\ H_1(alternative) & : \mathrm{E[X]} \neq \mathrm{E[Y]} \end{cases} \tag{2}$$

For data processing and enhanced efficiency of analysis, Equations (3) and (4) are substituted into X and Y, such that the data sets comprise parameters related to the driver, vehicle behavior, and targets. In this research, parameters describing driver behavior are regarded as paramters for control efforts of the automatic lane change system.

$$\mathrm{X} = \begin{bmatrix} \mathrm{X}_{\text{Drvier}} & \mathrm{X}_{\text{Vehicle}} & \mathrm{X}_{\text{Target A}} & \mathrm{X}_{\text{Target B}} & \mathrm{X}_{\text{Target C}} \end{bmatrix}^{\mathrm{T}} \tag{3}$$

$$\mathrm{Y} = \begin{bmatrix} \mathrm{Y}_{\text{Drvier}} & \mathrm{Y}_{\text{Vehicle}} & \mathrm{Y}_{\text{Target A}} & \mathrm{Y}_{\text{Target B}} & \mathrm{Y}_{\text{Target C}} \end{bmatrix}^{\mathrm{T}} \tag{4}$$

The t-ratio for the significance test of each parameter in relation to lane change acceptance is calculated as shown in Equation (5).

$$t = \frac{\bar{X} - \bar{Y}}{\sqrt{\frac{(n_X - 1)S_X^2 + (n_Y - 1)S_Y^2}{(n_X - 1)(n_Y - 1)}}\sqrt{\frac{1}{n_X} + \frac{1}{n_Y}}} \quad (5)$$

where $n_X$ and $n_Y$ are the sizes of samples in X and Y, $\bar{X}$, $\bar{Y}$ are the sample means, and $S_X^2$, $S_Y^2$ are the variances of X and Y.

Because, based on the results of the significance test, the sensitivity is defined in Equation (6) after descriptive statistics are compared for parameters at a significance level below 5 %, a sensitivity analysis is carried out to derive the final evaluation index. For parameters showing a sensitivity greater than 50 %, data are compared in relation to subjective acceptance and analyzed, and objective parameters are determined for a study of passenger acceptance evaluation for the automatic lane change system.

$$Sensitivity = \text{abs}\left[\frac{E[Y]-[X]}{E[X]}\right] \times 100\ (\%) \quad (6)$$

## 3. RESULTS

### 3.1. Outlines of Experiment Results and Subjected Data

An interaction database between driver, vehicle and traffic environment is constructed for this test. The database contains a massive amount of information on the results of subjective evaluations and various objective data for lane change situations on an expressway. As seen in Figure 3, 1,823 events are collected through this test; 45 % of those events were directed by the experimenter; the other cases were the results of the drivers' own decisions.

Although thousands of lane change cases are collected through the driver-vehicle experiment, only limited parts of the database are subjected to analysis in this study. Data analysis is performed for a total of 330 lane change cases; the results are categorized into "Accepted" and "Rejected" based on the definition (1) by passengers. As shown in Figure 4 (a), accepted cases account for approximately 80 %, and non-traffic situations account for 43 %. Figure 4 (b) shows the distribution of subjects falling under the two cases in relation to the position and number of target vehicles. The position of target vehicles with reference to the vehicle for the experiment is defined as shown in Figure 5.

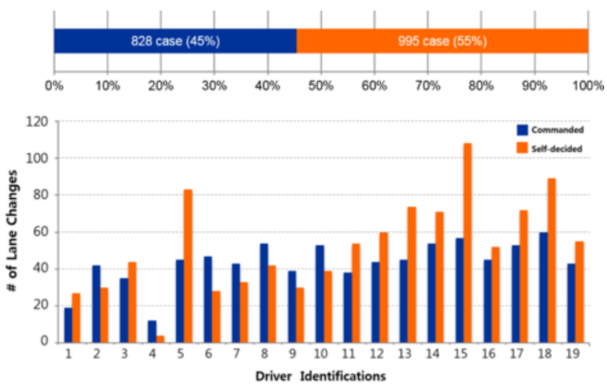



Figure 3. Overview of the constructed database.

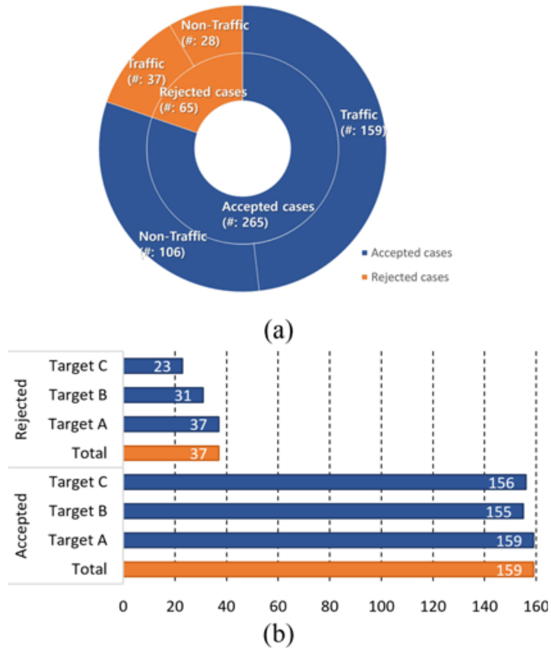



Figure 4. Component ratios of data subjected to analysis: (a) Accepted vs Rejected cases; (b) Target vehicles for accepted/rejected cases.

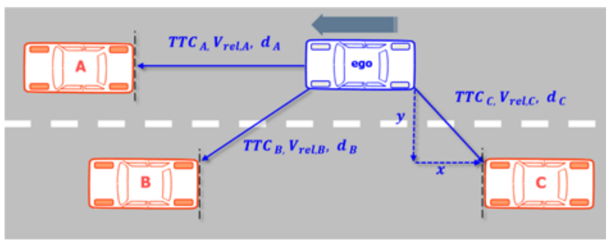



Figure 5. Relationship between the ego-vehicle and target vehicles.

### 3.2. Subjective Acceptance and Drivers' Behavior

The drivers' input parameters in relation to subjective acceptance are analyzed for significance and sensitivity. Data sets of the drivers' input parameters in relation to driver acceptance are defined by Equations (7) and (8).

Each set of parameters consists of descriptive statistics (minimum value, maximum value, median value, mean value, standard deviation), and a significance test is performed for the descriptive statistics. The descriptive statistics for parameters having a significance level below

Table 3. Descriptive statistics and significance test results of drivers' input parameters.

| | unit | Descriptive statistics | | | | Significance test[1)] | |
|---|---|---|---|---|---|---|---|
| | | Accepted | | Rejected | | | |
| | | E[X] | Var[X] | E[Y] | Var[Y] | *t* | p-value |
| $TPS_{sd}$ | % | 6.31 | 28.16 | 8.92 | 51.95 | – 2.230* | 0.027 |
| $SWV_{med}$ | deg/s | 1.49 | 1.31 | 1.90 | 1.24 | – 2.189* | 0.030 |
| $SWV_{mean}$ | deg/s | 2.58 | 1.49 | 3.16 | 1.44 | – 2.572* | 0.011 |
| $SWV_{sd}$ | deg/s | 2.88 | 1.58 | 3.41 | 1.28 | – 1.976* | 0.049 |

1)Level of significance: p < .05*, p < .01**, p < .001***


Figure 6. Sensitivities of drivers' input parameters.

5 % ($p < .05$) are shown and the results of the significance test are presented in Table 3.

$$X_{Drvier} = \begin{bmatrix} TPS^{Accepted} \\ SWA^{Accepted} \\ SWV^{Accepted} \end{bmatrix} = \begin{bmatrix} TPS_{min}^{Accepted} \sim n(\mu_{TPS_{min}^{Accepted}}, \sigma^2_{TPS_{min}^{Accepted}}) & \cdots & TPS_{sd}^{Accepted} \sim n(\mu_{TPS_{sd}^{Accepted}}, \sigma^2_{TPS_{sd}^{Accepted}}) \\ \vdots & \ddots & \vdots \\ SWV_{min}^{Accepted} \sim n(\mu_{SWV_{min}^{Accepted}}, \sigma^2_{SWV_{min}^{Accepted}}) & \cdots & SWV_{sd}^{Accepted} \sim n(\mu_{SWV_{sd}^{Accepted}}, \sigma^2_{SWV_{sd}^{Accepted}}) \end{bmatrix} \quad (7)$$

$$Y_{Drvier} = \begin{bmatrix} TPS^{N/Accepted} \\ SWA^{N/Accepted} \\ SWV^{N/Accepted} \end{bmatrix} = \begin{bmatrix} TPS_{min}^{N/Accepted} \sim n(\mu_{TPS_{min}^{N/Accepted}}, \sigma^2_{TPS_{min}^{N/Accepted}}) & \cdots & TPS_{sd}^{N/Accepted} \sim n(\mu_{TPS_{sd}^{N/Accepted}}, \sigma^2_{TPS_{sd}^{N/Accepted}}) \\ \vdots & \ddots & \vdots \\ SWV_{min}^{Accepted} \sim n(\mu_{SWV_{min}^{N/Accepted}}, \sigma^2_{SWV_{min}^{N/Accepted}}) & \cdots & SWV_{sd}^{N/Accepted} \sim n(\mu_{SWV_{sd}^{N/Accepted}}, \sigma^2_{SWV_{sd}^{N/Accepted}}) \end{bmatrix} \quad (8)$$

Figure 6 shows the results of the sensitivity analysis in relation to the subjective acceptance. $TPS_{sd}$ shows the highest sensitivity, and is associated with the range and frequency of control over the accelerator.

3.3. Subjective Acceptance and Dynamic Vehicle Behavior

The representative parameters of dynamic vehicle behavior in relation to subjective acceptance are analyzed for significance and sensitivity. The sets of parameters in relation to driver acceptance are defined by Equations (9) and (10).

$$X_{Vehicle} = \begin{bmatrix} Vx^{Accepted} & Ax^{Accepted} & Jx^{Accepted} & Vy^{Accepted} & Ay^{Accepted} & Jy^{Accepted} & \dot{\psi}^{Accepted} & \ddot{\psi}^{Accepted} & \phi^{Accepted} & \dot{\phi}^{Accepted} \end{bmatrix}^T$$
$$= \begin{bmatrix} Vx_{min}^{Accepted} \sim n(\mu_{Vx_{min}^{Accepted}}, \sigma^2_{Vx_{min}^{Accepted}}) & \cdots & Vx_{sd}^{Accepted} \sim n(\mu_{Vx_{sd}^{Accepted}}, \sigma^2_{Vx_{sd}^{Accepted}}) \\ \vdots & \ddots & \vdots \\ \dot{\phi}_{min}^{Accepted} \sim n(\mu_{\dot{\phi}_{min}^{Accepted}}, \sigma^2_{SWV_{min}^{Accepted}}) & \cdots & \dot{\phi}_{sd}^{Accepted} \sim n(\mu_{\dot{\phi}_{sd}^{Accepted}}, \sigma^2_{\dot{\phi}_{sd}^{Accepted}}) \end{bmatrix} \quad (9)$$

$$Y_{Vehicle} = \begin{bmatrix} Vx^{N/Accepted} & Ax^{N/Accepted} & Jx^{N/Accepted} & Vy^{N/Accepted} & Ay^{N/Accepted} & Jy^{N/Accepted} & \dot{\psi}^{N/Accepted} & \ddot{\psi}^{N/Accepted} & \phi^{N/Accepted} & \dot{\phi}^{N/Accepted} \end{bmatrix}^T$$
$$= \begin{bmatrix} Vx_{min}^{N/Accepted} \sim n(\mu_{Vx_{min}^{N/Accepted}}, \sigma^2_{Vx_{min}^{N/Accepted}}) & \cdots & Vx_{sd}^{N/Accepted} \sim n(\mu_{Vx_{sd}^{N/Accepted}}, \sigma^2_{Vx_{sd}^{N/Accepted}}) \\ \vdots & \ddots & \vdots \\ \dot{\phi}_{min}^{N/Accepted} \sim n(\mu_{\dot{\phi}_{min}^{N/Accepted}}, \sigma^2_{SWV_{min}^{N/Accepted}}) & \cdots & \dot{\phi}_{sd}^{N/Accepted} \sim n(\mu_{\dot{\phi}_{sd}^{N/Accepted}}, \sigma^2_{\dot{\phi}_{sd}^{N/Accepted}}) \end{bmatrix} \quad (10)$$

Similar to the previous section, Table 4 shows the descriptive statistics for parameters having a significance level below 5 % and presents the results of the significance test. Figure 7. gives the results of the sensitivity test in relation to subjective acceptance. High sensitivity is observed for longitudinal acceleration, jerk, and roll angle. The high sensitivity of longitudinal acceleration ($Ax_{sd}$) and jerk ($Jerk_{max}$) is consistent with the high sensitivity of changes in accelerator input, as derived from the analysis of drivers' input. These results show that drivers and passengers respond sensitively to acceleration/deceleration in the longitudinal direction. As for lane changes based on lateral movement, the minimum roll angle ($Roll_{min}$) shows a higher sensitivity than do the lateral acceleration or the yaw rate in relation to driver acceptance of lane change. The smaller minimum roll angle for positive acceptance cases indicates that subjective acceptance is influenced by both

Table 4. Descriptive statistics and significance test of parameters related to dynamic vehicle behavior.

| | unit | Descriptive statistics | | | | Significance test[1)] | |
|---|---|---|---|---|---|---|---|
| | | Accepted | | Rejected | | | |
| | | E[X] | Var[X] | E[Y] | Var[Y] | *t* | p-value |
| $Vx_{min}$ | m/s | 27.86 | 9.32 | 26.12 | 10.97 | 4.516*** | 0.000 |
| $Vx_{max}$ | m/s | 29.50 | 7.75 | 28.09 | 10.91 | 3.738*** | 0.000 |
| $Vx_{med}$ | m/s | 28.72 | 8.37 | 27.14 | 11.44 | 4.115*** | 0.000 |
| $Vx_{mean}$ | m/s | 28.70 | 8.31 | 27.13 | 11.13 | 4.154*** | 0.000 |
| $Ax_{min}$ | $m/s^2$ | – 0.37 | 0.17 | – 0.55 | 0.21 | 2.184* | 0.030 |
| $Ax_{sd}$ | $m/s^2$ | 0.15 | 0.02 | 0.23 | 0.03 | – 3.336*** | 0.001 |
| $Jx_{max}$ | $m/s^3$ | 0.40 | 0.22 | 0.64 | 0.33 | – 2.981** | 0.003 |
| $Ø_{min}$ | deg | 0.92 | 1.66 | 0.44 | 0.75 | 2.781** | 0.006 |
| $Ø_{med}$ | deg | 1.79 | 2.00 | 1.31 | 1.09 | 2.189* | 0.030 |
| $Ø_{mean}$ | deg | 1.80 | 1.85 | 1.32 | 0.96 | 2.355* | 0.019 |

1)Level of significance: p < .05*, p < .01**, p < .001***

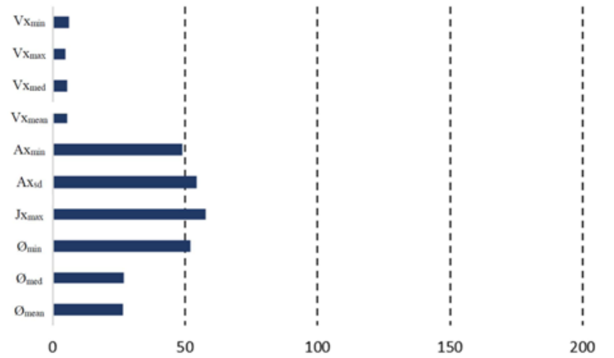



Figure 7. Sensitivities of dynamic vehicle behavior parameters.

roll and the relationship to target vehicles.

3.4. Analysis Results: Subjective Acceptance and Driving Environments

To analyze the significance and sensitivity of parameters related to the driving environment in relation to driver acceptance, the relative position of three target vehicles is defined as shown in Figure 5. The target vehicles are named Target A, Target B, and Target C; a separate analysis is performed for each vehicle. The primary parameters were time to collision (TTC), relative velocity (relV), and distance between vehicles (D); the definitions are given by Equations (11) ~ (13), respectively.

$$\mathrm{TTC_i} = \frac{\mathrm{abs}[P_{\mathrm{ego}} - P_{\mathrm{Target}}]}{V_{\mathrm{ego}}} \tag{11}$$

where $\mathrm{TTC}_i$ is the time to collision at the $i^{\mathrm{th}}$ step, $P_{\mathrm{ego}}$, $P_{\mathrm{Target}}$ are positions of the ego-vehicle and the target vehicles, and $V_{\mathrm{ego}}$ is the velocity of the ego-vehicle.

$$\mathrm{relV_i} = V_{\mathrm{ego}} - V_{\mathrm{Target}} \tag{12}$$

where $\mathrm{relV}_i$ is the relative velocity between the ego-vehicle and the target vehicles at the $i^{\mathrm{th}}$ step, and $V_{\mathrm{Target}}$ is the velocity of the target vehicles.

$$\mathrm{D_i} = \mathrm{abs}[P_{\mathrm{ego}} - P_{\mathrm{Target}}] \tag{13}$$

where $\mathrm{D}_i$ is the absolute distance between the ego-vehicle and the target vehicles at the $i^{\mathrm{th}}$ step.

The parameters related to the leading vehicle (Target A) in the active lane are also analyzed for significance and sensitivity in relation to subjective acceptance. The parameter sets in relation to driver acceptance are defined by Equations (14) and (15).

$$\mathrm{X_{Target\,A}} = \left[ TTC_{\mathrm{A}}^{\mathrm{Accepted}} \quad TTCx_{\mathrm{A}}^{\mathrm{Accepted}} \quad TTCy_{\mathrm{A}}^{\mathrm{Accepted}} \quad relV_{\mathrm{A}}^{\mathrm{Accepted}} \quad relVx_{\mathrm{A}}^{\mathrm{Accepted}} \quad relVy_{\mathrm{A}}^{\mathrm{Accepted}} \quad D_{\mathrm{A}}^{\mathrm{Accepted}} \quad Dx_{\mathrm{A}}^{\mathrm{Accepted}} \quad Dy_{\mathrm{A}}^{\mathrm{Accepted}} \right]^{\mathrm{T}}$$
$$= \begin{bmatrix} \begin{matrix} TTC_{\mathrm{A,min}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{TTC_{A,min}^{Accepted}}}, \sigma^2_{\mathrm{TTC_{A,min}^{Accepted}}}) \end{matrix} & \cdots & \begin{matrix} TTC_{\mathrm{A,sd}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{TTC_{A,sd}^{Accepted}}}, \sigma^2_{\mathrm{TTC_{A,sd}^{Accepted}}}) \end{matrix} \\ \vdots & \ddots & \vdots \\ \begin{matrix} Dy_{\mathrm{A,min}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{Dy_{A,min}^{Accepted}}}, \sigma^2_{\mathrm{Dy_{A,min}^{Accepted}}}) \end{matrix} & \cdots & \begin{matrix} Dy_{\mathrm{A,sd}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{Dy_{A,sd}^{Accepted}}}, \sigma^2_{\mathrm{Dy_{A,sd}^{Accepted}}}) \end{matrix} \end{bmatrix} \tag{14}$$

$$\mathrm{Y_{Target\,A}} = \left[ TTC_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad TTCx_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad TTCy_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad relV_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad relVx_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad relVy_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad D_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad Dx_{\mathrm{A}}^{\mathrm{N/Accepted}} \quad Dy_{\mathrm{A}}^{\mathrm{N/Accepted}} \right]^{\mathrm{T}}$$
$$= \begin{bmatrix} \begin{matrix} TTC_{\mathrm{A,min}}^{\mathrm{N/Accepted}} \\ \sim n(\mu_{\mathrm{TTC_{A,min}^{N/Accepted}}}, \sigma^2_{\mathrm{TTC_{A,min}^{N/Accepted}}}) \end{matrix} & \cdots & \begin{matrix} TTC_{\mathrm{A,sd}}^{\mathrm{N/Accepted}} \\ \sim n(\mu_{\mathrm{TTC_{A,sd}^{N/Accepted}}}, \sigma^2_{\mathrm{TTC_{A,sd}^{N/Accepted}}}) \end{matrix} \\ \vdots & \ddots & \vdots \\ \begin{matrix} Dy_{\mathrm{A,min}}^{\mathrm{N/Accepted}} \\ \sim n(\mu_{\mathrm{Dy_{A,min}^{N/Accepted}}}, \sigma^2_{\mathrm{Dy_{A,min}^{N/Accepted}}}) \end{matrix} & \cdots & \begin{matrix} Dy_{\mathrm{A,sd}}^{\mathrm{N/Accepted}} \\ \sim n(\mu_{\mathrm{Dy_{A,sd}^{N/Accepted}}}, \sigma^2_{\mathrm{Dy_{A,sd}^{N/Accepted}}}) \end{matrix} \end{bmatrix} \tag{15}$$

The descriptive statistics for parameters having a significance level below 5 % are shown and the results of significance test are presented in Table 5. Five parameters are found to be significant; Figure 8 gives the results of the sensitivity analysis for the significant parameters in relation to the subjective acceptance. High values are observed for time to collision and relative velocity. These results indicate that driver acceptance is more significantly influenced by the range and frequency of change than the absolute values of the parameters.

The parameters related to the leading vehicle (Target B) in the target lane for lane change are analyzed for significance and sensitivity in relation to subjective acceptance. The parameter sets in relation to driver acceptance are defined by Equations (16) and (17).

$$\mathrm{X_{Target\,B}} = \left[ TTC_{\mathrm{B}}^{\mathrm{Accepted}} \quad TTCx_{\mathrm{B}}^{\mathrm{Accepted}} \quad TTCy_{\mathrm{B}}^{\mathrm{Accepted}} \quad relV_{\mathrm{B}}^{\mathrm{Accepted}} \quad relVx_{\mathrm{B}}^{\mathrm{Accepted}} \quad relVy_{\mathrm{B}}^{\mathrm{Accepted}} \quad D_{\mathrm{B}}^{\mathrm{Accepted}} \quad Dx_{\mathrm{B}}^{\mathrm{Accepted}} \quad Dy_{\mathrm{B}}^{\mathrm{Accepted}} \right]^{\mathrm{T}}$$
$$= \begin{bmatrix} \begin{matrix} TTC_{\mathrm{B,min}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{TTC_{B,min}^{Accepted}}}, \sigma^2_{\mathrm{TTC_{B,min}^{Accepted}}}) \end{matrix} & \cdots & \begin{matrix} TTC_{\mathrm{B,sd}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{TTC_{B,sd}^{Accepted}}}, \sigma^2_{\mathrm{TTC_{B,sd}^{Accepted}}}) \end{matrix} \\ \vdots & \ddots & \vdots \\ \begin{matrix} Dy_{\mathrm{B,min}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{Dy_{B,min}^{Accepted}}}, \sigma^2_{\mathrm{Dy_{B,min}^{Accepted}}}) \end{matrix} & \cdots & \begin{matrix} Dy_{\mathrm{B,sd}}^{\mathrm{Accepted}} \\ \sim n(\mu_{\mathrm{Dy_{B,sd}^{Accepted}}}, \sigma^2_{\mathrm{Dy_{B,sd}^{Accepted}}}) \end{matrix} \end{bmatrix} \tag{16}$$

Table 5. Descriptive statistics and significance test of parameters related to the driving environment: Target A.

| | unit | Descriptive statistics | | | | Significance test[1)] | |
|---|---|---|---|---|---|---|---|
| | | Accepted | | Rejected | | | |
| | | E[X] | Var[X] | E[Y] | Var[Y] | *t* | p-value |
| $\mathrm{TTC_{max}}$ | s | 22.64 | 1189.14 | 37.57 | 2393.6 | – 2.500* | 0.013 |
| $\mathrm{TTC_{mean}}$ | s | 15.81 | 407.24 | 22.79 | 589.15 | – 2.024* | 0.043 |
| $\mathrm{TTC_{sd}}$ | s | 3.24 | 55.85 | 7.41 | 187.39 | – 3.129* | 0.002 |
| $\mathrm{relV_{sd}}$ | s | 0.37 | 1.04 | 1.12 | 8.78 | – 3.707*** | 0.000 |
| $\mathrm{relVx_{sd}}$ | m/s | 0.32 | 0.96 | 1.01 | 8.72 | – 3.504*** | 0.000 |

[1)]Level of significance: p < .05*, p < .01**, p < .001***

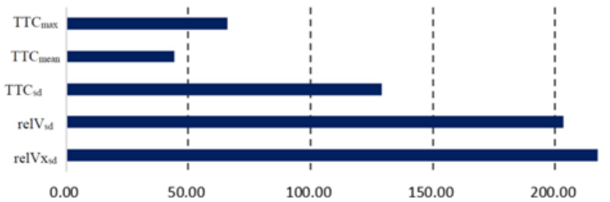



Figure 8. Sensitivity of parameters related to the driving environment: Target A.

$$
\begin{aligned}
\mathrm{Y}_{\text{Target B}} &= \big[ TTC_{\mathrm{B}}^{\mathrm{N/Accepted}} \quad TTCx_{\mathrm{B}}^{\mathrm{N/Accepted}} \quad TTCy_{\mathrm{B}}^{\mathrm{N/Accepted}} \quad relV_{\mathrm{B}}^{\mathrm{N/Accepted}} \quad relVx_{\mathrm{B}}^{\mathrm{N/Accepted}} \\
&\qquad relVy_{\mathrm{B}}^{\mathrm{N/Accepted}} \quad D_{\mathrm{B}}^{\mathrm{N/Accepted}} \quad Dx_{\mathrm{B}}^{\mathrm{N/Accepted}} \quad Dy_{\mathrm{B}}^{\mathrm{N/Accepted}} \big]^{\mathrm{T}} \\
&= \begin{bmatrix}
TTC_{\mathrm{B,min}}^{\mathrm{N/Accepted}} & & TTC_{\mathrm{B,sd}}^{\mathrm{N/Accepted}} \\
\sim n(\mu_{\mathrm{TTC}_{\mathrm{B,min}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{TTC}_{\mathrm{B,min}}^{\mathrm{N/Accepted}}}) & \cdots & \sim n(\mu_{\mathrm{TTC}_{\mathrm{B,sd}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{TTC}_{\mathrm{B,sd}}^{\mathrm{N/Accepted}}}) \\
\vdots & \ddots & \vdots \\
Dy_{\mathrm{B,min}}^{\mathrm{N/Accepted}} & & Dy_{\mathrm{B,sd}}^{\mathrm{N/Accepted}} \\
\sim n(\mu_{\mathrm{Dy}_{\mathrm{B,min}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{Dy}_{\mathrm{B,min}}^{\mathrm{N/Accepted}}}) & \cdots & \sim n(\mu_{\mathrm{Dy}_{\mathrm{B,sd}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{Dy}_{\mathrm{B,sd}}^{\mathrm{N/Accepted}}})
\end{bmatrix}
\end{aligned}
\tag{17}
$$

Table 6 shows the descriptive statistics for parameters having a significance level below 5 % and presents the results of the significance test. Sixteen parameters are found to be significant; Figure 9 gives the results of the sensitivity analysis for the significant parameters in relation to subjective acceptance. High sensitivity values are observed for time to collision and distance between vehicles in the lateral direction. These results indicate that the relationship between vehicles in the lateral direction has a significant influence due to the characteristics of lane change situations.

The parameters related to the trailing vehicle (Target C) in the target lane for a lane change are also analyzed for significance and sensitivity in relation to subjective acceptance. The sets of parameters in relation to driver acceptance are defined by Equations (18) and (19).

Table 6. Descriptive statistics and significance test of parameters related to the driving environment: Target B.

| | unit | Descriptive statistics | | | | Significance test[1] | |
|---|---|---|---|---|---|---|---|
| | | Accepted | | Rejected | | | |
| | | E[X] | Var[X] | E[Y] | Var[Y] | $t$ | p-value |
| $\mathrm{TTCy}_{min}$ | s | 0.70 | 22.18 | 3.43 | 233.01 | – 2.484* | 0.013 |
| $\mathrm{TTCy}_{max}$ | s | 2.21 | 32.85 | 5.96 | 225.71 | – 3.133* | 0.002 |
| $\mathrm{TTCy}_{med}$ | s | 1.12 | 16.57 | 4.86 | 198.52 | – 3.960*** | 0.000 |
| $\mathrm{TTCy}_{sd}$ | s | 1.14 | 16.49 | 4.94 | 210.29 | – 3.920*** | 0.000 |
| $\mathrm{D}_{min}$ | m | 38.95 | 1020.01 | 26.00 | 303.17 | 2.240* | 0.025 |
| $\mathrm{D}_{max}$ | m | 41.57 | 983.17 | 29.03 | 294.43 | 2.209* | 0.028 |
| $\mathrm{D}_{med}$ | m | 40.23 | 995.53 | 27.45 | 284.34 | 2.237* | 0.026 |
| $\mathrm{D}_{mean}$ | m | 40.23 | 994.64 | 27.48 | 284.17 | 2.235 | 0.026 |
| $\mathrm{Dx}_{min}$ | m | 38.73 | 1024.28 | 25.62 | 309.62 | 2.264* | 0.024 |
| $\mathrm{Dx}_{max}$ | m | 41.42 | 984.59 | 28.72 | 298.86 | 2.235* | 0.026 |
| $\mathrm{Dx}_{med}$ | m | 40.05 | 997.78 | 27.12 | 289.36 | 2.263* | 0.024 |
| $\mathrm{Dx}_{mean}$ | m | 40.05 | 997.13 | 27.14 | 289.15 | 2.259* | 0.024 |
| $\mathrm{Dy}_{min}$ | m | 2.36 | 8.40 | 4.62 | 19.15 | 3.898*** | 0.000 |
| $\mathrm{Dy}_{max}$ | m | 2.20 | 7.69 | 4.30 | 19.79 | 3.735*** | 0.000 |
| $\mathrm{Dy}_{med}$ | m | 2.25 | 7.72 | 4.45 | 19.30 | 3.997*** | 0.000 |
| $\mathrm{Dy}_{mean}$ | m | 2.26 | 7.71 | 4.46 | 19.19 | 3.938*** | 0.000 |

[1]Level of significance: p < .05*, p < .01**, p < .001***

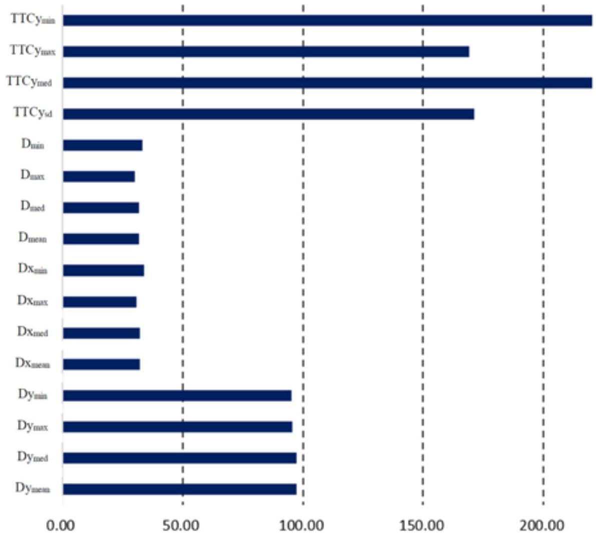



Figure 9. Sensitivity of parameters related to the driving environment: Target B.

$$
\begin{aligned}
\mathrm{X}_{\text{Target C}} &= \big[ TTC_{\mathrm{C}}^{\mathrm{Accepted}} \quad TTCx_{\mathrm{C}}^{\mathrm{Accepted}} \quad TTCy_{\mathrm{C}}^{\mathrm{Accepted}} \quad relV_{\mathrm{C}}^{\mathrm{Accepted}} \quad relVx_{\mathrm{C}}^{\mathrm{Accepted}} \\
&\qquad relVy_{\mathrm{C}}^{\mathrm{Accepted}} \quad D_{\mathrm{C}}^{\mathrm{Accepted}} \quad Dx_{\mathrm{C}}^{\mathrm{Accepted}} \quad Dy_{\mathrm{C}}^{\mathrm{Accepted}} \big]^{\mathrm{T}} \\
&= \begin{bmatrix}
TTC_{\mathrm{C,min}}^{\mathrm{Accepted}} & & TTC_{\mathrm{C,sd}}^{\mathrm{Accepted}} \\
\sim n(\mu_{\mathrm{TTC}_{\mathrm{C,min}}^{\mathrm{Accepted}}}, \sigma^2_{\mathrm{TTC}_{\mathrm{C,min}}^{\mathrm{Accepted}}}) & \cdots & \sim n(\mu_{\mathrm{TTC}_{\mathrm{C,sd}}^{\mathrm{Accepted}}}, \sigma^2_{\mathrm{TTC}_{\mathrm{C,sd}}^{\mathrm{Accepted}}}) \\
\vdots & \ddots & \vdots \\
Dy_{\mathrm{C,min}}^{\mathrm{Accepted}} & & Dy_{\mathrm{C,sd}}^{\mathrm{Accepted}} \\
\sim n(\mu_{\mathrm{Dy}_{\mathrm{C,min}}^{\mathrm{Accepted}}}, \sigma^2_{\mathrm{Dy}_{\mathrm{C,min}}^{\mathrm{Accepted}}}) & \cdots & \sim n(\mu_{\mathrm{Dy}_{\mathrm{C,sd}}^{\mathrm{Accepted}}}, \sigma^2_{\mathrm{Dy}_{\mathrm{C,sd}}^{\mathrm{Accepted}}})
\end{bmatrix}
\end{aligned}
\tag{18}
$$

$$
\begin{aligned}
\mathrm{Y}_{\text{Target C}} &= \big[ TTC_{\mathrm{C}}^{\mathrm{N/Accepted}} \quad TTCx_{\mathrm{C}}^{\mathrm{N/Accepted}} \quad TTCy_{\mathrm{C}}^{\mathrm{N/Accepted}} \quad relV_{\mathrm{C}}^{\mathrm{N/Accepted}} \quad relVx_{\mathrm{C}}^{\mathrm{N/Accepted}} \\
&\qquad relVy_{\mathrm{C}}^{\mathrm{N/Accepted}} \quad D_{\mathrm{C}}^{\mathrm{N/Accepted}} \quad Dx_{\mathrm{C}}^{\mathrm{N/Accepted}} \quad Dy_{\mathrm{C}}^{\mathrm{N/Accepted}} \big]^{\mathrm{T}} \\
&= \begin{bmatrix}
TTC_{\mathrm{C,min}}^{\mathrm{N/Accepted}} & & TTC_{\mathrm{B,sd}}^{\mathrm{N/Accepted}} \\
\sim n(\mu_{\mathrm{TTC}_{\mathrm{C,min}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{TTC}_{\mathrm{C,min}}^{\mathrm{N/Accepted}}}) & \cdots & \sim n(\mu_{\mathrm{TTC}_{\mathrm{C,sd}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{TTC}_{\mathrm{C,sd}}^{\mathrm{N/Accepted}}}) \\
\vdots & \ddots & \vdots \\
Dy_{\mathrm{C,min}}^{\mathrm{N/Accepted}} & & Dy_{\mathrm{C,sd}}^{\mathrm{N/Accepted}} \\
\sim n(\mu_{\mathrm{Dy}_{\mathrm{C,min}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{Dy}_{\mathrm{C,min}}^{\mathrm{N/Accepted}}}) & \cdots & \sim n(\mu_{\mathrm{Dy}_{\mathrm{C,sd}}^{\mathrm{N/Accepted}}}, \sigma^2_{\mathrm{Dy}_{\mathrm{C,sd}}^{\mathrm{N/Accepted}}})
\end{bmatrix}
\end{aligned}
\tag{19}
$$

Table 7 shows the descriptive statistics for parameters having a significance level below 5 % and presents the results of the significance test. Sixteen parameters are found to be significant; Figure 10 gives the results of the sensitivity analysis for the significant parameters in relation to subjective acceptance. High sensitivity values are observed for change in time to collision, maximum relative velocity in the longitudinal direction, and minimum distance between vehicles in the longitudinal direction. While the absolute sensitivity values are smaller than those of Target B, they have a well-distributed influence on driver acceptance. As such, they must be sufficiently considered in the development of the evaluation index for driver acceptance.

Table 7. Descriptive statistics and significance test of parameters related to the driving environment: Target C.

| | unit | Descriptive statistics | | | | Significance test[1)] | |
|---|---|---|---|---|---|---|---|
| | | Accepted | | Rejected | | | |
| | | E[X] | Var[X] | E[Y] | Var[Y] | $t$ | p-value |
| $TTC_{max}$ | s | 18.19 | 912.78 | 20.68 | 1709.5 | – 2.673** | 0.008 |
| $TTC_{med}$ | s | 13.27 | 228.59 | 15.00 | 1394.3 | – 3.161** | 0.002 |
| $TTC_{mean}$ | s | 13.75 | 271.22 | 14.34 | 791.09 | – 2.583* | 0.010 |
| $TTC_{sd}$ | s | 2.55 | 65.96 | 5.33 | 349.60 | – 4.263*** | 0.000 |
| $relV_{min}$ | m | 5.05 | 34.63 | 2.45 | 13.30 | 2.668** | 0.008 |
| $relV_{max}$ | m | 5.86 | 34.14 | 4.30 | 61.93 | 2.557* | 0.011 |
| $relV_{med}$ | m | 5.45 | 33.60 | 3.33 | 23.99 | 2.681** | 0.008 |
| $relV_{mean}$ | m | 5.45 | 33.57 | 3.34 | 23.97 | 2.674** | 0.008 |
| $relVx_{max}$ | m | – 6.67 | 87.46 | – 0.96 | 105.96 | – 1.975* | 0.049 |
| $relVx_{med}$ | m | – 6.97 | 86.29 | – 1.83 | 65.54 | – 1.972* | 0.049 |
| $relVx_{mean}$ | m | – 6.97 | 86.27 | – 1.81 | 65.61 | – 1.965* | 0.050 |
| $D_{max}$ | m | 48.26 | 1304.68 | 29.87 | 281.94 | 2.283* | 0.023 |
| $D_{med}$ | m | 45.27 | 1292.57 | 28.64 | 277.60 | 1.996* | 0.046 |
| $D_{mean}$ | m | 45.31 | 1291.57 | 28.68 | 277.23 | 1.995* | 0.046 |
| $D_{sd}$ | m | 1.96 | 4.35 | 0.87 | 3.63 | 3.272** | 0.001 |
| $Dx_{min}$ | m | 77.12 | 2294.08 | 39.07 | 1042.0 | – 1.970* | 0.049 |

[1)]Level of significance: p < .05*, p < .01**, p < .001***

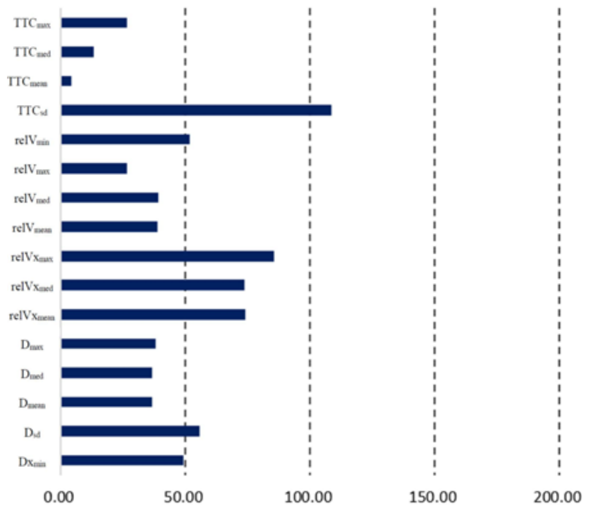



Figure 10. Sensitivity of parameters related to the driving environment: Target C.

## 4. DISCUSSION

### 4.1. Determination and Normalization of Parameters

Based on the results of the significance test and sensitivity analysis, the parameters are categorized according to their level of influence on subjective acceptance during lane change. Comparative analyses are performed for parameters having a sensitivity greater than 50 % (Sensitivity > 50 %). The determined data sets are normalized by Equations (20) and (21) for comparisons of parameters considering the passengers' subjective acceptance evaluation.

$$z_i^{Accepted} = \frac{x_i - [x]_{Lower}}{[x]_{Upper} - [x]_{Lower}} \quad (20)$$

$$z_i^{Rejected} = \frac{y_i - [x]_{Lower}}{[x]_{Upper} - [x]_{Lower}} \quad (21)$$

where $z_i^{Accepted}$, $z_i^{Rejected}$ are the $i$th normalized values, $x_i$ and $y_i$ are the $i$th raw data of accepted and rejected cases, and $[x]_{Lower}$ and $[x]_{Upper}$ are the lower and upper bounds for normalization, defined as below in Equations (22) and (23).

$$[x]_{Lower} = Q_1 - 1.5(IQR) \quad (22)$$

$$[x]_{Upper} = Q_3 + 1.5(IQR) \quad (23)$$

### 4.2. Comparisons of Determined Parameters in Relation to Driver Acceptance

In order to compare the derived parameters between accepted cases and rejected cases, normalization is carried out, and the box plots of Figure 11 (a) to (g) are used. While all the parameters for drivers' input have sensitivity values less than 50 %, they are included for the purpose of comparative study, as can be seen in Figure 11 (a).

As the accepted cases are compared with the rejected cases, in general, the distributions of selected parameters with high significance and sensitivity in relation to subjective acceptance show significant differences: Smaller driver inputs; smaller accelerations and jerk; smaller distribution of time to collision to target vehicles; and larger distance to target vehicles for the accepted cases. Several aspects are shown to be contrary to common senses in vehicle dynamics and vehicle relations; bigger roll angular motion, smaller time to collision, and smaller relative vehicle speed cause negative driver acceptance in general. In Figure 11 (b), the minimum value of vehicle roll motions for accepted case show bigger than those for rejected case. It is believed that effects of vehicle speeds must be exist, and it is necessarily needed to investigate correlation between the roll angular motion and other aspects in further study. In Figure 11 (c) to (g), most of time to collision and relative speed to target vehicles for accepted cases also appear smaller than those of rejected cases while distance to target vehicles are larger. Based on these aspects, it can be asserted that distance to target vehicles are the most effective factors on driver acceptance among driving environmental factors in vehicle relations. Drivers' input parameters with relatively low sensitivity are supposed to be negligible for acceptance evaluation because it is supposed that influences of those parameters are reflected in dynamic vehicle behavior as well as parameters having high significance and sensitivity in the given driving environments.

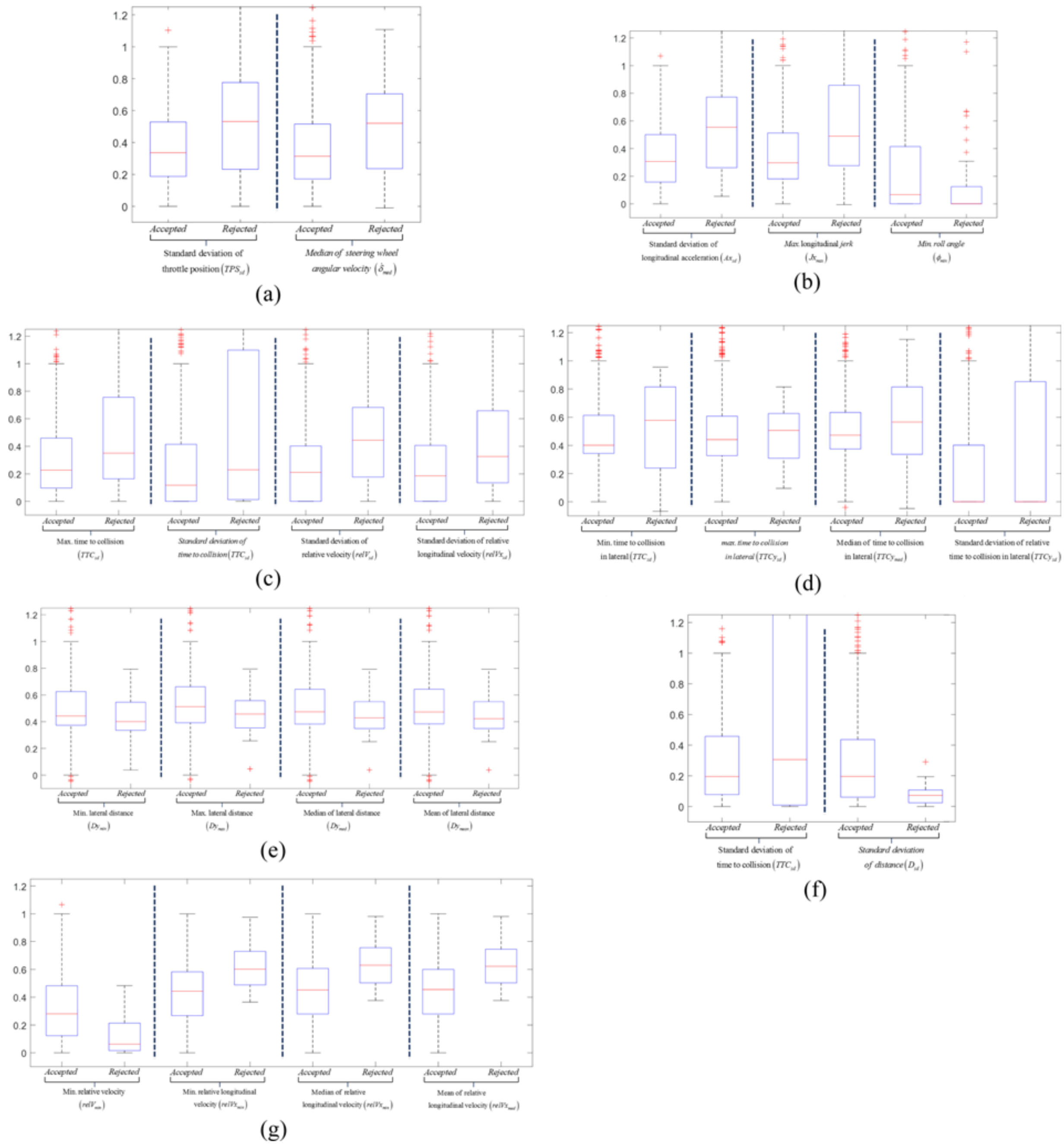



Figure 11. Boxplot comparison of evaluation index: (a) For drivers' inputs; (b) For vehicle dynamic behaviors; (c) For target A; (d), (e) For target B; (f), (g) For target C.

As shown in the results of the significance test, sensitivity analysis, and boxplot comparisons for objective parameters, driver acceptance is mostly influenced by driving environmental factors rather than driver's inputs and vehicle dynamic behaviors. It is also seen that driver acceptance is influenced by different parameters from each target vehicles: longitudinal parameters are dominant for the leading vehicle on the driving lane such as longitudinal relative vehicle speed; lateral parameters are dominant for the leading vehicle on the target lane such as time to collision in lateral; As for the trailing vehicle on the target lane, the influence on driver acceptance are evenly distributed across parameters such as time to collision, and longitudinal relative vehicle speed. In overall, the selected environmental factors are derived to be relatively more significant and sensitive to the subjective driver acceptance in comparisons with selected behavioral factors on driver and vehicle.

Table 8. Suggested index for acceptance evaluation of automatic lane change system.

| Classifications | Parameters | Unit | Descriptive Statistics | | Description |
|---|---|---|---|---|---|
| | | | E[X] | Var[X] | |
| Vehicle | $Ax_{sd}$ | $m/s^2$ | 0.15 | 0.02 | Standard deviation of longitudinal acceleration |
| | $Jx_{max}$ | $m/s^3$ | 0.40 | 0.22 | Max. value of derivative of longitudinal acceleration |
| | $Ø_{min}$ | deg | 0.92 | 1.66 | Min. value of roll angle |
| Target A | $TTC_{max}$ | s | 22.64 | 1189.14 | Max. value of time to collision to target A |
| | $TTC_{sd}$ | s | 3.24 | 55.85 | Standard deviation of time to collision to target A |
| | $relV_{sd}$ | m/s | 0.37 | 1.04 | Standard deviation of relative speed to target A |
| | $relVx_{sd}$ | m/s | 0.32 | 0.96 | Standard deviation of longitudinal relative speed to target A |
| Target B | $TTCy_{min}$ | s | 0.70 | 22.18 | Min. value time to collision to target B in lateral |
| | $TTCy_{max}$ | s | 2.21 | 32.85 | Max. value of time to collision to target B in lateral |
| | $TTCy_{med}$ | s | 1.12 | 16.57 | Median value of time to collision to target B in lateral |
| | $TTCy_{sd}$ | s | 1.14 | 16.49 | Standard deviation of time to collision to target B in lateral |
| | $Dy_{min}$ | m | 2.36 | 8.40 | Min. value of lateral distance to target B |
| | $Dy_{max}$ | m | 2.20 | 7.69 | Max. value of lateral distance to target B |
| | $Dy_{med}$ | m | 2.25 | 7.72 | Median value of lateral distance to target B |
| | $Dy_{mean}$ | m | 2.26 | 7.71 | Mean value of lateral distance to target B |
| Target C | $TTC_{sd}$ | s | 2.55 | 65.96 | Standard deviation of time to collision to target C |
| | $relV_{min}$ | m/s | 34.63 | 2.45 | Min. value of relative speed to target C |
| | $relVx_{max}$ | m/s | − 6.67 | 87.46 | Max. value of longitudinal relative speed to target C |
| | $relVx_{med}$ | m/s | − 6.97 | 86.29 | Median value of longitudinal relative speed to target C |
| | $relVx_{mean}$ | m/s | − 6.97 | 86.27 | Mean value of longitudinal relative speed to target C |
| | $D_{sd}$ | m | 1.96 | 4.35 | Standard deviation of distance to target C |

Thus, the parameters described in Table 8, associated high subjective acceptance can be suggested as objective evaluation index for driver acceptance of the automatic lane change system. The derived parameters for evaluation are seven in the longitudinal direction, nine in the lateral direction, and six in the longitudinal/lateral direction, amounting to a total of 21.

## 5. CONCLUSION

This study investigates whether drivers' subjective acceptance of an automatic lane change system is influenced by various types of objective parameters, observable and measurable. A database including a massive amount of information on drivers, vehicles, and traffic interactions is constructed for the investigation of the relationship between the subjective acceptance and lane change performance, considering such factors as driver input, dynamic vehicle behavior, and driving environment. For the construction of the database, a specific experimental program including several questionnaires and experimental environments is designed. In the database, 1,823 lane change events with 19 selected drivers are participated. Abundant information from an objective data and subjective evaluation for each lane change case is also included in the database. Significance test and sensitivity analysis are carried out to determine objective parameters using a part of the whole database, namely 330 cases of lane change to provide an objective evaluation of driver/passenger acceptance of the automatic lane change system.

Consequently, several parameters with descriptive statistics for acceptance evaluation are presented: six in the longitudinal direction, nine in the lateral direction, and six in the longitudinal/lateral direction, amounting to a total of 21. It is expected that the driver acceptance of lane change performance can be evaluated with the presented index. The results of this research can also be utilized as design criteria for control of advanced and automated driving systems. For further study, the range of analysis can be expanded to the entire database in order to reduce the numbers of parameters in the index, and calibrate and improve the reliability of the suggested evaluation index.

## REFERENCES


Adell, E. and Varhelyi, A. (2008). Driver comprehension and acceptance of the active accelerator pedal after long-term use. *Transportation Research Part F: Traffic Psychology and Behaviour* **11**, **1**, 37−51.

Adell, E. (2010). Acceptance of driver support systems. *Proc. European Conf. Human Centred Design for Intelligent Transport Systems*, 475−486.

Butakov, V. A. and Ioannou, P. (2015). Personalized driver/vehicle lane change models for ADAS. *IEEE Trans. Vehicular Technology* **64**, **10**, 4422−4431.

Davis, F. D., Bagozzi, R. P. and Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science* **35**, **8**, 982−1003.

Gindele, T., Brechtel, S. and Dillmann, R. (2015). Learning driver behavior models from traffic observations for decision making and planning. *IEEE Intelligent Transportation Systems Magazine* **7**, **1**, 69−79.

Kim, J. (2008). Analysis of handling performance based on simplified lateral vehicle dynamics. *Int. J. Automotive Technology* **9**, **6**, 687−693.

Kim, J. (2011). Objectification of on-center handling characteristics based on spring-mass-damper system. *Int. J. Automotive Technology* **12**, **6**, 857−864.

Neale, V. L., Dingus, T. A., Klauer, S. G., Sudweeks, J. and Goodman, M. (2005). An overview of the 100-car naturalistic study and findings. *National Highway Traffic Safety Administration*, Paper No. 05-0400.

Nobukawa, K., Bao, S., LeBlanc, D. J., Zhao, D., Peng, H. and Pan, C. S. (2016). Gap acceptance during lane changes by large-truck drivers – An image-based analysis. *IEEE Trans. Intelligent Transportation Systems* **17**, **3**, 772−781.

Nishiwaki, Y., Miyajima, C., Kitaoka, N., Terashima, R., Wakita, T. and Takeda, K. (2008). Generating lane-change trajectories of individual drivers. *IEEE Int. Conf. Vehicular Electronics and Safety*, 271−275.

Peden, M., Scurfield, R., Sleet, D., Mohan, A., Hyder, A., Jrawan, E. and Mathers, C. (2004). World Report on Road Traffic Injury Prevention. World Health Organization. World Bank. Geneva.

Regan, M., Mitsopoulos, E., Haworth, N. and Young, K. (2002). Acceptability of In-vehicle Intelligence Transport Systems to Victorian Car Drivers. Monash University Accident Research Centre.

Schade, J. and Baum, M. (2007). Reactance or acceptance? Reactions towards the introduction of road pricing. *Transportation Research Part A: Policy and Practice* **41**, **1**, 41−48.

Van Der Laan, J. D., Heino, A. and De Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. *Transportation Research Part C: Emerging Technologies* **5**, **1**, 1−10.

Venkatesh, V. and Morris, M. G. (2000). Why don't men ever stop to ask for directions? Gender, social influence, and their role in technology acceptance and usage behavior. *MIS Quarterly* **24**, **1**, 115−139.

Yao, W., Zhao, H., Bonnifait, P. and Zha, H. (2013). Lane change trajectory prediction by using recorded human driving data. *IEEE Intelligent Vehicles Symp. (IV)*, 430−436.