ISASE 2020

Risk Feeling Index of Autonomous Vehicle Behavior

– Modeling Individual differences based on Expectation Effect Theory –

Takashi HASHIMOTO*, Hideyoshi YANAGISAWA*

* *The University of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo 113-8654, Japan*

Abstract: Studies of autonomous driving systems are being conducted to realize a safe and secure mobile society. According to these studies, the safety of the system and the driver's feeling of security often do not match. To enable automatic driving control according to the driver's comfort, previous researchers introduced risk feeling index to quantify the driver's feeling of security, without accounting for the effects of drivers' individual differences. The purpose of this study is to quantify the risk feeling perceived by the driver while considering individual differences. We extracted the factor of individual differences comprehensively to examine the model of risk feeling based on the expectation effect theory. Using a driving simulator, we investigated the effect of the extracted factor on the subjective assessment of risk feeling while overtaking. The results suggest that risk is perceived based on both the individual driving characteristic of anxiety while driving and the experimentally manipulated prior prediction. These findings will enable the development of a secure automatic driving system that suits each driver by controlling the system appropriately based on the driver's driving characteristics.

Keywords: *Autonomous driving, Risk feeling, Individual differences, Expectation effect theory, Prediction error*

1. INTRODUCTION

Research and development of an automatic driving system that recognizes objects, make judgments, and operates in place of a driver, has been conducted with the aim of realizing a safe and secure mobile society [1]. The technological improvement of safety is expected, but driver safety includes psychological factors that cannot be achieved only by technical aspects. Therefore, the safety of the system itself and the driver's feeling of safety do not always match. For example, when the driver does not feel comfortable with the system even though the autonomous driving technology guarantees adequate safety, the spread of autonomous vehicles may stagnate. Therefore, it is important to design the system based not only on technical safety but also on the driver's feeling of security.

Studies have been conducted to index risk feeling [2, 3], however, there is not enough research about the effects of individual differences. Since there are individual differences in risk perception, it is necessary to consider the effect of individual differences while indexing risk feeling. The purpose of this study is to formulate the risk perceived by drivers considering their individual differences in order to control the autonomous driving system in a way that enables the drivers' to feel safe.

2. RELATED WORKS

2.1 Risk feeling indexes in automotive driving behavior

During a study that indexed the risk feeling perceived by the driver, Kondo [2] proposed that the risk perceived by the driver while approaching a preceding vehicle can be given as,

$$RF = \frac{5}{TTC} + \frac{1}{THW} \quad (1)$$

where RF is Risk Feeling perceived by driver, TTC (Time to Collision) is the time required for two vehicles to collide if they continue at their present speed and on the same path, THW (Time Head Way) is the time difference between any two successive vehicles when they cross a given point. This formula does not take individual differences into account.

2.2 Studies on individual differences in risk feeling of driving behavior

It is known that there are individual differences in the timing of brake operation when approaching a preceding vehicle. Kondo [3] proposed a personalized risk feeling index normalized by individual driving characteristic when approaching the preceding vehicle as follows.

$$RF_{ind} = (\frac{1}{THW})/(\frac{1}{THW_{ind}}) + (\frac{1}{TTC})/(\frac{1}{TTC_{ind}}) \quad (2)$$

Here, TTC_{ind} and THW_{ind} are the values of TTC and THW at the time of brake operation while approaching the preceding vehicle. It has been confirmed that this personalized risk feeling index has improved the accuracy of identifying when the driver' changes from the accelerator to the brake, compared to the conventional index. Since this index is intended for a driving assistance system equivalent to autonomous driving level 1 or 2, in which the driver is responsible for monitoring and responding to safe driving, it cannot be applied to autonomous driving systems of level 3 or higher, in which the system is responsible for monitoring and responding to safe driving. It may, however, be applied to a limited situation such as in the context of our study. In this paper, we analyze the factors of individual differences that affect the perception of risk, and index the perception of risk according to the extracted factors. We model the risk perception at the automatic driving level 3, in which it is necessary to control the autonomous driving system based on the individual belief of driving behavior.

2.3 Factors of individual differences in risk perception

In this study, based on the fact that the factors that determine individual differences in risk perception include personality, situation cognition, and option cognition [4], we analyze these factors of individual differences. Situation cognition is an individual's way of thinking and knowledge of each situation, and option cognition is the evaluation of the actions that can be actually selected.

Personality is a relatively stable characteristic of a person, and therefore the effect of option cognition is small in autonomous driving, where the system is responsible for the safe driving. In the quantification of individual differences in risk feeling, it is necessary to control the autonomous driving system in accordance with the expectations of the individual. So, we examine individual differences resulting from the situation cognitive factor. We made an assumption that the situation cognitive factor corresponded to the prior prediction in the expectation effect theory [5]. In this study, we examine the expected value and the uncertainty of the probability distribution of the prior prediction in the expectation effect theory as a factor of individual differences in the perception of the risk.

3. MODELING INDIVIDUAL DIFFERENCES OF RISK PERCEPTION IN AUTONOMOUS DRIVING BEHAVIOR

3.1 Modeling individual differences in risk feeling based on expectation effect theory

Based on the analysis of the factors that define individual differences in the perception of risk, we index risk feeling by using the expected value and the uncertainty of the prior distribution (probability distribution of prior prediction) in the expectation effect theory [5] proposed by Yanagisawa as factors of individual differences. In the expectation effect theory, perception is defined as the Bayesian estimate of physical quantities. The Bayesian *posterior*, distribution of perception, is formed by multiplying the *prior*, distribution of perception, and the *likelihood function* formed from sensory stimuli. Thus the prior expectation affects the posterior perception. This effect is called expectation effect. The prior $p(\theta)$ stochastically predicts the physical quantity θ by learning the frequency distribution of the physical quantity. The brain estimates the physical quantity based on the neural signal pattern R as the likelihood function $p(R|\theta)$. The posterior $p(\theta|R)$ follows the Bayesian estimate, and the posterior estimate $\hat{\theta}$ is the value of the maximum probability of the posterior. The *expectation effect* ϵ is defined as follows.

$$\epsilon = \hat{\theta} - \theta_{lik} \quad (3)$$

The *prediction error* δ is the difference between the expected value of the prior distribution $E[p(\theta)]$ and the maximum likelihood estimate θ_{lik} and is defined as follows.

$$\delta = \theta_{lik} - E[p(\theta)] \quad (4)$$

It is known that the larger the prediction error, the more attention a person dedicates to obtaining information and to learning new stimuli to update existing knowledge [6]. There are two types of expected effects: *assimilation*, which underestimates the prediction error when the prediction error is small, and *contrast*, which overestimates the prediction error when the prediction error is large. The variance $V[p(\theta)]$ of the prior distribution is called *uncertainty*, and the magnitude of the uncertainty affects the strength of the expected effect. When the uncertainty is high, the magnitude of the expected effect decreases, and when the uncertainty is low, the magnitude of the expected effect increases. Since the prediction error affects expectation effect, we examined the effect of the prediction error on the driver's risk perception. We assumed that the difference between the expected value of the driving characteristic of the individual and the driving characteristics of the automatic driving system corresponds to the prediction error.

Based on the expectation effect theory, we hypothesized that the difference between the prediction based on the individual driving characteristic and the actual driving behavior (i.e. prediction error) affects risk perception. In other words, if the actual driving behavior is more dangerous than predicted, the sense of risk increases, and if it is safer, the sense of risk decreases.

3.2 Formulation of individual differences

The most common cause of a traffic accident is a rear-end collision with a vehicle that has stopped in a lane [7]. In this study, based on the following hypothesis, we examined the risk feeling index considering the effect of the individual differences by using the distance from the preceding vehicle while overtaking a vehicle that has stopped.

Hypothesis: The difference between a prediction based on individual driving characteristics and actual driving behavior (prediction error) gives a sense of risk.

In the condition where the prediction error from the expected value of the individual driving characteristic (e.g. inter-vehicle distance) is small, it is thought that risk feeling is evaluated to be smaller than actual due to the effect of the assimilation of the expectation effect. In the condition where the prediction error is large, risk feeling is evaluated to be larger than actual due to the effect of the contrast effect, and it is considered that there is no change in the risk feeling even if the prediction error further increases. Therefore, we considered that the risk perception follows an S-curved-function such as the sigmoidal function. Based on the hypothesis, we formulated the risk feeling index taking into account the effect of a prediction error as in formula (5). The plot is shown in Figure 1.

$$\begin{pmatrix}\text{Risk Feeling considering the effect of}\\ \text{prediction error}\end{pmatrix} = \frac{a}{1+\exp(b\times(d_{actual}-d_{ind})+c)} \quad (5)$$

Where, d_{actual} is the inter-vehicle distance between the host vehicle and the vehicle in front that has stopped in the lane, and d_{ind} is the expected value of the individual driving characteristics. a and b are positive constants, and c is an arbitrary constant.

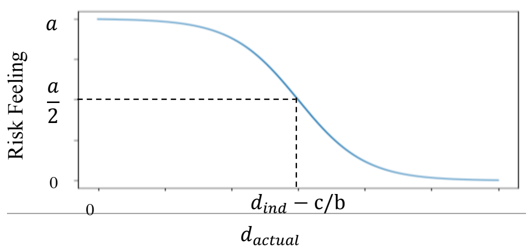

Figure 1: The Plot of Formula (5)

4. EXPERIMENT ON THE EFFECT OF THE PREDICTION ERROR ON RISK FEELING

4.1 Method

Ten University of Tokyo students in their twenties who have driver's licenses, took part as participants. We used a driving simulator and presented an overtaking scene, shown in Figure 2, to the experiment participants. We manipulated the length of the inter-vehicle distance between the subject vehicle and the front vehicle stopping in the front lane, d_{actual}. We examined the effect of the factor and the expected value of the inter-vehicle distance of changing lanes based on individual senses on risk feeling, d_{ind}. We obtained the participants' evaluation of "Perceived risk based on individual driving characteristic before learning" (Evaluation 1).

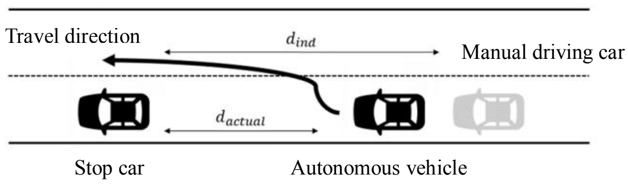

Figure 2: Overtaking Scene and Definition of Factors

In order to obtain the participants' evaluation we prepared two types of scenes: scenes for manual driving (manual driving scene) and scenes for the participants of the experiment to evaluate the perceived risk in the driving behavior of autonomous driving (evaluation scene). We manipulated the inter-vehicle distance in the evaluation scene as shown in Table 1. We randomly presented the 16 scenes with different length of inter-vehicle distance. We divided participants into two groups, and achieved a counterbalance by reversing the presentation order of the evaluation scenes.

Table 1: Experimental Condition of and Evaluation Scene

	Length of d_{actual} [m]	Number of presentations
Evaluation scene	10, 12 ,15, 18, 22, 25, 28, 31, 34, 37, 40, 43, 46, 49, 52, 55	1 time

In order to obtain Evaluation 1, we asked participants to drive manually and then to evaluate the evaluation scene.

In the manual driving session, the participants operated the steering wheel and accelerator pedal and changed lanes to avoid a stopping car. We obtained the inter-vehicle distance at which the participant started to change the lane and marked it as the individual's driving characteristic. In the evaluation session, we manipulated the inter-vehicle distance at which the autonomous vehicle switches lanes, and obtained the evaluation of the risk perceived by the participants on nine levels: "very safe,"

"safe," "relatively safe," "slightly safe," "neither safe nor dangerous," "slightly dangerous," "relatively dangerous," "dangerous," and "very dangerous."

4.2 Results

In Figure 3, the relationship between "d_{actual}" and the participants' evaluation of "risk feeling based on individual driving characteristic" (Evaluation 1) are shown. The correlation coefficient was r = 0.770.

In Figure 4, the relationship between "d_{actual}-d_{ind}" and the participants' evaluation of "risk feeling based on individual driving characteristic" (Evaluation 1) are shown. The correlation coefficient was r = -0.818. From Figure 3 and Figure 4, it is evident that the relationship between "d_{actual}-d_{ind}" and risk feeling is stronger than that between "d_{actual}" and risk feeling.

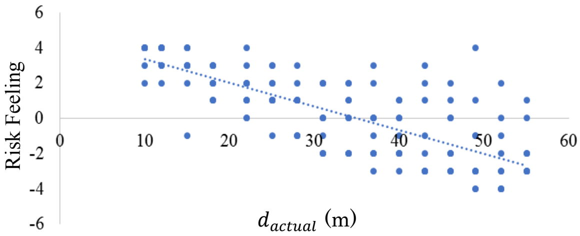

Figure 3: Relationship Between "d_{actual}" and Risk Feeling Based on Individual Driving Characteristic

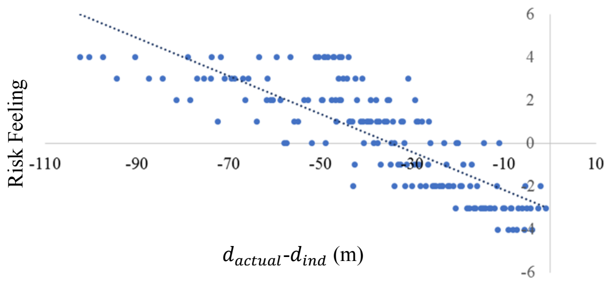

Figure 4: Relationship Between "d_{actual}-d_{ind}" and Risk Feeling Based on Individual Driving Characteristic

4.3 Discussion

From Figure 3 and Figure 4, it is observed that the correlation between the inter-vehicle distance based on the individual driving characteristics and risk feeling is stronger than that between the inter-vehicle distance alone and risk feeling. This supports the hypothesis that risk is perceived based on the expected value of the individual driving characteristics.

5. CONCLUSION

The purpose of this study was to extract the factors that define individual differences in risk perception, and to quantify the risk perception taking into account the effects of individual differences by expressing the individual differences of drivers using quantitative features. Assuming that prediction error is a factor of individual differences, we verified the risk perception by experimentally manipulating the factor, and found that risk is perceived based on the prediction error i.e., the difference between the participants' belief of the inter-vehicle distance at which participants switched lanes to avoid the preceding vehicle and the actual inter-vehicle distance in autonomous driving mode.

The investigation and discussion of the individual differences that affect the perception of risk feeling in this study is broad, and as such the proposed risk feeling model and findings can be applied to different driving scenarios in future studies of autonomous driving systems, although further examination and improvements are needed.

ACKNOWLEDGMENTS

We are very grateful to the participants who cooperated with the experiment.

REFERENCES

[1] N. Suganuma; Technical Overview of Autonomous Driving System, Journal of the Japan Society of Applied Electromagnetics and Mechanics; 4(25), pp.373-378, 2017.

[2] T. Kondoh. T, Yamamura, S, Kitazaki, N, Kuge, and Boer. E. R; Identification of visual cues and quantification of drivers' perception of proximity risk to the lead vehicle in car-following situations, Journal of Mechanical Systems for Transportation and Logistics; 1(2), pp.170-180, 2008

[3] T. Kondoh, T. Hirose, and N. Furuyama; A proposal of tailor-made risk feeling formula when closing on the lead vehicle, Japan Ergonomics Society; 50(6), pp.350-358, 2014.

[4] H. Ueichi, and T. Kusumi; Effects of personality, cognitive, and situational variables on risk taking behavior, Shinrigaku kenkyu: The Japanese Journal of Psychology; 69(2), 81-88, 1998.

[5] H. Yanagisawa; A Computational Model of Perceptual Expectation Effect Based on Neural Coding Principles, Journal of Sensory Studies; 31(5), pp.430-439, 2016.

[6] Christoph. M., Rheinberger, James. K., Hammitt; Dinner with Bayes: On the revision of risk beliefs, Journal of Risk and Uncertainty; 57, pp.253–280, 2018.

[7] National Police Agency Traffic Bureau; The situation of traffic accidents during 2017, 2018, Available: https://www.npa.go.jp/publications/statistics/koutsuu/H29zennjiko.pdf.