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How Drivers Feel When Traversing Speed Humps under a Variety of Driving Conditions †

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Abstract: Speeding is known to be one of the main causes of traffic crashes. Therefore, various speed management techniques are applied to prevent accidents caused by speeding in many countries. Among them, speed humps are regarded as a cost-effective facility compared to other speed management techniques. Although the development of speed bumps continues through various studies, most studies focus on reducing the amount of impact, so there is no study that can comprehensively determine the driver's feeling. Therefore, in this study, a generalized ordered regression model was used to demonstrate the driver's feelings when passing a speed hump under various driving conditions through field experiments.

Keywords: speed humps; user preference; generalized ordered logit model; sinusoidal; speed management

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1. Introduction

Speeding is known to be one of the main causes of traffic accidents. According to Injury Facts, speeding was a factor accounting for 29% of all road fatalities in 2020, killing 11,258 people, representing an average of more than 30 deaths per day [1]. Therefore, many states in the United States are applying various speed-reducing traffic calming techniques to prevent accidents caused by speeding [2]. There are various techniques that can be applied to traffic calming techniques, such as speed bumps, cameras, and signs [3]. Among them, speed bumps are considered the most excellent facility for speed reduction compared to other speed management technologies [4]. They cause problems such as discomfort due to vehicle passing impact [5], vehicle damage [6], occupant injury [7], and noise pollution [8]. Among these problems, several studies have been conducted to develop various types of speed bumps in order to reduce the amount of impact applied to the driver [8–10].

However, most studies only deal with how the impact amount changes depending on the shape, so there is no research to measure the degree of comfort felt by the driver even if the impact amount is reduced. Therefore, the purpose of this study is not only to reduce the amount of impact by changing the shape, but also to determine whether the comfort or discomfort increases or decreases under what conditions because the comfort felt by the driver can vary depending on the shape and the passing condition. In this study, a generalized ordered logit model that can be applied by relaxing the assumption of the parallel line that the influence of the dependent variable is the same is used to reflect the size of the influence of the driving conditions according to the driver's emotional state [11].

2. Methodology

The ordered logit model is a model suitable for verifying the effect of an independent variable on a dependent variable when the dependent variable has a sequence relationship [12]. It is used when there is a hierarchy of dependent variables, such as accident severity (injury, minor injury, serious injury, death) or satisfaction level (very dissatisfied, dissatisfied, neutral, satisfied, very satisfied) [13]. The biggest feature of the ordered logit model is that it assumes parallelism. In the model, the inclination coefficients of the independent variables have the same value, and only the intercept terms of the regression lines are different. That is, they have different parallel regression lines. For this reason, the ordered logit model is also known as the proportional odds model.

However, the parallel regression line assumption is not always satisfied. This assumption is frequently violated, in which case the use of sequence logit models is inappropriate. Therefore, in this study, the "autofit" command (STATA) was used to determine whether the assumption of parallelism of various variables was violated. In addition, the omodel command was used to determine the significance of the ordered logit model results. If it determines that the sequence logit model results are not significant, it can provide a basis for applying a generalized ordinal logit model with relaxed parallelism assumptions.

The generalized ordered logit model is a model that considers that the inclination may not be parallel by alleviating the parallelism assumption of the ordered logit model [14]. In this study, we ran a generalized ordered logit model using the STATA module gologit2 and checked the *p*-values of each variable to determine whether the variables were parallel. After this process, we interpreted the results of the generalized ordered logit model.

3. Study Procedure

3.1. Variables

The dependent variable of the data is Satisfaction (SAT), which is categorized into Dissatisfied, Neutral, and Satisfied. The independent variables were career, car, speed, shock, and bump type. Car type and bump type were set as categorical variables and used as dummy variables; car_1 means a van, car_2 means a truck, and type_A, type_B, and type_C mean s-type bump types A, B, and C. (Table 1)

Table 1. Variable description.

Variables	Description	Measurement
Satisfaction	Driver's satisfaction through poll	Dissatisfy = 1, Neutral = 2, Satisfy = 3
speed humps type_A type_B type_C	4 type of speed humps passed by drivers (dummy variable)	Passing type A = 1, else = 0 Passing type B = 1, else = 0 Passing type C = 1, else = 0 (Passing type O: type_A, type_B, type_C = 0)
Car type car_1 car_2	3 type of cars with drivers (dummy variable)	Ride in a van = 1, else = 0 Ride in a truck = 1, else = 0 (Ride in a passenger car: car_1, car_1 = 0)
Career	Driver's driving experience	years
speed	Car's speed passing speed hump	km/h
shock	impact the driver receives	$m/s^{1.75}$

3.2. Data

We conducted an experiment at Automobile Safety Research Institute of Korea Transportation Safety Authority. For the field experiment, four types of speed bumps were installed, including parabolic ones. In addition, a field experiment was conducted by setting a human body impulse measurer and a satisfaction survey questionnaire. The experimental vehicles consisted of passenger cars, SUVs, and trucks, and a total of 10 drivers drove through four types of speed bumps at a speed of 10 km/h to 50 km/h and had them fill out a satisfaction questionnaire. And research was conducted. (Figure 1)

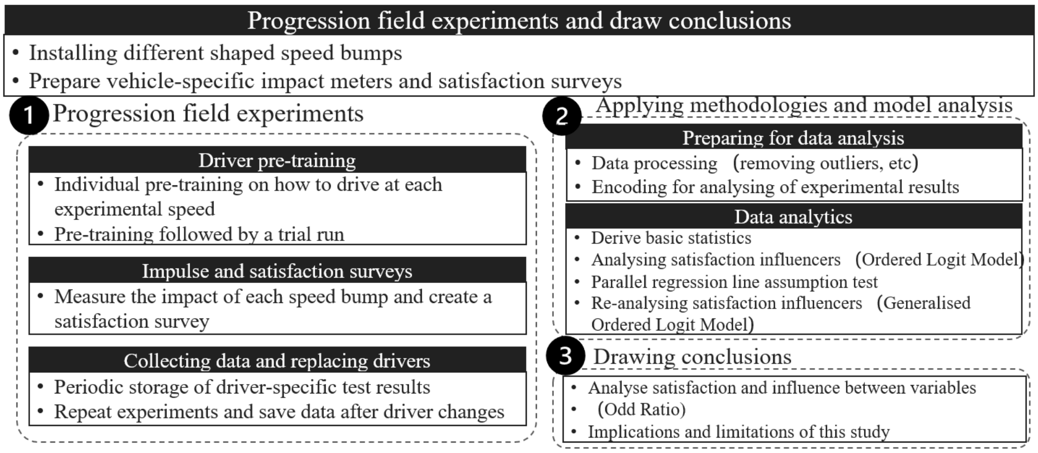

Figure 1. Research Progression.

4. Result

4.1. Result of Ordered Logit Model

In this study, the results of the ordered logit model were first drawn. We utilized STATA's module ologit and showed the odds ratio of each variable (Table 2).

Table 2. Result of ordered logit model.

Variables	type_A	type_B	type_C	car_1	car_2	Career	Speed	Shock	/cut1	/cut2
Coefficient	0.3297	0.2665	0.6329	−1.2217	−2.4531	0.1763	−0.1207	−0.7192	−6.3696	−4.8559
Odds ratio	1.3905	1.3054	1.8831	0.2947	0.0860	1.1927	0.8863	0.4872	−6.3696	−4.8559
$p > \|z\|$	0.273	0.370	0.036	0	0	0	0	0		

4.2. Assessing Parallel-Line Assumption

However, since the ordered logit model assumes that the regression lines are all parallel, it is necessary to test whether the results of this model are significant. Therefore, in this study, the parallel regression line assumption was tested using the autofit module as shown in Table 3. Among all the variables, the car_2, speed, and shock variables had *p*-values below 0.05, so we rejected the assumption of parallelism. For the remaining variables, the *p*-value was greater than or equal to 0.05, so the assumption of parallelism was accepted, confirming that the slopes of the regression lines are equal.

Table 3. Autofit result of Parallel-Line Assumption.

Variables	type_A	type_B	type_C	car_1	car_2	Career	Speed	Shock
p Value	0.0873	0.1906	0.8832	0.8147	0.0089	0.3633	0.0001	0.0109

Prob > chi2 = 0.3104.

4.3. Result of Generalized Ordered Logit Model

As shown in Table 4, the variables for types A and B are not statistically significant ($p > 0.05$), while all other variables are statistically significant ($p < 0.05$). First, looking at the relationship between speed bump type and satisfaction, when passing type C rather than type O, the possibility that the driver chooses a higher level of satisfaction increases by about 96% ((1.9655 − 1) × 100 = 96). When selecting a truck, the probability that the driver chooses satisfaction over dissatisfaction decreases by about 96%, and the probability of choosing satisfaction over dissatisfaction or average decreases by about 86%. That is, passenger cars, vans, and trucks showed high satisfaction in that order [14].

Table 4. Result of generalized ordered logit model.

	Variables	type_A	type_B	type_C	car_1	car_2	Career	Speed	Shock	Cons
1	Coefficient	0.3199	0.2793	0.6757	0.179	−1.1583	−3.202	−0.1592	−0.4809	7.5232
	Odds ratio	1.3769	1.3222	1.9655	1.1961	0.314	0.0407	0.8528	0.6182	1850.54
	$p > \lvert z \rvert$	0.29	0.35	0.026	0	0	0	0	0.003	0
2	Coefficient	0.3199	0.2793	0.6757	0.179	−1.1583	−1.9609	−0.0985	−0.9804	4.4392
	Odds ratio	1.3769	1.3222	1.9655	1.1961	0.314	0.1407	0.9062	0.3752	84.7063
	$p > \lvert z \rvert$	0.29	0.35	0.026	0	0	0	0	0	0

5. Conclusions

First of all, the level of satisfaction with type C of the s-shaped bumps was higher than that of the original arc type. Therefore, replacing the existing arc-shaped bumps with type C bumps can be one of the countermeasures to reduce the driver's discomfort due to the existing speed bumps. In addition, the satisfaction level of vans and trucks was lower than that of passenger cars. Therefore, when crossing a speed bump, the driver of a van or truck must reduce the speed more than a passenger car. Through this, if you make them aware of this fact during driving education, it will be possible to reduce the inconvenience caused by speed bumps to drivers. Finally, satisfaction decreased as passing speed increased. Through this, it was confirmed numerically that the speed bumps, whose purpose is to reduce the speed of passing vehicles, are effective.

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