

A Model of Driver Behavior in Response to Road Roughness: A Case Study of Yazd Arterials

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Abstract

The impact of pavement distresses on the comfort of road users has been extensively studied so far, while little attention has been paid to investigating their effect on road safety. Some types of distresses, such as the polished aggregates of road pavements, influence vehicle stopping distance. Some other types of distresses influence the behavior of drivers due to the roughness they create on the road surface. In this study, a model of driver behavior in response to road roughness is calibrated which takes into account the geometric aspects of distresses, traffic parameters and road specifications. The behavior of drivers in response to road roughness is categorized into the two states of non-reaction and reaction (which includes either braking and crossing over distresses or deviating from the path) and is analyzed using logit model. The data which were collected through personal on-site observation in Yazd city pertain to the following variables; distress location, distress area, distress length, distress width, distress type, distance from lining, average hourly traffic, the average speed of vehicles, and the number of distresses within 100 meters. These data were collected from 15 randomly-selected distress areas with arterial functionality for 450 vehicles passing them. Based on the model results, a number of factors were found to increase the likelihood of drivers' reactions when facing distress areas. These factors include distress area, distress in fast lanes, and the reduction of average hourly traffic.

Keywords: driver behavior, logit model, pavement distress, road roughness.

1. Introduction

The number of traffic accidents in Iran is higher than that in many other countries, with 24.1 fatalities per 100,000 inhabitants; whereas this rate was 5.1 for the European Union member countries in 2014 [1, 2]. Extensive research has been carried out on the safety of transport [3-6]. Pavement distresses, as one of the factors affecting the comfort of road users, has been investigated, but not as a measure of road safety. Usually, in such studies on

pavement management, only economic and financial factors have been considered, while safety criteria have usually been neglected. Thus, it seems necessary to further study the relationship between safety, pavement distress, and the driver behavior as his response or reaction to distress areas.

From among pavement distress types, some affect the friction between the tires and the surface of the pavement and decrease road safety [7, 8]. Some of these distresses can cause pavement surfaces not to remain smooth or level. Among these are potholes or bumps in the locations of where they are not properly installed. These types of distresses in pavements are common in developing countries. Potholes are produced when traffic abrades small pieces of pavement surface. Pavement then continues to disintegrate because of poor surface mixtures, weak spots in the base or sub grade, or because they have reached a condition of high severity alligator cracking. Their growth is accelerated by the free moisture collection inside the hole [9]. A large number of manhole covers are seen on the roadways of Iran. Due to the variety of manholes (water, sewage, and gas), they vary in size and shape. Many are not properly installed, and there is a significant distance between the surface of the manhole cover and that of the pavement. Also, some manhole covers are not properly protected, so they have turned into a challenge for road safety. Depending on different factors, such as geometrical characteristics, drivers make their decisions on how to respond when facing them. Such decisions can include a wide range of responses such as crossing over the distress with no reaction, braking and crossing over the distress or deviating from the path. An understanding of the mechanism of drivers in response to such encounters can be very helpful in road safety and planning the Pavement Management System (PMS).

The purpose of this paper is to model drivers behavior in response to road roughness. The factors considered in this modeling are the geometric characteristics of distresses, traffic parameters and street specifications on drivers behavior; whether they react or show non-reaction when facing road roughness. In the next section, we will review the studies which have investigated the effects of pavement distresses on road safety. In sections 3 and 4, the data collection procedure and the methodology of the research are presented, respectively. In section 5, the model results and the

validation procedure are addressed, followed by the conclusions and some recommendations.

2. Literature Review

From among the factors which influence transport safety, pavement distresses have been known as one of those affecting the comfort of road users, yet they have not been extensively studied as one of the determining factors in the safety of roads.

Based on the information available about the accidents and pavement conditions in the state of Texas, the USA between the years 2008 and 2009, Li et al. studied the relationship between pavement conditions and the severity of accidents. They classified the pavements according to the degree of distresses, as very poor, poor, good, and very good. Their results indicated that the severity of accidents in “poor” and “very good” pavements was higher than that in the others. They explained that the accidents in “poor” pavements are due to sudden maneuvers for avoiding the distresses. Also, in “very good” pavements, drivers tend to drive at very high speeds, so the severity of accidents has increased in these pavements [10].

Jiang et al. evaluated the effects of integrating pavement management and traditional traffic engineering factors on the injuries severity of two-vehicle crashes. They inferred that rougher roads have less severe injuries compared to smoother roads [11].

Polished aggregates lead to the reduction of friction in pavement surfaces and the reduction of safety. Bella et al. investigated the effect of friction reduction on motorcycles’ road safety in curved paths. A dynamic simulation code was used through Bikesim software to comprehend the dynamic behavior of motorcyclists as crossing the curves with different radii and under different speed values. Finally, they came up with a model for the dynamic behavior of motorcyclists and suggested a useful tool for planning maintenance based on the risk associated with the asphalt polishing of the pavement [12]. Based on the studies carried out on the pavements of the United States, it was found that the severity of accidents occurring in horizontal curves with pavements having low friction coefficients is high. They also recommended that a measure of lateral friction coefficient should be considered in the Pavement Management System (PMS), particularly at curved road segments [13]. Bella et al. examined the relationship between the safety of motorcyclists and pavement potholes. They took some characteristics into account, including potholes dimensions and locations, climate conditions, vehicle speed, and the density of potholes. They also came up with predictive models based on the variables studied and the diagrams for evaluating the risk level of different driving conditions characterized by the presence of potholes on the road surface [14]. Using statistical models in the investigation and understanding the issues related to transport have wide applications [15-17]. Logit models and classification and regression trees (CART) can be applied to investigating discrete variables such as severity of accidents and drivers behavior [18-21]. Chang investigated the effect of manhole covers on the behavior of motorcyclists, using classification and regression trees (CART). The variable of driver behavior included three levels: 1- drivers crossing over manhole covers without showing any reaction, 2- drivers firstly reducing their speed by braking, then crossing over manhole covers, and 3- drivers deviating their paths to avoid manhole covers and passing next to them. Based on his study, it was found that 50 percent of the drivers showed no reaction when facing manhole covers. Also, it was found that the height difference between manhole covers and asphalt, covers asphalt conditions, and cover size put an impact on the behavior of drivers [22]. Wu et al. investigated the

severity of single- and multi-vehicle crashes on rural America's two-lane highways, using a logit model. They examined factors such as driver behavior, climate and environmental conditions, geometrical characteristics and road traffic. According to their findings, overtaking actions can increase the severity of single-vehicle crashes [23]. Due to the discrete nature of response variable (driver behavior) used in this research, logit models were used to investigate the factors influencing driver behavior in the face of distress.

3. Data collection

The data collected for this research include the details and parameters of fifteen pavement distresses with different geometric characteristics, for which the minimum difference between the surface of the distress and that of the pavement is 75 mm, on 5 streets with arterial function in Yazd city. The information related to the geometric characteristics of the distresses, the streets specifications, and the traffic data was collected between 9:00 o'clock and 14:30 hours on 15 business days in 2014. Driver behavior was recorded through field observation by expert observers without attracting drivers’ attention. This behavior was classified into two main types: 1- the driver crossing over the distress showing no reaction and 2- the driver reacting to the distress (by braking and passing over the distress or by deviating from the path and avoiding the distress) (Fig. 1). It should be noted that the collected data are limited to the vehicles that had a direct path to the distress.

The data were collected in three parts: 1- distress characteristics, 2- street specifications, 3- traffic characteristics. Table 1 shows the collected data for this research along with their descriptive statistics.

If the pavement around the manhole cover is damaged, it is also taken into account in measuring the distress area. The variable of “distance from lining” has been operationalized as the distance between the center of distress and the street’s left lining. If the distress is located in a fast lane, the variable of the location of distress is coded as 1. If it is located in a slow lane, it is assigned the code of 3, and if it is located on the lining, between the fast and slow lanes, it is coded as 2.

When moving in the direction of traffic flow, the number of distresses you face at a distance of 100 meters before the specified distress has been considered as the number of distresses within 100 meters of distress. The average speed of the vehicle has been calculated by considering how long it takes the vehicle to cross the specified distance. It should be noted that a certain part of the street has been used to calculate the average speed of the vehicles. In choosing this specific part of the road, caution was practiced to select a part in which the distress would have no effect on the vehicle’s speed. The volume of vehicle traffic has been obtained by counting the number of vehicles crossing the specified location in an interval of 15 minutes.

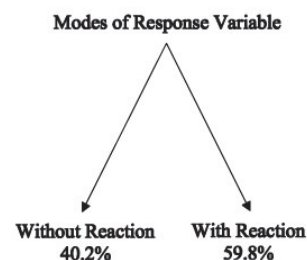


Fig 1: Two modes of the response variable.

4. Methodology

The research data were collected through field observation. Eighty percent of collected data were used in the process of modeling and the others reserved for validation of the final model. The logit model and SPSS software were used to analyze the data. Logit models are suitable for situations in which the research aims at

predicting the occurrence or non-occurrence of one variable. This model is similar to linear regression models, but it is appropriate for situations in which dependent variables are discrete [24].

Table 1: Collected data for this research.

Variables	Sign	Coding	Mean	Std. Dev.	Min.	Max.
driver behavior(response variable)	Behavior	without reaction-0 with reaction-1	0.6	0.49	0	1
Location of distress	Location	lane 1-1 Between lane 1,2-2 lane2-3	2.67	0.6	1	3
Area of distress	Area	continuous variable without code (cm ²)	21291.1	30243.36	750	93600
Length of distress	Length	continuous variable without code (cm)	121	83.96	25	310
Width of distress	Width	continuous variable without code(cm)	108.67	97.81	30	360
Distance from center of distress to left lining	Distance	continuous variable without code (cm)	161	76.86	0	305
Type of distress	TOD	sag -0 bump-1	0.6	0.49	0	1
Average hourly traffic	AHT	continuous variable without code	515.6	223.01	112	894
Average speed of vehicle	V	continuous variable without code (km/hr)	48.32	11.75	27	79
Number of distresses within 100 meters of the distress	t.kh.100	continuous variable without code	1.2	0.98	0	3

In this investigation, two states of driver behavior (with reaction or without reaction) were used.

Hence, the set of alternatives is as follows:

$$C = \{\text{with reaction (WR), without reaction (WOR)}\} \quad (1)$$

So, the logit probability function will be as follows:

$$P_{WOR} = \frac{e^{V_{WOR}}}{e^{V_{WOR}} + e^{V_{WR}}} \quad (2)$$

and

$$P_{WR} = \frac{e^{V_{WR}}}{e^{V_{WOR}} + e^{V_{WR}}} \quad (3)$$

In which:

P_{WOR} stands for the possibility that the driver shows no reaction.

P_{WR} stands for the possibility that the driver shows some reaction.

It is also worth noting that in modeling by means of SPSS, the differences between the coefficients of the desired functions are obtained. For example in this research, the coefficient values of $V_{WR} - V_{WOR} = A_0 + A_1X_1 + A_2X_2 + \dots + A_nX_n$ indicated by A_0-A_n have been obtained for the probability that the driver shows no reaction.

That is, in the mentioned function with the form of $P_{WOR} = \frac{1}{1 + e^{V_{WR} - V_{WOR}}}$, the obtained negative amounts of the

coefficients in the model, given the nominal of the independent variables (values 0 and 1), if variable to be 1, the increase of possibility that driver will not show reaction in the case of positive coefficients, the possibility that driver will show reaction, will be presented.

5. Model findings and interpretation

Based on the results of Pearson correlation analysis, the independent variables which had high correlations (greater than 0.7) with each other were identified. Moreover, the significance level of the correlations between the independent variables and the response variable was also investigated.

The relationship between each independent variable and the response variable was examined independent of other factors, and an independent role was assumed for each factor. Yet, in the final models, the joint effect of factors was shown. It is possible for a variable which has proved significant in isolation to become insignificant in the final model, or vice versa. This may be due to

the multicollinearity phenomenon or the probability of an insignificant factor proving significant when taken along with the other variables of the model.

To come up with the final model about 600 models at 0.05 significance level were generated using eighty percent of total data and the final model was validated by means of twenty percent of reserved data. The no-response alternative was set as the base alternative. So, the variables with negative coefficients would increase the likelihood of showing no response by the driver, and vice versa (Tables 2 and 3). As shown in table 4, percent correct of twenty percent of data for validation is completely matched with those of final model.

Table 2: Variables in the Equation.

Variable	Coefficient	P-Value
Constant	-0.973	0.026
AHT	-0.001	0.038
LN(Area)	0.356	0.00
Location	-0.478	0.033

Sample size= 360

$$\rho^2 = 1 - \frac{LL(\beta)}{LL(0)} = 0.138$$

$$\rho_c^2 = 1 - \frac{LL(\beta)}{LL(C)} = 0.102$$

LL(0)= -257.624 (log-likelihood at equal shares)
 LL(C)= -247.296 (log-likelihood at market shares)
 LL(β)= -222.072 (log-likelihood at convergence)

Percent correctly predicted: 63.6%

Table 3: Frequency of observed and predicted values of the model based on 80% of data.

Predicted \ Observed	Without Reaction (code=0)	With Reaction (code=1)	Total predicted frequency
Without Reaction (code=0)	67	56	123
With Reaction (code=1)	75	162	237
Total observed frequency	142	218	360

Table 4: Results of validation of the final model.

Predicted \ Observed	Without Reaction (code=0)	With Reaction (code=1)	Total predicted frequency
Without Reaction (code=0)	20	14	34
With Reaction (code=1)	19	37	56
Total observed frequency	39	51	90

Sample size= 90

Percent correctly predicted: 63.33%

I. Average hourly traffic

As already shown, on roads with heavy traffic of vehicles, it is more probable that drivers show no reaction to facing pavement distresses, due to the following reasons:

- As the traffic increases, the distance vision of drives decreases, so they will be less able to show any reaction in facing distresses.
- As traffic increases, the vehicle speed decreases, so it will be much easier for drivers to cross over distresses with their current speed.

II. Distress area

By increasing the area of distress, drivers are more likely to show reactions in facing distresses. Naturally, by increasing the area of distress, drivers attempt to cross the distress with appropriate reactions to keep their vehicles safe and make road users feel comfortable.

III. Location of distress

The vehicles moving in fast lanes are more likely to show reaction to distresses than those moving in slow lanes. Due to the lower speed in slow lanes, drivers have the chance to cross the distresses safely, and there is almost no need for any reactions.

6. Conclusions and recommendations

Pavement conditions are among the factors affecting the comfort of drivers, but they have seldom been investigated as determining factors in road safety. The distresses causing roughness on road pavements are common in developing countries. Based on various conditions, drivers show different reactions such as crossing over the distress, sudden braking, deviating from the path, or a combination of these reactions. An investigation into drivers behavior can be helpful in providing safety. In this paper, driver behavior includes two levels: “with reaction” and “without reaction”. Eighty percent of collected data were used in the process of modeling and the others reserved for validation of final model. Univariate models were calibrated to investigate the role of different factors for both response variables. More than 600 models were obtained with different variables (combined, dummy). Final model including LL(β), significant of variables and correct percentage was made.

The data related to 450 vehicles crossing over 15 distress areas in streets with arterial function in Yazd were collected during 15 business days in 2014 through field observation and personal judgment by expert observers and without attracting drivers’ attention.

Based on the results: 1- increasing the average hourly traffic decreases the probability of driver reaction, 2- increasing the distress area makes drivers more likely to show reaction, 3- drivers are more likely to show reaction in facing distresses located on fast lanes than in facing those located on slow lanes. Therefore, it is essential to give priority to reconstructing roads with larger distress areas and lighter traffic. Priority should also be given to repairing the distresses located in fast lanes. According to the results of the research, it is essential that the manhole covers belonging to different organizations occupy less area. Due to the gradual formation of pavement distresses around manhole covers and the increase of distress areas, it is necessary that manhole covers be examined regularly. Based on this paper, the existence of distress areas in fast lanes increases the probability of driver reaction, and by increasing the area of distress this probability grows. Although this probability increase does not necessarily lead to accidents, it does rise the likelihood of accidents. So, to upgrade road safety, it is a good idea to do further research on exploring the option of incorporating ‘pavement distress impact on road safety measurement’ into Pavement Management System (PMS) databases.

Because the focus of the present paper has been on the streets with arterial function, it is recommended that further studies be carried out regarding the impact of these distresses on the behavior of

drivers on other urban roads. The present paper has addressed the impact of distresses on the behavior of drivers. Although a sudden change in the behavior of drivers (sudden braking or path deviation) increases the likelihood of accidents, it does not necessarily lead to an accident. So, it is recommended that further studies address the relationship between these distresses and the rate and severity of accidents on urban streets.

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