Моделювання серйозності травмування водія при лобовому зіткненні з урахуванням несумісності транспортних засобів

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Моделювання серйозності зіткнень відіграє важливу роль в досліженнях із безпеки дорожнього руху. В цій статті змодельовано ступінь серйозності травмування водія при лобових зіткненнях двох різних автомобілів, у яких є по одному пасажирові. Несумісність транспортних засобів – це невідповідність і відмінності між транспортними засобами за вагою, величиною, формою, розмірами, міцністю та потужністю. Розвиток різноманітних технологій проектування транспортних засобів спричинив розбіжності в стандартах для транспортних засобів і, як наслідок, їхню несумісність. У цій статті розглянуто роль фундаментальних характеристик пасажирських автомобілів, таких як статичні та динамічні характеристики (вага, висота, ширина та швидкість) і засоби безпеки у транспортних засобах (повітряна подушка безпеки, ремінь безпеки, виштовхування водія) при різних ступенях серйозності лобових зіткнень. Метод моделювання таких зіткнень є подвійний. Водій одного з автомобілів може бути більш травмованим. Отже, логістична регресійна модель застосовується з метою передбачення ступеня травмування водія при лобових зіткненнях. Проаналізовано 458 спостережень за лобовими зіткненнями за допомогою Fars (Системи аналізу смертності). Кінцева модель здатна правильно передбачити 80,6 % випадків. Аналізуючи гнучкість і вплив побічних чинників, виявлено різні ступені серйозності лобових зіткнень. Встановлено, що:

1. Висока вага транспортних засобів, ремені безпеки та повітряні подушки безпеки є найважливішими чинниками зменшення ризику травмування водія.
2. Важчі пасажирські автомобілі менше пошкоджені при лобових зіткненнях.
3. Розміри транспортних засобів не мають великого впливу на серйозність лобових зіткнень. Тому різниця у вазі транспортних засобів є найбільш небезпечним аспектом їхньої несумісності.
4. Висока швидкість і викидання водія є чинниками, які можуть збільшити можливість серйозного травмування.

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Modeling of Driver Injury Severity in Head-on Accidents Considering the Vehicle Mismatch

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Abstract – In this study, the driver injury severity of head-on accidents considering the vehicle mismatch is modeled. For this purpose, logistic regression method is applied. Using this method determines which driver is more injured. According to final results, seat belt, air bag and weight of vehicles are most effective variables in injury prevention of driver. High speed and driver ejection are the factors that can increase the probability of injury severity. Furthermore, the vehicle dimensions have not a powerful effect on severity of head-on accidents. Therefore, different weight of vehicles is most dangerous aspect of vehicle mismatch.

Keywords – driver injury severity, head-on accidents, vehicle mismatch, logistic regression

I. Introduction

The number of traffic accidents is considerably growing in Iran. The number of injuries and the value of damages impose a high cost to the country. So, attention to traffic safety has always been among the basic programs of the Iranian governments and car companies. On the one hand, to study the effect of various parameters in enhancing the safety, researchers utilize statistical models to modeling the real world observations. On the other hand, the experts investigate the effect of different parameters by simulation software or accident reconstruction in vitro. Researchers are recently studying factors which the real-world data have not given this possibility in the past few years. Variables such as static and dynamic characteristics of the vehicles are such as these parameters.

Development of different technologies in design of the vehicles has caused variety vehicles standards. For example, the standards related to reduction of fuel consumption made new cars lighter. In order to optimize utilization of urban spaces, the dimensions of new vehicles have been decreased which lead axes to be closer to each other. Based on aerodynamic principles, the new vehicle's chassis and the height of body have been shorter. There are different opinions among analysts and designers about the properties of the vehicles. Manufacturers have not yet succeeded to evaluate many features of vehicle characteristics according to experts' opinions of different technologies. They could not achieve an optimal characteristic for the best designs. Thus, many automotive companies still suffer from multiple policies in designing. The vehicle mismatch is one of the most complex problems of these companies. As analysts of different sciences are moving in line of automotive technology advances, traffic experts have had the new achievements in this case. Cars safety has always been the most important matter for traffic researchers and experts.

II. Literature Review

Traffic accident is one of the main reasons of the people death. Scientists expect that traffic accident will be third cause of unnatural death until 2020. Investigation of effecting factors to injury severity of occupants is important for researchers, governments and companies. Vehicle mismatch is one of the most dangerous reasons in increasing of severity. Vehicle mismatch is an incompatibility and dissimilar of vehicles in weight, dimensions, shape, size, stiffness and power (1, 2). Significantly increasing sport utility vehicle (SUV) and pick-up trucks (PU) registration, many studies have addressed the more hazardous to lighter and smaller vehicle. The fatality rate for 900-kg passenger cars is 50% greater than the fatality rate for 1800-kg passenger cars. Occupants of smaller cars appear to be at greater risk than larger car occupants in many types of collision scenarios (3, 4).

The European Commission (EC) has stated that if all cars were designed to be equal in standard to best car currently available in each class, then an estimated 50% of all fatal and disabling injuries could be avoided (5). Desapriya et al (6) analyzed vehicle mismatch crashes. They investigated on general severity and types of injuries, crash characteristics and information on restraint use and driver age and gender. They demonstrated the changing composition of vehicle fleets has a considerable effect on crash types and injury severity. Kahane (7) estimated that a 100 pound reduction in the average weight of light trucks, defined as PU, vans and SUVs, results in a reduction of 40 fatalities per year in US. Importantly, Kahane shows that decline of 100 pounds in the average weight of the typical passenger car results in an estimated increase of 302 more fatalities per year. The results also indicate that 80% of the injuries/fatalities associated with car-light truck collisions are occupants of passenger cars.

Braitman (8) examined changes in the mix of passenger vehicles between 1988 and 2004 and concurrent changes in driver fatality rates and vehicle incompatibility. He argued the driver death decreased but it was considerable for SUV divers. In a research by Fredette et al (9), they examined the effects of vehicle incompatibility on the risk of death or major injury to drivers involved in two-vehicle collisions. Utilizing logistic regression to model the risk of driver death or major injury (defined has being hospitalized), their analyses show that pickup trucks, minivans and SUVs are more aggressive than cars for the driver of the other vehicle and more protective for their own drivers.

III. Data Description

In this study, head-on accidents have been investigated. Fig. 1 shows different type of crashes. According to NHTSA data center (FARS[1]) (10), code 2 recognizes as head-on accident.

Comparison basis for surveying the severity of accident is assumed according to the driver injury severity. In many previous studies, it is pointed out that driver injury severity is the best factor to represents the crash severity. First of all, whole vehicles are the same in having one driver and the place for seating the driver in the car is same in all passenger cars. Secondly, study on driver injury allows that factors such as seat belts and air bags be evaluated. FARS database has provided the following table for the severity of injuries.

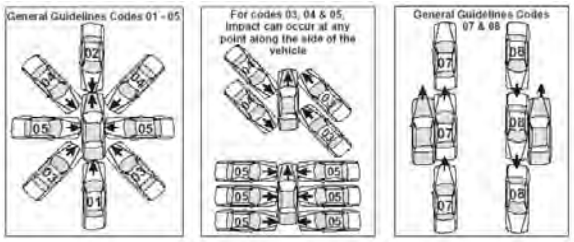

Fig. 1. Different Crash Types Based on FARS

Table 1

Injury Severities

Injury Severity	*Variable*
No Injury (O)	0
Possible Injury (C)	1
Non-incapaciting Evident Injury (B)	2
Incapaciting Injury (A)	3
Fatal Injury (K)	4

Modeling method of this type of accidents will be binary. The driver of first or second car might be more injured. Logistic regression model is designed for this purpose and its accuracy of prediction will be surveyed.

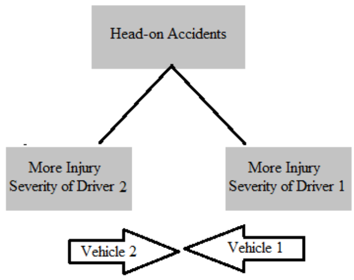

Fig. 2. Binary Modeling of Head-on Accidents

In this research, 458 head-on accidents of the year 2008 will be studied. The accidents have been selected somehow that the drivers are the only occupants in both passenger cars. This makes the comparison of intensity easier according to the driver injury severity. Logistic regression model will be estimated for 80 percent of observations and then will be controlled by 20 percent of observations. Analyzing the coefficients of the estimated model for the first section of observations, we will investigate the studied variables. Finally, using control set of observations, prediction accuracy of the model will be assessed.

Speed at the moment of crash (mile/hr), vehicle weight (lbs), external height (inches) and external width (inches) of both vehicles are used in modeling as continuous variables. A reasons of selecting the injury severity of driver as an indicator of accidents intensity, was that the effect of factors such as seat belts and airbag can be studied. Ejection of the driver’s body out of the vehicle is very dangerous. Avoiding from this happening has been analyzed as one of the car capabilities. Application of these variables in the modeling can also be useful.

[1] Fatal Analysis Reporting System

IV. Methodology

Logistic regression models are appropriate for the conditions in which prediction of a variable's occurrence is the main objective. Head-on accidents are divided to two categories; more injury severity of first vehicle's driver (Z_1) and more injury severity of second vehicle's driver (Z_2). The logistic probability function (11, 12) can be expressed as Eqs. (1) and (2).

$$P_{Z_1} = \frac{e^{U_{Z_1}}}{e^{U_{Z_1}} + e^{U_{Z_2}}} \quad (1)$$

$$P_{Z_2} = \frac{e^{U_{Z_2}}}{e^{U_{Z_1}} + e^{U_{Z_2}}} \quad (2)$$

Then:

$$P_{Z_2} = \frac{e^{U_{Z_2}}}{e^{U_{Z_2}}\left(1 + e^{U_{Z_1}} \big/ e^{U_{Z_2}}\right)} = \frac{1}{1 + e^{U_{Z_1} - U_{Z_2}}} \quad (3)$$

On the other hand:

$$P_{Z_2} = 1 - P_{Z_1} \quad (4)$$

In which: P_{Z_1} : The probability of more injury severity of first driver; P_{Z_2} : The probability of more injury severity of second driver; U_{Z_1} : The utility function of more injury severity of first driver in head-on accident; U_{Z_2} : The utility function of more injury severity of second driver in head-on accident.

The utility function can be expressed as follow:

$$U_i = a_i + a_{1i}x_{1i} + \mathbf{L} + a_{ni}x_{ni} + e_i \quad (5)$$

In which: x_{ji} :The value of variable j for alternative i. And j=1,2,..., n; a_{ji} : The utility function coefficient. And j=1, 2, …, n; e_i : The error term

Modeling is a repetitive process which aims to develop better models. Logistic Regression is a model as type of Maximum Likelihood Function which is defined as:

$$L(b) = \prod_{n=1}^{N_i} p_n(i) \prod_{n=1}^{N_j} p_n(i) \quad (6)$$

In which: $L(b)$: Maximum likelihood functions for b coeficients The target is to find some βs which maximum the forementioned function.

Goodness of fit (ρ^2) is a value that determines the model quality of observation's fitting. This parameter varies between 0 and 1. The more closed value to 1, shows better fitting.

$$p^2 = 1 - \frac{LL(b)}{LL(0)} \quad (7)$$

$LL(0)$: Log-likelihood function for zero coefficients; $LL(b)$: Log-likelihood function for estimated b coefficients

V. Results

80 percent of the observations are considered for model estimation and 20 percent of them are for evaluation of model prediction. Table 2 shows the coefficients of logit model.

Table 2

Logistic Regression Model

Variable	Coefficient	t-Statistic	Elasticity (Marginal Eff.)	Mean
Constant	-0.101	-0.02	----- (-0.02)	-----
Airbag1	-1.000	-3.07	-0.276 (-3.07)	0.68
Ejection1	+0.252	+0.42	+0.007 (+0.42)	0.06
Belt1	-1.040	-3.28	-0.250 (-3.28)	0.58
Speed1	+0.014	+1.34	+0.299 (+1.34)	50.10
Weight1	-0.001	-3.62	-1.563 (-3.62)	3663.9
Height1	-0.003	-0.13	-0.098 (-0.13)	62.73
Width1	-0.064	-1.37	-1.978 (-1.37)	72.29
Airbag2	+0.727	+2.05	+0.239 (+2.05)	0.76
Ejection2	-0.465	-0.53	-0.006 (-0.53)	0.03
Belt2	+1.127	+3.23	+0.355 (+3.23)	0.74
Speed2	-0.012	-0.96	-0.255 (-0.96)	49.05
Weight2	+0.001	+2.02	+1.098 (+2.02)	3634.1
Height2	+0.085	+2.72	+1.310 (+2.72)	63.55
Width2	+0.030	+0.65	+0.926 (+0.65)	72.26

Variables that their names have No.1 are related to the first vehicle in two-car head-on accident, and variables that their names have No.2 are related to the second vehicle in two-car head-on accident. No matter in a head-on accident which vehicle is marked by No.1 or No.2, but the important matter is that the vehicle No.1 characteristics in driver injury severity are considered for the car No.1 and vice versa. In this study, 458 observations of head-on accidents have been investigated; each accident separately has 14 independent variables (seven independent variables for each vehicle) and two dependent variables (driver injury severity). Whereas, the dependent variable has been as 0 and 1 (indicates more injury of car No.1 driver or car No.2 driver). In the first part, the models have been calibrated with 80 percent of observations (366 crashes). The values indicate statistical significance of studied variables in model and whatever the t-Statistic is more, the variable has the higher level of confidence. The coefficients column represents coefficient of variables in estimated utility function.

Table 3 indicates the main characteristic of model. As can be seen, this model has accurately predicted 295 (168+127) cases of accidents. In fact it can predict 80.6 percent of observations correctly of total 366 crashes.

Table 3

Main Characteristics of Model

Indexes	
Pseudo R-squared	0.3853
LL(β)	-154.83
LL(0)	-251.91
Correct Prediction	80.60%

Predictions			
		Predicted	
		0	1
Actual	0	127	38
	1	33	168

Also, the model predicts 78 percent of 92 accidents which have been considered for evaluation of the model precision. The Pseudo R-squared is equal to 0.38 that indicates a proper ability to fitting data.

Elasticity and marginal effect functions are used to evaluation the role of variables in the model. These functions are used to analysis the importance of each variable in utility functions. Also, the value of these functions helps to examine the relative importance of variables. Table 2 shows elasticity and marginal effect values of the variables, too.

Positive coefficients mean that the variables cause more injury severity probability of driver of car No.1. The negative coefficients mean that the variables cause more injury severity probability of driver of car No.2. Higher t-values show statistical importance of variables. According to the results, weight, height, air bag, seat belt and speed have the acceptable importance in estimated model. Consideration to variable unit and type of variable is basic points in analysis of the coefficients. Seatbelt, airbag and driver ejection are Dummy variables and the others are continuous. In fact, increasing one unit in these two types of variables has different meanings. So, the coefficient of weight in table 2 is less than the coefficient of driver ejection. Mean of variables in the last column of Table 2 clarifies this difference. To prevention of such errors in analysis of parameters, both elasticity and marginal effect functions are calculated.

According to Table 2, air bag, seat belt and vehicle weight are the most important parameters in driver safety. However, the variables of vehicle height and width are somehow effective in reducing the risk of driver injury. Speed and driver ejection are the only variables which increasing the probability of injury severity. For example, positive coefficient for Speed1 variable indicates that more speed of car No. 1 can increase the probability of injury severity of its driver. While negative coefficient of Weight1 means the reducing of risk of injury in him/her.

Conclusion

This study surveys the role of fundamental features of passenger cars such as static and dynamic characteristics (weight, height, width and speed) and vehicle safety equipment (air bag, seat belt, driver ejection) in the severity of head-on accidents. Logistic regression model is applied to prediction of driver injury severity of head-on accidents. Finally, importance of the studied variables is analyzed based on elasticity and marginal effect functions. 80 percent of the observations are considered for model estimation and 20 percent of them are for evaluation of model prediction. Model accurately predicts 295 (168+127) cases of accidents. In fact it can predict 80.6 percent of observations correctly of total 366 crashes. Also, the model predicts 78 percent of 92 accidents which have been considered for evaluation of the model precision. The Pseudo R-squared is equal to 0.38 that indicates a proper ability to fitting data. Elasticity and marginal effect functions are used to evaluation the role of variables in the model. These functions can analyze the importance of each variable in utility functions. According to final results:

1. High weight of vehicles, safety belts and air bags are the most important factors result in reducing the risk of driver injury.

2. Heavier passenger cars have safer performances in head-on accidents.

3. Vehicle dimensions have not a powerful effect on severity of head-on accidents. Therefore, different weight of vehicles is most dangerous aspect of vehicle mismatch.

4. High speed and driver ejection are the factors that can increase the probability of injury severity.

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