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INDEXING CRASHWORTHINESS FOR MAJOR VEHICLE BRANDS IN ROLLOVER CRASHES: A CASE STUDY OF IRAN

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ABSTRACT

Road crashes are one of the major causes of fatality worldwide, especially in developing countries such as Iran; where the number of lives lost in road crashes is around 16500 per year. Single vehicle and especially rollover crashes are one of the most important types of crashes. While rollover crashes make up a small proportion of crashes, they are the reason of a great proportion of crash deaths and thus, it is necessary to investigate them carefully. This study aims at indexing crashworthiness of the 20 most frequently used vehicle brands in Iran. In this regard, the data of 42,118 rollover crashes of urban and rural roads of Iran that occurred from 2009 to 2012 were used. A Binomial Logistic Regression Model was applied in order to define crashworthiness index based on driver's injury severity level. Although the results revealed that Proton and Hyundai/Light truck have the best performances in rollover crashes, no special trend was found regarding to crashworthiness capability of foreign and Iranian brands. Findings of the current study can be utilized to mitigate serious rollover crash injuries. Our findings might also be integrated with the findings of other similar studies around the world. This could be helpful for car manufacturers both in Iran and across the world in order to benchmark the best performing car brand in vehicle safety domain and improve the designing of their own car brands.

Key words: Rollover crashes, crashworthiness, binomial logistic regression model, vehicle brand, Iranian brands, driver's injury severity.

1. INTRODUCTION AND LITERATURE REVIEW

Road crashes are one of the major causes of morbidity and mortality worldwide, especially in developing countries like Iran. One of the most important types of single vehicle crashes regarding to injury severity risk is rollover crashes. While rollover crashes make up a small proportion of crashes, they are the reason of a great proportion of crash deaths and therefore, it is necessary to investigate them (Naing et al., 2008, Liu and Xia, 2015, Digges and Malliaris, 1998).

In 1999, Malliaris and Diggs examined the crash involvement and occupant safety of Sport Utility Vehicles (SUVs) in comparison to passenger cars, vans, and pick-ups by a descriptive statistical analysis. They reported that SUV occupants are overexposed to rollover crashes. The authors also argued that SUV occupants are 3.8 times more frequently involved in rollover crashes and 3.5 times more frequently exposed to ejections than the occupants of other vehicle types (Malliaris and Digges, 1999).

Kockelman and Kweon (2002) investigated driver injury severity by ordered probit models. They studied all crash types, two-vehicle crashes, and single-vehicle crashes separately. The results suggested that pickups and SUVs are less safe than passenger cars under single-vehicle crash conditions. However, these vehicle types showed less severe injuries for drivers in two-vehicle crashes (Kockelman and Kweon, 2002).

Penny in 2004 studied rollover of SUVs. He did so using fundamental physics concepts. The author argued that vehicles track width and height of center of mass above road are two main features which affect vehicles and especially SUVs rollovers explaining that the more the track width, and the less the height of center of mass, the safer the vehicle would be (Penny, 2004).

Fotovati et al (2011) has conducted a study on evaluating crash severity in rollover crashes in rural roads of Iran. They meant to compare national and international car brands. They first introduced an index called hazard index (HI) for how a car is hazardous in a crash and then calculated the so-called index for each car brand. In the next stage, the authors tried to find the best statistical distribution which best described the calculated HI for all brands. They finally found out that Orlang distribution is the best. Consequently, they could compare the HI of different brands. The results showed that international brands have better performances than national brands in rollover crashes.

In 2011, Huang et al studied crash incompatibility between vehicles on roads by indexing crash worthiness and crash aggressivity of different vehicle types. They did so by a Bayesian hierarchical ordered logistic model. The results of the study showed that vehicle size and mass are not necessarily correlated with vehicle overall safety (Huang et al., 2011a, Huang et al., 2011b).

Recently, Huang et al. (2016) have investigated the correlation between vehicle type (different brands), occupant injury and vehicle damage. In order to reach the specified goal, they used a Bayesian bivariate hierarchical ordered logistic model. They compared different car brands by defining two indices: Occupant Protectiveness (OP) and Vehicle Protectiveness (VP). The results showed that Cadillac, Volvo and Lexus are the best and Kia and Saturn are the worst brands regarding to OP and VP.

In some other studies, such as (Conroy et al., 2006, Huelke et al., 1985) roof crush, occupants' ejection through vehicle side glass areas, and using materials in vehicle interior which absorb energy in order to reduce occupants' injuries within the vehicle prior to ejection were also recognized as the influencing factors related to injury severity level of the occupants.

Single vehicle crashes constitute only 10 percent of Iran crashes, but they are responsible for approximately 45 percent of drivers' deaths. Two major types of single vehicle crashes are rollover and run-off road crashes (involving collisions with roadside objects) which occur mostly in rural roads of Iran (an 86 percent share). Thus, studying single vehicle crashes are of a main concern in Iran. Few studies dealt with single vehicle crashes of Iranian fleet; and among them fewer concentrated on single vehicle crashes and vehicle brands crashworthiness capability, simultaneously.

On the one hand, the literature review reveals that study of single vehicle crashes is still an ongoing issue; on the other hand, the importance of perusing single vehicle crashes in Iran was shown. There is one extra motivation –and maybe the strongest one- for conducting this research. During the last thirty years, Iran government pursues a policy in the field of car manufacturing industry; that is the limitation of car importation. As a result of this policy, share of Iranian brands or brands that are manufactured inside the country (including passenger cars, buses, trucks and pick-ups) raised to about 80 percent in Iran traffic flow. Due to this fact and the critical conditions of road traffic safety as well, a major controversy has been ensued among Iranian experts, mainly comparing domestic brands with foreign ones. Some experts argue that domestic brands are the main cause of low-level traffic safety in Iran, while the others believe that there are no meaningful differences between safety capabilities of foreign and domestic brands.

Considering the purpose of this study, merely rollover crashes were included and the relation between different car brands crashworthiness capabilities and driver's Injury Severity (IS) level was investigated. In this regard, crashworthiness index (CWI) for 20 of the most frequently used vehicle brands in Iran was calculated. Then all the brands were compared to a reference brand by their CWI to find out whether there are any meaningful differences between their crashworthiness capabilities.

"*Are there any meaningful differences between crashworthiness capability of different vehicle brands in case of a rollover crash?*". With respect to previous paragraphs, the overall objective of this paper is to answer the before mentioned question considering the most prevalently brands of Iranian fleet.

Rest of the paper is organized as follows: section 2 is about crash data preparation and a brief explanation of the methodology. In section 3 results and discussions are presented and finally the 4^{th} section presents the conclusion of the paper.

2. METHODOLOGY

2.1 Crash data

In order to achieve the goal of this study, historical crash records of all urban and rural roads of Iran from 2009 to 2012, which contains 1,360,415 crash and 2,407,196 driver records (including all types of crashes), was used. The data were collected from Iran traffic police crash database. After cleaning the data base, the intended dataset was organized with the following considerations:

- Only rollover crashes were included.
- The database was exactly reviewed and only 20 most frequently used vehicle brands (different types of each vehicle brand may be available) plus motorcycles were kept.
- The focus was on *driver's* IS level as the seating position of the driver is fixed compared to other occupants.
- Forasmuch as there are significant differences in injury severity level of female and male drivers in traffic crashes (Ulfarsson and Mannering, 2004), gender of the driver as a control variable was included in the model.
- Area type variable (i.e. rural or urban) as a surrogate factor for the variation of vehicles' mean speeds in rural and urban roads was included in the model. This variable is considered as another control variable.

Finally, data filtering yields to a 42,118 crash and driver record dataset. In Table 1 percentages of vehicle brands and motorcycle (treated as a brand in here) in the study dataset as well as the place of manufacturing for each brand has been brought. Peugeot 405, Pride and Peykan (passenger cars and pick-ups) constitute almost 60 % of the dataset brands.

Motorcycle crashes data were also included to verify the model.

It should be mentioned that crash data of the database are based on police crash reports. These data are obtained from the Iranian Traffic Crash Record Form, known as KAM 114, which is filled in by a trained police officer at the crash scene and subsequently entered into the Traffic Police crash database. The information covers several attributes of crashes including:

a) general characteristics about each crash (such as collision type, vehicle type, area type, lighting condition, weather condition, etc.);

b) data regarding all the drivers involved (such as age, gender, driving license type, and injury severity (i.e., no-injury, injury, fatality)); so, the driver's IS level is what is observed at the crash scene by the police officer. Unfortunately, medical history of the driver (e.g. being killed after 30 days from crash injuries) is not available for this study;

c) data concerning the pedestrians injured in the crash, and

d) data relating to the injured occupants involved in each crash (Kashani and Besharati, 2016).

Therefore, reported crash data depends on the experience and skills of the reporting police officer, his judgment, and how well he records the data. This might be regarded as one of the limitations of this study.

Table 1- percentages of vehicle brands and motorcycle in the study dataset

Brands	No. of each brand in the crash dataset	% of each brand in the crash dataset	Manufactured in
Peugeot 405[1]	9378	22.27%	Iran[2]
Pride (as reference group)	8905	21.14%	Iran
Peykan/Pick-up truck	3356	7.97%	Iran
Peykan	3305	7.85%	Iran
Mercedes-Benz/Bus, Truck, Minibus	3298	7.83%	Germany
Samand	3066	7.28%	Iran
Motorcycle (different brands)	2786	6.61%	-
Zamiad/Pick-up, Light Truck	2575	6.11%	Iran
Peugeot 206	1219	2.89%	Iran
Renault	982	2.33%	France
Mazda/Pick-up truck	564	1.34%	Japan
Toyota/Pick-up truck	481	1.14%	Japan
Citroen	384	0.91%	France
Hyundai/Light truck	287	0.68%	South Korea
Toyota	256	0.61%	Japan
Nissan	206	0.49%	Japan
Hyundai	167	0.40%	South Korea
Rio	150	0.36%	Iran
Renault/Truck	136	0.32%	France
Sepand	129	0.31%	Iran
Daewoo	127	0.30%	South Korea
Mazda	97	0.23%	Japan
MVM	87	0.21%	China
Mercedes-Benz	51	0.12%	Germany
Kia	40	0.09%	South Korea
Suzuki	31	0.07%	Japan
Proton	28	0.07%	Malaysia
BMW	27	0.06%	Germany
Total	42118	100.00%	

[1] By default, passenger car type of the brand unless otherwise stated.
[2] According to the Iranian culture and industrial atmosphere of Iran industries, considering some models of a special international brand as a separate brand is logical. Obviously for other international brands, those models that exist in Iran's fleet are of a concern.

2.2 Model specifications

Driver's IS level[3] was considered as a dichotomous dependent variable in the current study (code 0= Not Injured and code 1= Injured/Dead); and a Binomial Logistic Regression Model (BLRM) was employed. As a result of data limitation, the authors decided to combine driver's death and injury levels and consider them as a single level. For some brands, number of dead drivers were too low and this could lead to very low significant levels for those special brands.

Logistic regression is a mathematical modeling approach that can be used to describe the relationship among several independent variables and a dichotomous dependent variable (Gail et al., 2007, Gujarati, 2014). Using BLRM as a data mining tool, a relationship between driver's IS level and different brands' crashworthiness indices is established.

To begin, logistic function is

$$f(z) = \frac{1}{1+e^{-z}} \quad (1)$$

If one sets $z = \alpha + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k$ (X: independent variable, k: index of independent variable) then

$$f(z) = \frac{1}{1+e^{-(\alpha + \sum \beta_i X_i)}} \quad (2)$$

Since the outcome of a logistic function is something between 0 and 1, it could be written as

$$P(result = 1 | X_1, X_2, ..., X_k) = \frac{1}{1+e^{-(\alpha + \sum \beta_i X_i)}} \quad (3)$$

Or

$$P(X) = \frac{1}{1+e^{-(\alpha + \sum \beta_i X_i)}} \quad (4)$$

Where X is a shortcut notation for the collection of variables X_1 through X_k.

Logit transformation, denoted as *logit* $P(X)$, is

$$logit\, P(X) = \ln[\frac{P(X)}{1-P(X)}] \quad (5)$$

Using some algebra, *logit* $P(X)$ will look like

$$logit\, P(X) = \alpha + \sum \beta_i X_i \quad (6)$$

where $P(X) = \frac{1}{1+e^{-(\alpha + \sum \beta_i X_i)}}$.

It is worth noting that $\frac{P(X)}{1-P(X)} =$ odds of X (the probability of happening over the probability of not happening for X), therefor *logit* $P(X)$ is the *log odds* of X. In a logistic regression model α is the background log odds and β_i shows the change in log odds of its corresponding variable, X_i.

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[3] In the database only three levels of driver's injury severity have been defined: the dead, the injured, and the uninjured.

If someone considers a special level of a multilevel independent variable as a reference group, and code it as 0, then all β's of different levels of that independent variable represent purely the log odds of their own levels compared to the reference category. Another important topic is that each independent variable contributes to the model by a product form.

For example, suppose that driver age between 25 and 45, and urban crashes are set as reference categories of driver age and area type independent variables, respectively. Then $\beta_{rural} = -0.228$ would mean that the odds of a diver being killed or injured in a rural crash is almost $e^{-0.228} = 0.80$ times of the same crash happens in an urban area. The same is for $\beta_{under25} = 0.202$; again it means that the odds of an under-25 age driver to be killed or injured in a crash is about $e^{0.202} = 1.22$ times of the same driver to be killed or injured with an age between 25 and 45, keeping all other effective factors fixed. If one wants to check the effects of these two variables on the dependent variable simultaneously, as mentioned before, it would be

$e^{-0.228} \times e^{0.202} = 0.80 \times 1.22 = 0.98$ meaning that the odds of an under-25 age driver being killed or injured in a rural crash is nearly 0.98 times of (or approximately the same as) a driver with the age of 25 to 45 being killed or injured in an urban crash, keeping other effective factors constant. For more information please refer to (Gail et al., 2007, Gujarati, 2014).

2.2.1 Control variables

Obviously, driver's IS level depends not only on the characteristics of vehicle, but also to some other factors such as driver's age, driver's gender, speed of vehicle at the crash moment and so on. Thus, to better identify the effect of vehicle characteristics on driver's IS, other external factors have to be controlled. Considered control variables of this study are summarized in Table 2.

Table 2- Description of control variables

Control variables	Description	Descriptive statistic
Area type	Urban=0 (reference)	Urban:14.2%
	Rural=1	Rural:85.8%
Driver gender	Female=0 (reference)	Female:4.5%
	Male=1	Male:95.5%
Driver age	<19=1	<19:1%
	19-25=4	19-25:14.1
	25-45=0 (reference)	25-45:65.1%
	45-65=2	45-65:18.5%
	>65=3	>65:1.3%

In summary, in this study there are four independent variables: vehicle brand (the intended independent variable), area type, age and gender of driver and one dichotomous dependent variable; that is driver's IS level.

2.2.2 Crashworthiness Index

In order to index crashworthiness, driver's IS level for each brand is considered. If vehicle driver is killed or injured, the dependent variable will be set as 1; otherwise it would be 0.

3. RESULTS AND DISCUSSION

For indexing crashworthiness of vehicle brands in rollover crashes, a BLRM was run. The results of model running have been shown in the following subsections.

3.1 Crashworthiness of passenger car brands

In Table 3, 20 of the most frequently used passenger car brads in Iran sorted according to their performance in rollover crashes.

Table 3- Crashworthiness by passenger car brands

Number of vehicles=42118	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)		Rank
							Lower	Upper	
Vehicle model (pride (Iran) as reference)			2795.249	27	0.000				
Proton (Malaysia)	-1.437	0.735	3.827	1.000	0.050	0.238	0.056	1.003	1
Suzuki (Japan)	-0.824	0.537	2.357	1.000	**0.125**	0.438	0.153	1.256	2
Mercedes-Benz (Germany)	-0.698	0.408	2.926	1.000	0.087	0.498	0.224	1.107	3
Samand (Iran)	-0.467	0.054	74.061	1.000	0.000	0.627	0.563	0.697	4
Kia (South Korea)	-0.457	0.418	1.200	1.000	**0.273**	0.633	0.279	1.435	5
Mazda (Japan)	-0.432	0.269	2.592	1.000	**0.107**	0.649	0.383	1.099	6
Peugeot 206 (Iran)	-0.426	0.079	29.268	1.000	0.000	0.653	0.560	0.762	7
Hyundai (South Korea)	-0.417	0.203	4.208	1.000	0.040	0.659	0.442	0.982	8
Rio (Iran)	-0.234	0.204	1.317	1.000	**0.251**	0.792	0.531	1.180	9
Citroen (France)	-0.212	0.128	2.719	1.000	0.099	0.809	0.629	1.041	10
Renault (France)	-0.130	0.081	2.585	1.000	**0.108**	0.878	0.750	1.029	11
Nissan (Japan)	-0.096	0.169	0.321	1.000	**0.571**	0.909	0.652	1.266	12
MVM (China)	-0.095	0.253	0.142	1.000	**0.707**	0.909	0.554	1.493	13
Peugeot 405 (Iran)	-0.063	0.035	3.289	1.000	0.070	0.939	0.877	1.005	14
Toyota (Japan)	-0.009	0.148	0.003	1.000	**0.954**	0.992	0.741	1.326	15
Pride (Iran)						1.000			16
Peykan (Iran)	0.168	0.046	13.087	1.000	0.000	1.183	1.080	1.296	17
BMW (Germany)	0.216	0.423	0.260	1.000	**0.610**	1.241	0.541	2.846	18
Daewoo (South Korea)	0.398	0.191	4.364	1.000	0.037	1.489	1.025	2.164	19
Sepand (Iran)	0.417	0.188	4.904	1.000	0.027	1.517	1.049	2.193	20

Base on this table, 9 out of 20 passenger car brands are not significant at 90% level of confidence (significant levels which are in bold). This could be due to small sample size of these brands.

As can be seen Proton, Suzuki, Mercedes-Benz, and Samand are the top four passenger car brands, respectively; which means that they have the best performances in rollover crashes than the other brands (of course, Suzuki is not significant at 90%). On the other hand, Sepand, Daewoo, BMW and Peykan are the worst brands, respectively (BMW is not significant at 90%). The odds ratio of Samand as the best Iranian brand is about 0.63. It means that the odds of a Samand driver to be killed or injured in a rollover crash is 37% lower than a Pride (the reference brand) driver. Having this mind, only four passenger car brands have poorer performances than Pride (i.e. odds ratios of greater than 1). For example, comparing Sepand and Pride car brands, the odds of a Sepand driver being killed or injured in a crash is 1.52 times more than a Pride driver.

3.2 Crashworthiness of bus, minibus, truck, Light truck and pick-up brands

Table 4 shows the results of non-passenger car performances in rollover crashes. From this table, only one brand is not significant at 90% level of confidence; that is Renault/Truck.

The first place goes to Hyundai/Light truck, surprisingly with an odds of 0.38. With a glance at Table 4, it will be clear that five of seven non-passenger car brands have better performances than Pride in rollover crashes! Only Peykan/Pick-up truck and Toyota/Pick-up truck have poorer performances than Pride with odds ratios of 1.41 and 1.91, respectively.

Table 4- Crashworthiness by vehicle brands (bus, truck, pick-up truck, light truck and minibus)

Number of vehicles=42118	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)		Rank
							Lower	Upper	
vehicle_model (pride (Iran) as reference)			2795.249	27	0.000				
Hyundai/Light truck (South Korea)	-0.960	0.195	24.321	1.000	0.000	0.383	0.261	0.561	1
Mercedes-Benz/Truck, Bus, Minibus (Germany)	-0.559	0.055	102.552	1.000	0.000	0.572	0.513	0.637	2
Mazda/Pick-up truck (Japan)	-0.413	0.114	13.067	1.000	0.000	0.662	0.529	0.828	3
Renault/Truck (France)	-0.367	0.227	2.622	1.000	**0.105**	0.693	0.444	1.080	4
Zamiad/ Light Truck, Pick-up truck (Iran)	-0.352	0.057	37.789	1.000	0.000	0.703	0.629	0.787	5
Pride (Iran)						1.000			
Peykan/Pick-up truck (Iran)	0.342	0.045	57.396	1.000	0.000	1.407	1.288	1.537	6
Toyota/Pick-up truck (Japan)	0.644	0.097	43.672	1.000	0.000	1.905	1.573	2.306	7

One explanation for the appeared results could be as follows:

Considering non-passenger car part of the brands, light trucks make up most from Hyundai and Zamiad brands. Generally, light trucks travel in cities or in the suburbs by a low speed and thus, high level of driver's IS level is not expected. But in the case of Mercedes-Benz and Renault, it can be said that because of great proportion of trucks in their sample size, they show better performances than Pride; this is because of low moving speed of trucks on rural roads and their more experienced drivers. However, these hypothesizes need further researches.

3.3 Control variables

Analysis results of control variables are summarized in Table 5. Based on this table, all control variables are significant at 90% level of confidence. Interpretation of these results is the same as previous tables. Male drivers are safer than female drivers in case of a rollover crash. The most dangerous driving age recognized as under 19. It is worth mentioning that driving with the age of under 19 is illegal in Iran; in other words, gaining a driver's license is impossible by an age of under 19.

Table 5 Control variables of crashworthiness model

Control variables of CW	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
Area type (urban as reference)								
rural collisions	-0.222	0.034	43.708	1	0.000	0.801	0.750	0.855
Sex (Female as reference)								
Male	-0.272	0.054	25.365	1	0.000	0.762	0.685	0.847
Age (between 25 and 45 years old as reference)			65.224	4	0.000			
Under 19	0.836	0.136	37.975	1	0.000	2.307	1.769	3.010
19-25	0.171	0.034	25.642	1	0.000	1.186	1.110	1.267
45-65	0.056	0.031	3.225	1	0.073	1.058	0.995	1.125
65 and 65+	0.270	0.100	7.285	1	0.007	1.310	1.077	1.593
Constant	-0.724	0.061	140.605	1	0.000	0.485		

The result of area type control variable shows that in rollover crashes, crashes which take place at rural areas are about 20% safer than urban rollover crashes! This is somehow strange; because one expects higher level of driver's IS in rural crashes according to the higher mean speeds of vehicles, delay in providing emergency services due to the high distance and so on; but checking descriptive statistics confirmed this result.

Chi-square test indicated a statistically significant association between driver's IS level and area type (chi2=477.94, P-value=0.000), and Table 6 presents a descriptive statistic of the number of drivers in rollover crashes according to area type. Using the data of Table 6, Table 7 is created. In Table 7 relative risk is calculated by dividing the number of dead and injured drives over the number of uninjured drivers (approximately the same as the concept of BLRM). It is clear from Table 7 that out of each 100 uninjured drivers in urban rollover crashes, 59 drivers are killed or injured, while out of each 100 uninjured drivers in rural rollover crashes, 33 drivers are killed or injured; which means that urban rollover crashes are more dangerous than rural rollover crashes. Moreover, higher urban odds ratio can be a result of inattention to seatbelt fastening inside the cities. Another explanation for why urban crashes were obtained more dangerous than rural crashes can be this: if it is assumed that some of the high injury rollover crashes occur at the entrance of the cities due to driver drowsiness, driver wrong perception of road conditions, etc., while those crashes categorized as urban crashes, then the bias in results can be explained. These results confirm the out puts of the BLRM which have been displayed in Table 5.

Table 6 Number of dead, injured and uninjured drivers in rollover crashes by area type

	No. of dead drivers	No. of injured drivers	No. of uninjured drivers
Urban	140	2086	3757
Rural	1030	7908	27197
			Total = 42118

Table 7 Relative risk of rollover crashes by area type

	No. of dead and injured drivers	No. of uninjured drivers	Relative risk
Urban	2226	3757	59
Rural	8938	27197	33

3.4 All together

In order to compare all vehicle brands (including passenger car and non-passenger car brands) together, Table 8 has been created. As it is apparent, the results of motorcycles' crashworthiness have been shown in this table. Considering the fact that motorcycles have the least rider protectiveness in comparison with the other vehicles, the poorest performance regarding to crashworthiness was expected for motorcycles before model running; and this is exactly what has happened. Motorcycles placed at the bottom of the crashworthiness ranking table. This compatible outcome can verify our model.

Table 8 Ranking tables of different vehicle brands

Brands	CWI	Ranks
Proton (Malaysia)	0.238	1
Hyundai/Light truck (South Korea)	0.383	2
Suzuki (Japan)	0.438	3
Mercedes-Benz (Germany)	0.498	4
Mercedes-Benz/Bus, Truck, Minibus (Germany)	0.572	5
Samand (Iran)	0.627	6
Kia (South Korea)	0.633	7
Mazda (Japan)	0.649	8
Peugeot 206 (Iran)	0.653	9
Hyundai (South Korea)	0.659	10
Mazda/Pick-up truck (Japan)	0.662	11
Renault/Truck (France)	0.693	12
Zamiad/Pick-up truck, Light Truck (Iran)	0.703	13
Rio (Iran)	0.792	14
Citroen (France)	0.809	15

Renault (France)	0.878	16
Nissan (Japan)	0.909	17
MVM (China)	0.909	18
Peugeot 405 (Iran)	0.939	19
Toyota (Japan)	0.992	20
Pride (Iran)	1.000	21
Peykan (Iran)	1.183	22
BMW (Germany)	1.241	23
Peykan/Pick-up truck (Iran)	1.407	24
Daewoo (South Korea)	1.489	25
Sepand (Iran)	1.517	26
Toyota/Pick-up truck (Japan)	1.905	27
Motorcycle (different brands)	10.320	28

Based on Table 8 some of the non-passenger car brands (such as Zamiad, Hyundai/Light truck, etc.) have better performances than Pride, a passenger car, in rollover crashes. Although it may seem a little abnormal but can be justified by the driver behavior of these kinds of vehicles, the vehicle's resistance, lower speed at crash moment in comparison to passenger cars, and so on. However, this subject needs further studies.

Figure 1 and Figure 2 have been depicted according to the data of Table 8. For Figure 1, the closer the plot to the center, the better that brand would be and vice versa; thus, Proton is the best and Toyota/Pick-up truck is the worst brand in crashworthiness index.

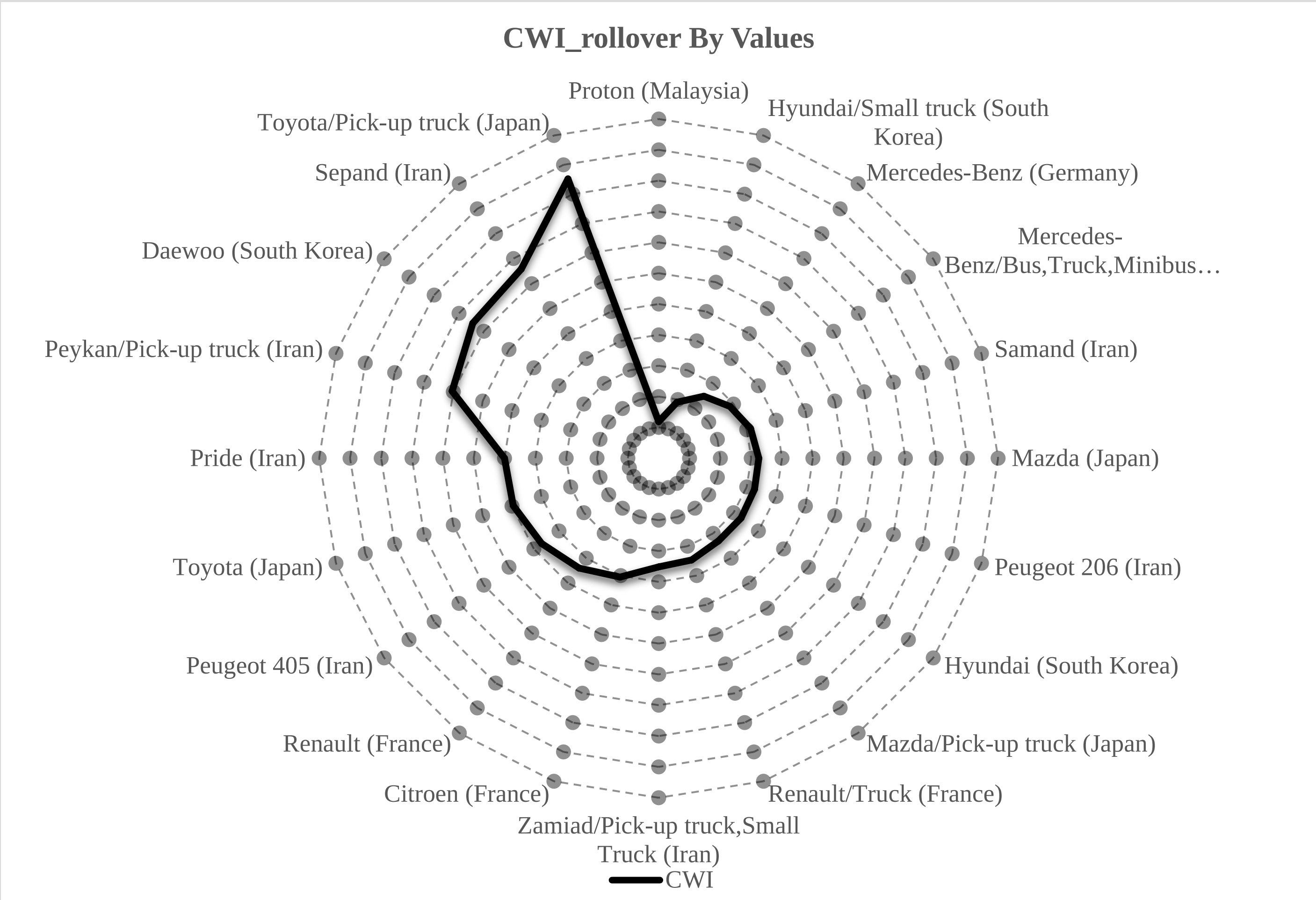

Figure 1 Crashworthiness odds ratios for different vehicle brands (Pride as reference brand and exclude motorcycles)

For Figure 2, the shorter a bar, the better that brand and vice versa (the dashed line represents the reference brand, Pride); so it becomes evident that motorcycles are by far the most dangerous vehicle type in rollover crashes (by an odds of 10.32).

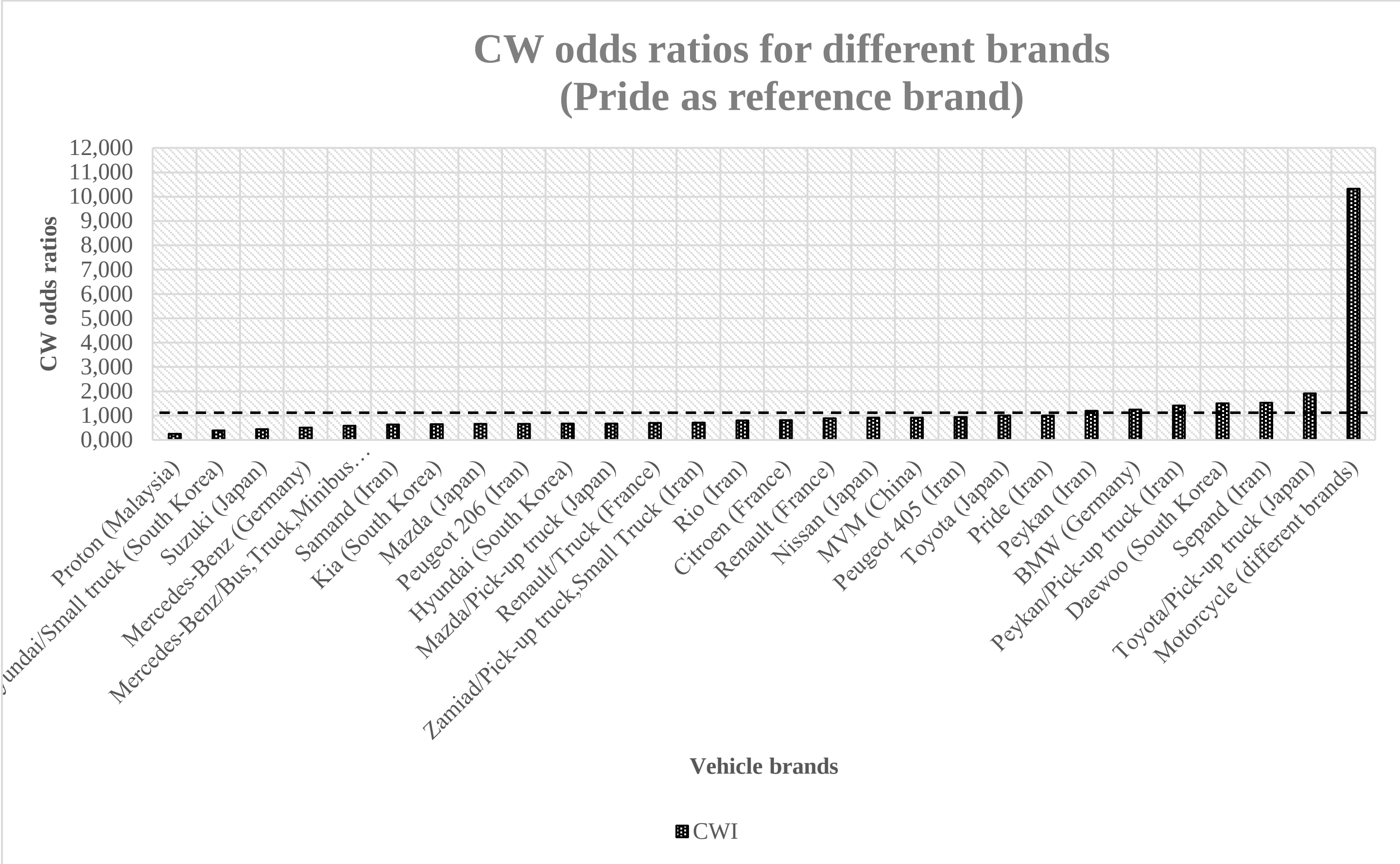

Figure 2- Comparing crashworthiness indices of different vehicle brands

4. CONCLUSION AND SUMMARY

Road crashes are one of the notable causes of human death across the world and especially in developing countries such as Iran. Among different types of road crashes, rollover crashes are of a main concern; because while they make up a small proportion of crashes, they are responsible for a remarkable part of road fatalities. Therefore, there is indeed a need to study safety impacts of rollover crashes especially in Iran where lack of these kind of studies are strongly felt.

In this regard, the relation between driver's Injury Severity (IS) level and crashworthiness capability of 20 most prevalently used vehicle brands of Iranian fleet was modeled in the current study using a Binomial Logistic Regression Model (BLRM). Next, based on the calculated Crashworthiness Index (CWI) of each brand, their performances in rollover crashes were compared with each other.

The results revealed that Proton (Malaysia) and Hyundai/Light truck (South Korea) were the best and Toyota/pick-up truck (Japan) and Sepand (Iran) were the worst brands compared to Pride (one of the most famous productions of SAIPA that raised a lot of complaints from safety experts, recently). Among Iranian brands, the first place went to Samand with an odds ratio of 0.63. No special trend was found regarding to crashworthiness capability of foreign and Iranian brands.

To verify the results of CW model, motorcycle crashes were added to the analysis dataset and the model was rerun. results confirmed the original results of the model.

Findings of the current study can be utilized to mitigate serious rollover crash injuries. Our findings might also be integrated with the findings of other similar studies around the world. This could be helpful for car manufacturers both in Iran and across the world in order to benchmark the best performing car brand in vehicle safety domain and improve the designing of their own car brands. This study also uncovered the potential of crash databases for analyzing the effects of vehicle brand/type on the safety of vehicle occupants. In addition, the employed methodology (BLRM) is easily applicable for similar safety studies.

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