Research Article

Analysis of Factors Associated with Traffic Injury Severity on Urban Roads in Different Lighting Conditions

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Keywords	Abstract
	This research has studied the severity of vehicle-to-vehicle accidents in Rasht City in various lighting conditions. In the present study, the target variable is the severity of an accident, which is split into two classes of no injury and injury/death. The effects of independent variables, including environmental, human, and roadway-related factors, on the vehicle-to-vehicle accident severity, have been investigated. The classification and regression tree (CART) method has been used for modeling purposes. The results showed that on daylight accidents if the not-at-fault driver is a motorcycle, the accident tends to be fatal or injury with the probability of 95.6%. At night with enough lighting, if the at-fault vehicle is a motorcycle and the not-at-fault vehicle is not a motorcycle, there is a probability of 72% of injury or death in case of inattention to the front. Also, if the accident reason is inattention to the front and the not-at-fault driver is route familiar, there is a 95.1% probability of injury and death. In addition, at night accidents without enough lighting, if the not-at-fault vehicle is a motorcycle and the accident does not occur in the summer, with the 100% probability, the accident leads to injury and death.

1. Introduction

Traffic safety is of paramount importance when it comes to transportation because it can affect people's lives. Accidents kill an average of approximately 1.25 million people worldwide each year and cause substantial damage [1]. Also, since Iran is one of the most hazardous countries globally regarding the number of people who died in accidents per 100,000 population, studying the contributing factors of accidents in order to reduce their severity is vital. To reduce the rate of accidents and subsequently reduce the resulting mortality rate, it is necessary to investigate the factors affecting road accidents [2]. Factors affecting the accidents are primarily split into three general categories: road characteristics, vehicle characteristics, and human factors, each of which has different sub-sections [3, 4]. One of the

most important sub-sections in the category of road characteristics is the road lighting condition that has been studied in the literature of traffic safety. This factor is also very influential on the severity of accidents. In a study conducted in 2009 in Norway, it was found that the effect of lighting in reducing accidents at dusk is 2.3 times higher than its effect at nights [5]. Also, in a study conducted by Vanik in London in 2005, it was shown that although only 1.4 of trips will be made during the night (between 7 pm and 8 am), 40% of death and injury of accidents occurred during this time. These results indicate that the lighting factor in the road, despite the lighter traffic flow at night, is so effective in the accident severity [6, 7]. In addition, it can be the result that lighting can improve users' vision, specifically drivers of motor vehicles at night. As a result, the transportation system experiences fewer accidents. In a study conducted by Hafezi

et al. in Iran in 2020, it was shown that the presence of lighting on rural roads in the condition of foggy weather and also raise of lighting in urban roads reduces the number of collisions at night. This is because accidents during the night are more severe and more dangerous than accidents during the day. After all, darkness can affect drivers' attention [8], sight distance, and as a result, their proper maneuvering [9, 10]. Additionally, by studying the necessity of lighting conditions in the roads and intersections, the results reported a 25% reduction in the rate of accidents at night, 39% reduction in the number of accidents at night, and 31% reduction in accidents in the lighted intersections comparing their unlighted counterparts [11, 12]. Since many factors may influence the severity of the accidents, it is required to investigate the relationship in different scenarios [13]. The present research analyzed influential variables in three scenarios, including three lighting conditions while accidents happen (day and night with and without enough lighting).

2. Methodology

The decision tree is one of the machine learning methods that recently has been the prevalent tool in transportation analysis [8, 14]. This method has appropriate application in the severity of the accident analysis. The classification and regression tree (CART) algorithm has been used to generate the decision trees in this research [8]. In the CART model's first stage, the input data are concentrated in the first node located at the top of the tree. Input data is split into branches based on the independent variables, which make the best homogeneity in each branch. The Gini index is used in this method, one of the best purity criteria so that the lowest value of the Gini coefficient causes the best splitting. The Gini index for the node t is as below:

$$Gini(t) = 1 - \sum [P(j|t)]^2 \qquad (1)$$

Where P(j|t) is the relative frequency of j class in the node t. By using the Gini coefficient, the data are split into the number of the child which derives from parents [14].

3. Results

3.1. Descriptive Analysis Results

In this research, the severity of vehicle-to-vehicle accidents has been modeled in three separate lighting scenarios, i.e., day and night with and without lighting, which has been investigated. The frequency of accidents in the study area based on lighting conditions (based on Rasht City urban traffic police database from 2015 to 2021 using KAM 114 forms) shows 7144, 2848, and 256 accidents for daylight and night with and without enough lighting, respectively. Due to the objective of this study, the target variable is the accident severity, a binary variable including two values of no injury or injury/fatal[15, 16]. The independent variables consist of 13 variables, including

human, environmental, and road characteristics-related factors. Table 1 reports the frequency of crash severities by independent variables separately. The number of accidents based on month reported that the most and the least number of accidents were occurred in September and November, respectively. The reason for this can be the higher number of tourists who travel to Guilan province during these months. The accidents frequency during the days of the week shows that the least and the most accidents occurred on Friday and Saturday, respectively. This distribution indicates that on the weekend, the number of accidents decreased. Based on the accidents' statistics, the clear weather and dry pavement surface have the greatest casualties. Another factor under consideration is the collision angle according to which head-on and side-impact accidents have the most fatalities. Another examined factor is the characteristics of the vehicle and driver. The frequency of vehicle types shows that the automobiles made in Iran and the motorcycles have the most injury and fatalities. The at-fault and not-at-fault driver's age specifications show that most accidents occurred for drivers aged 30 to 55. The casualties are much more in men compared to women.

3.2. Results of CART Method

As previously stated, the models have split into three scenarios of accidents regarding variables' combination [14] on days and nights with and without lighting. The influential variables have been investigated in each of these three models.

3.2.1. Accidents at Daylight

According to longer hours and heavier traffic flow of days (because more land uses are active during the daylight hours) [13, 14]compared to nights, there are more accidents at daylights. In this research, 7144 accidents have been recorded, including 21 deaths and 3032 injuries. Figure 1 represents the result of the CART model. The results show that if the not-at-fault vehicle is a motorcycle, the accidents lead to injury or death with the probability of 95.6%. Also, the results show that if the not-at-fault vehicle is a foreign company-made vehicle and the at-fault vehicle is a motorcycle, there is a 91.7% probability of injury or death. These results indicate that in the case of a motorcycle accident, if the vehicle is manufactured by a foreign company and the at-fault driver is unfamiliar, and their vehicle is Iranian-made, the accidents will be no-injury with the probability of 94.1%. Also, the results show that if the collision angle is head-on, the at-fault vehicle is not a motorcycle, the vehicle is Iranian-made, and the not-at-fault vehicle is not a foreign company-made vehicle and motorcycle, the accident is no injury with the probability of 83.7%.

Table 2 shows the prediction accuracy of the developed CART model. According to the prediction percentage, this model correctly predicts 97.3% and 57.9% of accidents, no injury and injury/fatal crashes, respectively. Also, the model's overall prediction accuracy was 80.5%.

Table 1. Description of variables

| Variables	Category	Accident severity		Total accidents
		No injury accidents	Injury/Fatal accidents	
Day of week	Saturday	848	700	1548
	Sunday	742	703	1445
	Monday	835	637	1472
	Tuesday	811	655	1466
	Wednesday	817	715	1532
	Thursday	884	688	1572
	Friday	655	558	1213
Season	Spring	1274	1290	2564
	Summer	1399	1344	2743
	Fall	1289	1060	2349
	Winter	1630	962	2592
Year	1394	569	856	1425
	1395	645	668	1313
	1396	596	834	1430
	1397	1227	942	2169
	1398	1195	540	1735
	1399	1360	816	2176
Angle	Head-on	561	755	1316
	Rear-end	2101	1095	3196
	Side Swipe	806	683	1489
	Side-Impact	2124	2107	4231
Surface Condition	Dry	4870	4203	9073
	Wet	722	453	1175
Weather Condition	Clear	280	423	703
	Cloudy	4714	3877	8591
	Rainy	575	348	923
	Snowy	23	8	31
Light condition	daylight	4091	3053	7144
	dark- lighted	68	188	256
	dark-not-lighted	1433	1415	2848
At-Fault Driver	Familiar	3902	3934	7836
	Unfamiliar	1690	722	2412
Not At-Fault Driver	Familiar	3923	4107	8030
	Unfamiliar	1299	432	1731
At-Fault Vehicle (AFV)	Passenger Car–made in Iran (PCIR)	3468	3371	6839
	Passenger Car–made in other countries (PCOC)	1273	486	1759
	Motorcycle	64	540	604
	Pickup	333	160	493
	Heavy Vehicle	454	99	553
Not At-Fault Vehicle (NAFV)	Passenger Car – made in Iran (PCIR)	3390	2068	5458
	Passenger Car – made in other countries	1633	293	1926
	Motorcycle (PCOC)	91	2099	2190
	Pickup	259	111	370
	Heavy Vehicle	219	85	304
At-Fault Driver Age (AF Age)	< 30	1623	1371	2994
	31-55	3043	2079	5122
	>56	543	391	934
Not At-Fault Driver Age (NAF Age)	< 30	1454	1573	3027
	31-55	3135	1764	4899
	>56	489	327	816
At-Fault Driver Gender	Male	4884	4128	9012
	Female	708	528	1236
Not At-Fault Driver Gender	Male	4813	4323	9136
	Female	778	333	1111
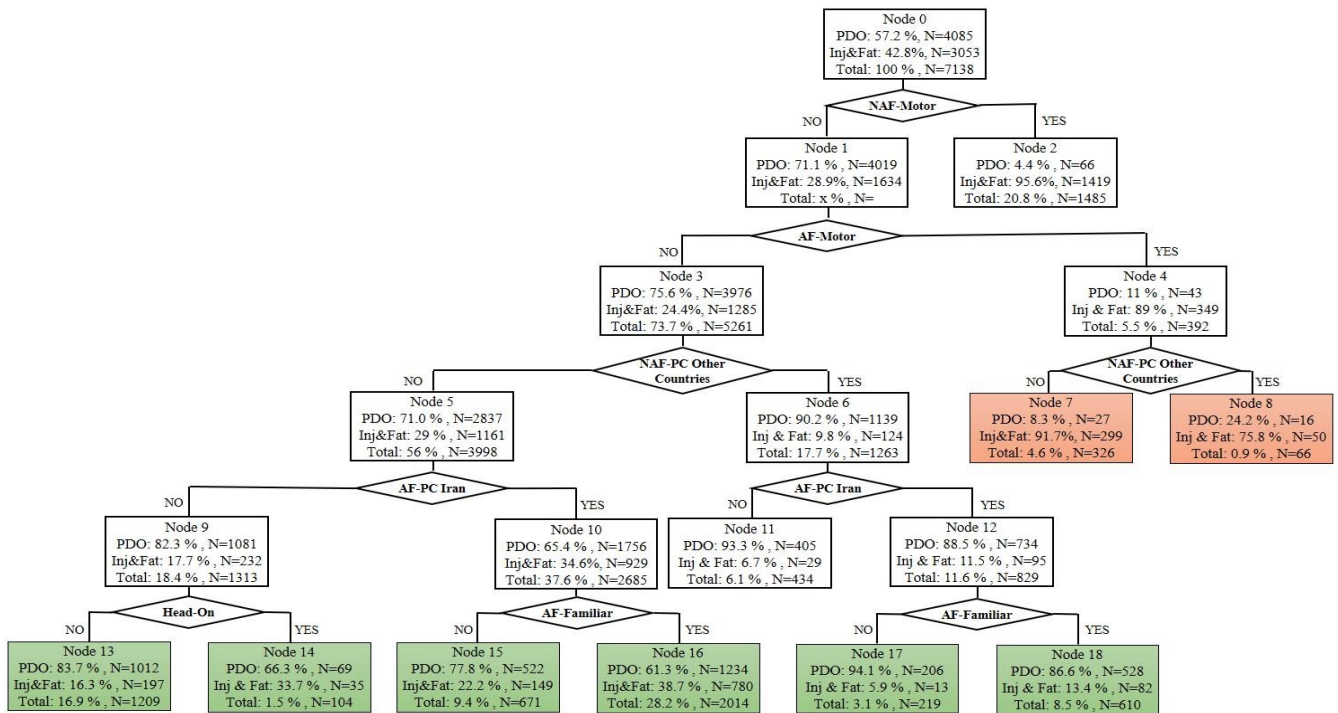
Figure 1. The results of the developed CART model for vehicle-to-vehicle crashes at daylight condition

Table 2. Prediction accuracy of the model developed for daylight condition

| | | Predicted | | |
| | | Accidents severity | | Correct |
Observed		PDO	Injury & Fatal	percentage
Accidents severity	PDO	3976	109	97.3
	Injury & Fatal	1285	1768	57.9
Overall percentage		73.7	26.3	80.5

3.2.2. Accidents at Night with Lighting

Urban roads in Rasht are often equipped with enough lighting due to their heavy traffic flow. Overall, 2848 accidents have occurred at night with lighting on urban roads of Rasht City, which have left 10 death and 1433 injuries. Figure 2 shows the results of the CART model for this scenario. According to the results, if the at-fault vehicle is a motorcycle and the not-at-fault is not a motorcycle, in the case of not paying attention to the front, there is a probability of 72% of death or injury. Also, if the reason for the accident is inattention to the front and the not-at-fault driver is rout familiar, there is a probability of 95.1% of injury and death. If the not-at-fault driver is unfamiliar, the likelihood of injury or death is 73.3%. It can be deduced from the results that if the not-at-fault driver is familiar, there is a greater chance of injury and death, about 20%. Also, the results show that if neither of at-fault and not-at-fault vehicles is not a motorcycle and a foreign company-made vehicle, in the case of a familiar at-fault driver, the accident leads to death with a probability of 50.6%.

Table 3 shows the prediction accuracy of the developed model. According to the prediction accuracy, this model correctly predicts 68% and 78.4% of no injury and injury/fatal accidents, respectively. Also, in general, the model accuracy is 73.2%.

3.2.3. Accidents at night without lighting

Considering that Rasht City is the capital of Guilan province, most of its roads have lighting. However, some of the roads do not have sufficient lighting, causing 256 accidents, of which 3 and 185 accidents have led to death and injury, respectively. Figure 3 shows the model created from the CART method. This research gives the possibility that if the not-at-fault driver is a motorcycle and the accident does not occur in summer, with a probability of 100%, the accident leads to injury and death. Also, if the accident happens in summer, the likelihood of accidents leading to injury or death is 96.4%. It can also be mentioned that if the at-fault and not-at-fault vehicles are not a motorcycle, and the collision angle is head-on, with a probability of 91.7%, the accidents lead to injury or death.

Table 4 shows the percentage of the model prediction. According to the prediction percentage, this model correctly predicts 83.8% and 77.7% of no injury and injury/fatal accidents, respectively. Also, in general, the model accuracy is 79.3%.
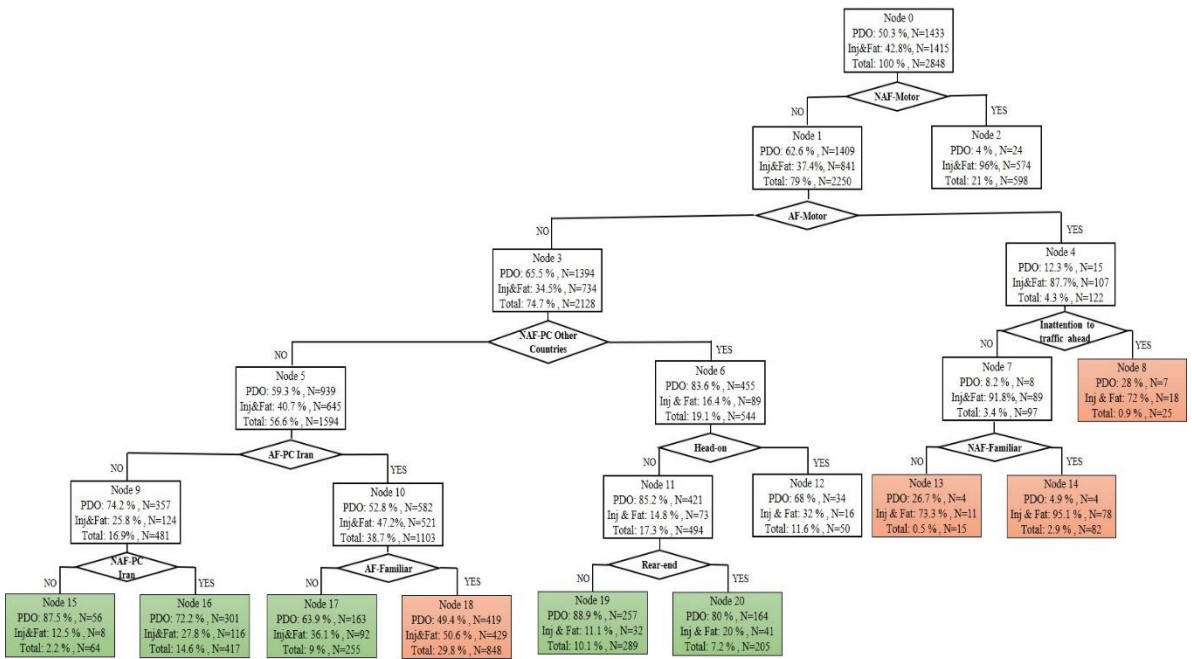
Figure 2. The results of the developed CART model for vehicle-to-vehicle crashes at night with enough lighting conditions.

Table 3. Prediction accuracy of the model developed for nights with enough lighting condition

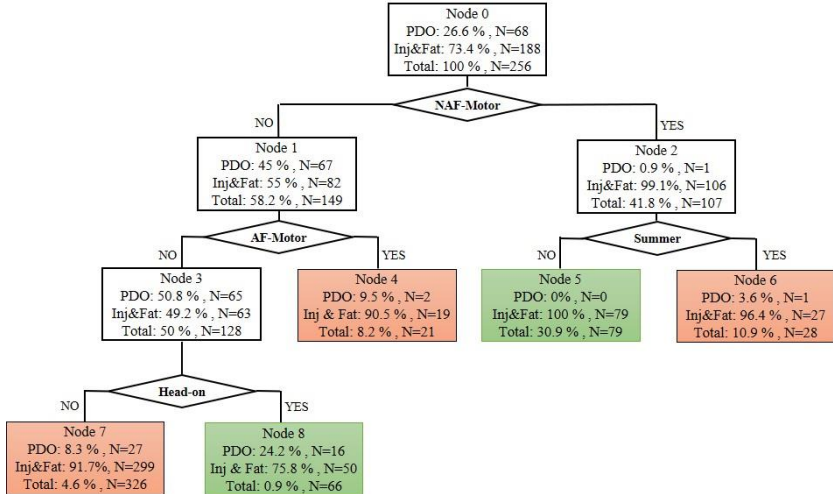|		Predicted		
		Accidents severity		Correct
Observed		PDO	Injury & Fatal	percentage
Accidents severity	PDO	975	458	68
	Injury & Fatal	305	1110	78.4
Overall percentage		44.9	55.1	73.2

Figure 3. The results of the developed CART model for vehicle-to-vehicle crashes at night without lighting conditions.

Table 4. Prediction accuracy of the model developed for night without lighting condition

		Predicted		
		Accidents severity		Correct
Observed		PDO	Injury & Fatal	percentage
Accidents severity	PDO	57	11	83.8
	Injury & Fatal	42	146	77.7
Overall percentage		38.7	61.3	79.3

3.3. Variables' Importance Across the Developed CARTs

Table 5 shows the effective variables in developing CART models across the three scenarios of this study. Most results were somehow consistent between the two modeling approaches. In other words, all three models were able to identify somehow similar important predictors, which highlighted the similarity between these models' results. In all three models, motorcycles play a significant role in developing trees, whether at-fault or not-at-fault. On the other hand, for example, drivers' age was only influential when the crash occurred on a night without enough lighting. This can clearly indicate that unlighted streets at night are complicated driving situations, especially for inexperienced (young) drivers [17]. Overall, the results were primarily similar between daylight and lighted conditions at night; yet, they were both different with night crashes in unlighted situations.

Table 5. Importance rank of the variables under different lighting conditions.

Rank	Daylight	Night with enough lighting	Night without lighting
(1)	NAF-Motorcycle	NAF-Motorcycle	NAF-Motorcycle
(2)	AF-Motorcycle	AF-Motorcycle	NAF- Familiar
(3)	NAF- PCOC	NAF- PCOC	AF-Motorcycle
(4)	NAF-PCIR	NAF-PCIR	NAF-PCIR
(5)	AF-PCIR	AF-PCIR	Head-On
(6)	AF- Familiar	AF- PCOC	NAF Young (Age <30)
(7)	AF- PCOC	Swerving	Fall
(8)	Head-On	Loosing vehicle's control	Ignoring right of way
(9)	Loosing vehicle's control	Head-On	Cloudy
(10)	AF- Pickup	Inattention to traffic ahead	Deviation to left
(11)	Deviation to left	Rear-End	Side-Swipe

4. Conclusion

The first step for controlling traffic deaths and injuries is finding influential factors. Yet, accidents' influential factors may play varying roles in different conditions. One of the most effective factors whose effect may greatly influence other factors in a crash is the lighting condition. This study aimed to investigate the factors affecting the severity of urban two-vehicle crashes in different lighting conditions [18]. Three scenarios, including the crashes that occurred at daylights, nights with enough lighting, and nights without lighting, were defined. Using the CART model, results showed that influential factors were mostly similar between daylight crashes and crashes that happened on lighted streets at night. However, dark streets at night were able to involve some other factors in the severity of two-vehicle crashes [19].

Policymakers can consider the results of this study to prioritize the improvements needed to be made in different streets.

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