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Research Paper

Evaluating and Prioritizing the Effect of Human and Road Factors on Road Accidents and Providing Solutions (Case Study: Northern Roads of Ardabil Province)

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Abstract

A combination of various human and road factors leads to accident occurrence. By studying drivers' behavior, changing and developing geometric factors of the road, securing, and control measures, number of accidents will change significantly. This research focuses on human and road factors. Based on analysis of accidents in the northern roads of Ardabil province, accidents have been evaluated and analyzed using R software and the main causes have been identified. Also, based on CMF and N predicted (accident number prediction) methods in the Highway Safety Manual (HSM), the impact of lane widening, correcting some geometric factors, and converting the two-lane two-way road into a separated four-lane road on accident numbers was examined. The results of the human factors study indicate that exceeding the safe speed limit, unauthorized overtaking and the driver's failure to pay attention to the front are the most important factors in the accidents of roadways, which are responsible for more than 90% of the accidents, and the modification measures of the road geometry (such as widening and converting from two-lane to four-lane) as well as, securing the route and intersections, have a significant effect on reducing accidents. Prediction models indicate that widening the route and providing an 11m width including asphalt shoulders, applying the above measures, and controlling the road with cameras will lead to a 40% reduction in accidents in the short and medium term, and converting the two-lane route into a four-lane one will result in a 34% reduction in accidents.

Keywords: human factors, geometric correction factors, accident count prediction models, suburban roads

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1. Introduction

Every year in the world, road accidents cause many casualties, severe injuries, and heavy and irreparable damages. Due to the important role, they play in the transportation of goods and passengers, intercity roads are a large part of road transportation system, and many accidents with heavy casualties occur there. Identifying the factors contributing to accidents and determining the effect of each of these factors on traffic accidents is essential. In general, the main factors of accidents can be categorized in four groups: road, vehicles, human factors, and environmental factors, all interconnected in a chain. A significant share of Iran's suburban road networks includes two-way two-lane routes. Main suburban roads make up 30% of Iran's road network, and still the majority of trips are made via road and by private vehicle. According to the statistics published by the Transportation Research Institute of the Ministry of Roads and Urban Development, the number of road casualties in Iran is 20 times higher than that of industrialized countries and 5 times higher than that of countries on par with Iran (Tavakkoli and Kashani, 2017).Therefore, the necessity of investigating the causes and factors of accidents and finding practical solutions to solve this problem is evident, and solutions must be sought to address this critical issue that causes irreparable damage to the social and economic body of the country every year. Contributing factors in accidents: as a general rule, four factors-road (geometric characteristics of the road), human (characteristics, behavior, physiological and psychological ability of the driver), vehicle (vehicle capability, technical failure of parts), and environment (environmental and atmospheric conditions)—are known as the effective causes of accidents, based on which the conceptual model of this research has been designed in Figure 1 in the form of these four factors.

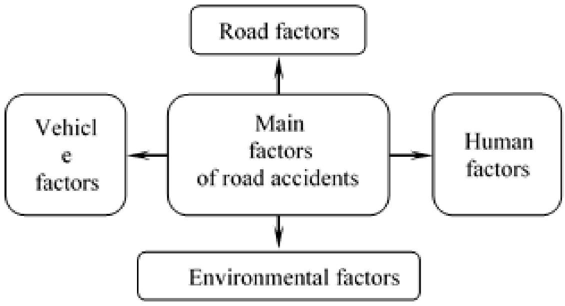

Figure 1. The main factors of road accidents

2. Research Background

Sajed and Shafabakhsh, (2019) conducted a study entitled providing a risk model to identify and prioritize accident-prone areas. In this study, the main roads of Ardabil province were divided into sections of one to two kilometers and classified based on geometric and traffic conditions. The accident-prone areas were identified by using binomial distribution models and hierarchical Poisson gamma. The results of this study indicated that the parameters related to the non-native license plate at-fault, horizontal curves, longitudinal slope of the road, curvature, combination of horizontal curves and slope, section length and residential area were more significant and their coefficients show the significant effect of these parameters on the number of accidents and their severity. And it can be said that these points are among the accident-prone areas on the road, and the driver's unfamiliarity with the road (non-native license plate at-fault) as a traffic and human factor has also contributed significantly to the increase in accidents in those areas.

In a research by Haghighi, seven commonly applied HSID methods (accident frequency (AF), PIARC coefficient based equivalent property damage only (EPDO), P-value(Islamic Republic of Iran Ministry Roads and Urban development), accident rate (AR), combined criteria, empirical Bayes (EB), societal risk-based) were compared against six robust and informative quantitative evaluation criteria (site consistency test, method consistency test, total rank differences test, total score test, sensitivity test and specificity test). These tests evaluate each method performance in a variety of areas, such as efficiency in identifying sites that show consistently poor safety performance, reliability in identifying the same black spots in subsequent time periods. To evaluate the HSID methods, three years of crash data from the Kerman state were used. Analytical Hierarchy Process (AHP) method has been used for determination the importance coefficients of evaluation tests and as a result, showed that the total rank differences test is the most appropriate test. The quantitative evaluation tests showed that the EB method performs better than the other HSID method. Test results highlight that the EB method is the most consistent and reliable method for identifying priority investigation locations [Haghighi and Karimi, 2018].

Safety visits is a method that was investigated in the study of Sajed and Azimi. In order to study the case, 14 tunnels of suburban roads of Ardabil province were selected and then important factors affecting the safety of tunnels, such as tunnel lighting and tunnel placement in archways were determined and Tunnel Safety Index (SI) were calculated for their safety assessment and compared with the accident statistics of tunnels. Finally, the Risk levels (RL) of the tunnels were proposed to prioritize the safety measures [Sajed et al., 2016].

Rosulinova and Tersa (2014) investigated the effect of road geometry, weather conditions, and traffic conditions on the number of accidents in different severity of accidents by using the Poisson-lognormal method. In this research, it has been shown that modeling accidents with different severities separately will lead to neglect of common information in unobserved errors, reduce the efficiency of parameter estimation, and create deviations in the data. The variables used in this research are: horizontal curve length, radius of curvature, vertical curve length, shoulder width, road width, maximum speed on the road, average daily traffic. The results of this research showed that the road condition has a great effect on the occurrence of accidents. For example, on a road with a steeper curve, the probability of severe accidents increases, and increasing the width of the dirt shoulder reduces the accidents with low severity.

Another paper aims at presenting a novel approach, capable of identifying the location as well as the length of high crash road segments. It focuses on the location of accidents occurred along the road and their effective regions. In other words, due to applicability and budget limitations in improving safety of road segments, it is not possible to recognize all high crash road segments. Therefore, it is of utmost importance to identify high crash road segments and their real length to be able to prioritize the safety improvement in roads [Boroujerdian et al., 2014].

Cafiso et al. (2010) have presented a quantitative safety assessment process to identify and rank road sections. They demonstrated that despite the subjective nature and personal safety inspections, there is a statistically significant level of agreement between the ranking of points based on the defined risk index and the ranking of points by the empirical Bayesian method. In this method, inspections are performed using checklists related to the main features of the road. Checklists are filled in for both directions and typically 200m sections.

Tavakoli Kashani et al. (2024) conducted a study aimed at examining and determining the contribution of the three main factors—human, vehicle, and road—in the occurrence of traffic crashes in Isfahan Province. The research analyzed both the causes of crashes and the factors contributing to injuries and fatalities among drivers and passengers. Additionally, the study investigated the differences in the nature of contributing factors before and during the crash based on the Haddon Matrix. The results indicated that human factors played a role in 97.5% of crashes, road-related factors in 36.9%, and vehicle-related factors in 8.9% of the cases.

In-depth analyses revealed that risky driver behaviors such as inattention, speeding, and other unsafe actions accounted for over 85% of all crashes. The findings suggest that eliminating these behaviors could prevent a significant portion of traffic incidents. Furthermore, in analyzing injury severity, the contribution of human factors was estimated at 83.4%, vehicles at 45.2%, and road conditions at 30.6%, highlighting the substantial role of vehicles in causing injuries to drivers and passengers during crashes.

Tavakoli Kashani et al. (2024) investigated the impact of vehicle type and weight on occupant protection in fixed-object crashes. In this analysis, the outcomes were compared with rollovers and two-vehicle collisions to provide a more detailed assessment of the performance of different vehicle types. Data from fixed-object, rollover, and two-vehicle crashes in Iran over the past six years were examined. The Crashworthiness (CW) index was defined using a Binomial Logistic Regression model based on the driver's injury status. The results showed that rollover crashes were significantly more dangerous than fixed-object or two-vehicle crashes. Trucks and SUVs demonstrated better performance compared to other vehicle types. The evaluation of vehicle weight showed that increased weight does not always equate to better safety; in fact, the weight range of 1500 to 2000 kg was identified as the least hazardous. These findings provide a comprehensive understanding of vehicle safety and the severity of occupant injuries across various crash types.

Taheri et al. (2023) conducted a study to examine the impact of the COVID-19 pandemic on the severity of road traffic crashes in Iran's Khorasan Razavi province. Using a Classification and Regression Tree (CART) model and a data fusion approach, they analyzed crash data across three time periods: pre-pandemic, strict lockdown, and post-lockdown, covering the period from May 2019 to October 2021. The results indicated an increase in the proportion of fatal crashes during the strict lockdown phase, while in the pre- and post-lockdown periods, most crashes were non-fatal. Key factors influencing crash severity included traffic volume, risky driver behaviors such as lack of awareness, and weather conditions like cloudiness. The study also found that although higher traffic volumes were associated with more crashes, the resulting lower speeds contributed to reduced crash severity.

Yousefifard et al. (2021) conducted a systematic review and meta-analysis to identify the key risk factors for road traffic mortality in Iran. The study included 20 articles with data on over 2.6 million traffic crash victims and 23,272 fatalities, reporting a mortality rate of 1.28%. Risk factors were categorized into age, gender, road characteristics, user behavior, speeding, and lighting conditions. The results showed that men were 1.66 times more likely to die than women, and with each additional year of age, the risk of death increased by 1%. Major contributing factors included road defects (OR=2.15), unsafe road geometry (OR=1.60), and speeding (OR=3.16). Behavioral factors such as lack of attention to the road (OR=2.99), not wearing a seatbelt (OR=3.11), and reckless overtaking (OR=4.04) also had strong associations with mortality. Pedestrians were found to be 2.07 times more likely to die compared to drivers and passengers, and crashes occurring during daylight hours were associated with lower fatality risk.

3. Research Methodology

In this study, statistical data on fatal accidents on the main roads of Ardabil province (Ardabil–Meshginshahr, Kangarlu–Sarband junction, Ardabil–Germi, Ardabil–Astara, Ardabil–Nir, Ardabil–Sarcham Meshginshahr–Ahar, Parsabad–Jafarabad, and Parsabad–Aslandooz) during the years 2018, 2019, and 2020, totaling 278 accidents, were analyzed using statistical tests and regression analysis. To analyze and prioritize the impact of each human factor on the number of fatal accidents, the statistical software R was employed. Furthermore, based on the Crash Modification Factors (CMFs) and N predicted accident prediction methods outlined in the Highway Safety Manual (HSM-2010), the impact of lane widening, geometric improvements, and converting two-way two-lane roads into separated four-lane roads on the number of accidents was examined. Geometric correction factors included lane width, shoulder width, horizontal curves, super elevation, and grade; and safety/control factors included speed control cameras and night lighting. According to the HSM, these correction factors and their respective coefficients are listed in Tables 1 through 5. Additionally, the impact of geometric corrections is reflected in Equations 1 through 5. Due to limitations in data access regarding the type and quantity of accident records, regression methods and the R statistical software were used. Naturally, if more detailed and accurate baseline accident data were available—including accident count and severity—machine learning methods could also be employed.

Table 1. Crash modification factors of the equation

CMF Description	CMF	Facility Type
Lane Width	CMF_{1r}	
Shoulder Width and Type	CMF_{2r}	
Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions	CMF_{3r}	
Horizontal Curves: Super elevation	CMF_{4r}	
Grades	CMF_{5r}	
Driveway Density	CMF_{6r}	Rural Two-Lane Two-way Roadway segments
Lighting	CMF_{11r}	
Automated speed Enforcement	CMF_{12r}	

•Effect of Roadway Width

$$\mathrm{CMF}_{1\mathrm{RD}} = (\mathrm{CMF}_{1\mathrm{rA}} - 1) \times P_{\mathrm{RU}} + 1 \quad (1)$$

Table 2. Crash modification factors of the effect of shoulder width in terms of annual average daily traffic

Lane Width	AADT (vehicles per day)		
	<400	2000 400-	>2000
9 ft or less	1.05	$1.05+2.81\times10^{-4}$(AADT-400)	1.50
10 ft	1.02	$1.02+1.75\times10^{-4}$(AADT-400)	1.30
11 ft	1.01	$1.01+2.5\times10^{-5}$(AADT-400)	1.05
12 ft or more	1.00	1.00	1.00

•Effect of right shoulder width

$$\mathrm{CMF}_{2\mathrm{nd}} = a \times 1 \quad (2)$$

Table 3. Crash modification factors of the effect of the right shoulder in terms of annual average daily traffic

	AADT (vehicles per day)		
Shoulder Width	<400	2000 400-	>2000
0 ft	1.10	$1.10+2.5\times10^{-4}$(AADT-400)	1.50
2 ft	1.07	$1.07+1.43\times10^{-4}$(AADT-400)	1.30
4 ft	1.02	$1.02+8.125\times10^{-5}$(AADT-400)	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98-6.875\times10^{-5}$(AADT-400)	0.87

•Effect of horizontal curve (length and radius), presence or absence of clothoids

- Effect of horizontal curve, superelevation

$$\mathrm{CMF}_{4r} = 1.00 \text{ for SV } < 0.01$$
$$\mathrm{CMF}_{4r} = 1.00 + 6 \times (\mathrm{SV} - 0.01) \text{ for } 0.01 \le \mathrm{SV} < 0.02 \quad (3)$$
$$\mathrm{CMF}_{4r} = 1.06 + 3 \times (\mathrm{SV} - 0.02) \text{ for SV} \ge 0.02$$

- Effect of longitudinal slope

$$\mathrm{CMF}_{5\mathrm{nd}} = b \quad (4)$$

Table 4. Crash modification factors of the effect of the road longitudinal slope

Approximate Grade (%)		
Level grade (3%)	Moderate terrain (3% < grade6%)	Steep terrain (>6%)
1.00	1.10	1.16

- Effect of traffic control cameras

If the camera is installed sufficiently along the road, the factor value for all accidents is considered to be 0.93.

- Effect of lighting

$$\mathrm{CMF}_{4\mathrm{RD}} = 1 - [(1 - 0.72 \times p_{\mathrm{inr}} - 0.83 p_{\mathrm{pnr}}) \times p_{\mathrm{nr}}] \quad (5)$$

P_{inr}: The ratio of night-time accidents to total injury and fatal accidents in the section without lighting

P_{pnr}: The ratio of night-time accidents with property damage to total accidents in the section without lighting

P_{nr}: Total proportion of night-time accidents and in the section without lighting.

Table 5. Default value for factors

Roadway Type	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury P_{inr}	$PDOP_{pnr}$	P_{nr}
2U	0.382	0.618	0.370

In this research, the models for predicting the number of accidents are examined based on the Highway Safety Manual (HSM). Moreover, the influential parameters of traffic, geometric and lighting conditions, as well as the application of laws and control of driving violations are taken into account, and the effect of each in reducing accidents are investigated and evaluated. Considering that the Ardabil-Mughan Road in the north of the province has been the most accident-prone area over the last 3 years due to the number of fatal and injury accidents, and in this road, the 55 km section of Kangarlu to Qarah Aghaj (K-Q section) was the most accident-prone in 2019, with over 20 fatal accidents, therefore, this section is investigated as a case study for predicting accidents.

4. Accident Analysis and prediction Modeling

In this section, the influential factors in the fatal accidents of the main transportation roads of Ardabil province (Ardabil-Meshkinshahr, the three-way section of Kangarlu–Sarband, Ardabil-Garmi, Ardabil-Astara, Ardabil-Nir, Ardabil–Sarcham, Meshkinshahr-Ahar, Parsabad-Jafarabad, Parsabad-Aslanduz) for the years 2018, 2019, and 2020 a total of 278 accidents-have been examined and analyzed based on statistical tests and regression analysis. The purpose of this work is to identify the factors that play the most important role in fatal accidents. In addition, the effect of geometric parameters including lane width, shoulder width, road grade, curvature, and lighting conditions, as well as traffic control conditions—and finally, the effect of converting the road from a two-way two-lane to a four-lane configuration—were also evaluated regarding their impact on the number of accidents.

4.1. Identification and Prioritization of Traffic Accident Contributing Factors Using Regression Methods

The data of fatal accidents on the roads of Ardabil province were analyzed using R statistical software. First, accident factors are tested using a variance analysis test (comparison of multiple means) to determine if there is a significant difference between the factors of accidents in 2018, 2019, and 2020; therefore, the data should be first tested for normality, and if it is normal, parametric methods will be used, otherwise non-parametric methods will be employed to test the mean comparison. The normality test for the mentioned data was performed using the Shapiro-Wilk method in R software, the output of which is equation (6).

> x=c(13,15,15,+ 6,11,5,+ 11,12,6,+ 3,6,8,+2,2,1+ 2,0,0,+ 5,4,3,+ 0,0,3)
> shapiro.test(x) Shapiro-Wilk normality test (6)
data: xW = 0.89239, p-value = 0.0149

Table 6. The frequency of the cause of fatal accidents on the main roads of Ardabil province in the years 2018 to 2020 (source: Road Maintenance & Transportation Organization)

Leading cause of accident	Total
Exceeding safe speed limit	64
Turning and passing on the left	103
Failure to pay attention to the front	42
Fatigue and sleepiness	22
Inability to control the vehicle	11
Failure to yield the right of way	9
Other	27
Sum	278

The above data are related to the factors of fatal accidents on the roads of Ardabil province for the years 2018, 2019, and 2020, and the data of 13, 15, and 15 accidents related to exceeding the speed limit (speeding) are for the years 2018, 2019, and 2020, respectively; therefore, the positive sign between the data means the cause change. It is obvious that the data of factors are not normal because the number of data is very small (3 numbers); thus, we carried out the normality test for the total data of accidents, the p-value of which is approximately 0.015, and as a result, at the significance level of 0.05, the normality assumption is rejected. As a result, a comparison test is performed using Friedman's non-parametric method. The output of the Friedman test is displayed in table (7). Tables (7 to 9) are R software outputs.

Table 7. Friedman test results

Accident cause	Priority
Exceeding the safe speed limit	7
Turning and passing on the left	6.77
Failure to pay attention to the front	5.33
Other	3.5
Fatigue and sleepiness	3.67
Inability to control the vehicle	3.17
Failure to yield the right of way	2
Test Statistics:	
N=3, Chi-Square=17.750	
Df=6, Asymp. Sig.=0.009	

According to the result of Friedman's test, the table demonstrates the mean of the ranks and the accident factors. It shows that "exceeding the safe speed limit" with a mean ranking of 7 had the greatest effect on fatal accidents, and the two factors "failure to pay attention to the front" and " turning and passing on the left" are almost the same, and the factors "fatigue and sleepiness" and "lack of vehicle control" had similar effects. The principle of analysis according to the lower part of the table is that, according to the significance level of 0.009, it is highly significant at the first type error level of 0.05; that is, the effective factors in accidents are very different from each other. In the above-mentioned table, N is the number of data for each cause (years 2011, 2012, and 2013), the value of the chi-square statistic is 17.750, and the freedom degree of factors is 6 (the number of factors minus one). Furthermore, using Scheffe post hoc method, it is also possible to show which factors have the greatest effect on fatal accidents.

In the Scheffe post hoc method, the factors of exceeding the speed limit, unauthorized overtaking, turning to the left, failure to pay attention to the front, others, fatigue and sleepiness, inability to control the vehicle, and failure to yield the right of way are numbered from 1 to 7 signs, respectively. (Part of the output of this method is shown in Table 3). According to the mentioned table, the second column from the left side displays the mean difference, and each column with an asterisk means that it is significant at the first type error level of 0.05 and has a significant difference in influencing accidents. The third column from the left is the standard deviation of the mean difference, the fourth column is the significance level of the test, the fifth and sixth columns indicate the lower bound and the upper bound of the confidence interval for the mean difference at the 95% level, respectively. The columns of the mean difference and the significance level are consistent with each other, which means that wherever the significance level is greater than 0.05, the mean difference is less, and as a result, there is no asterisk. According to the significance level column (fourth column from the left) and the second row from the top, at the 0.05 level, factor 1 has no significant difference with factors 2 and 3; that is, the effects of factors 1, 2, and 3 are the same in accidents, but the factor 1 has a significant difference with the rest of the factors. The rest of the rows can be analyzed in the same way.

According to the mean ranks, Friedman's test, and Scheffe's post hoc test, it can be concluded that the three factors "exceeding the speed limit", "turning and overtaking on the left" and "failure to pay attention to the front" are the most important factors of fatal accidents on the province roads; therefore, these factors should be seriously considered and solutions should be provided to reduce the effect of these factors.

Table 8. The results of Scheffe post hoc method (for fatal-injury accidents)

Factors (I)	Factors (J)	Mean Difference (I-J)	Std.Error	Sig.	95% Confidence Interval	
					Lower bound	Upper bound
	2	*19.36788	3.12186	0.002	6.7895	32.5655
	3	*19.12456	3.12186	0.001	7.8959	32.8456
1	4	*24.56733	3.12186	0	11.3345	37.4578
	5	*26.14567	3.12186	0	13.4567	38.6984
	7	*25.34567	3.12186	0	12.1145	38.1145
	1	*-14.67566	3.12186	0.011	-28.5711	-2.7622
	2	4.34533	3.12186	0.876	-9.5711	16.2378
2	4	8.56784	3.12186	0.335	-5.2378	20.5711
	5	9.45678	3.12186	0.247	-3.5711	22.2378
	6	9.12346	3.12186	0.225	-4.2378	21.5711

* The mean difference is significant at the 95% confidence level.

In this section, it is examined whether there is a linear relationship between the number of accidents (dependent variable) and independent variables such as Exceeding the speed limit, failure to pay attention to the front, and etc. In Table (9), the significance level for the regression coefficients is almost zero (sig. =0.000); that is, the null hypothesis of the rejected coefficients indicates that there is a linear relationship between the factors and the number of accidents. In the following, the regression coefficient estimation output is elaborated to identify the most effective factor on the number of accidents.

Table 9. The regression relationship of accident factors with the number of accidents in the main roadways of Ardabil province

Accident Causes (Independent Variables)	Weighting Coefficients Beta	t	Sig.
Constant		0	1
Exceeding the safe speed limit	0.713	5.876	0
Turning and overtaking on the left	0.345	3.294	0
Failure to pay attention to the front	0.412	1.001	0
Fatigue and sleepiness	0.165	1.243	0
Inability to control the vehicle	0.112	3.123	0
Failure to yield the right of way	0.114	6.567	0

Table 9 rejects the zero y-intercept (constant... sig. =1); that is, according to the significance level of 1, 100% of the y-intercept is not zero. The assumption that the coefficients of other factors are equal to zero is also rejected due to their significance level, which are all less than 0.05; however, according to the estimation of the coefficients, it is clear that the two factors "turning and overtaking on the left" (unauthorized overtaking) and "exceeding the safe speed limit" have the greatest effect on accidents (the coefficient of exceeding is equal to 0.713). As the coefficients get closer to zero, the factor loses its effect and is completely unaffected at zero, and on the contrary, as it gets closer to 1, it has 100% effect. According to the coefficients (Beta), it can be concluded that in almost 70% of the cases, exceeding the speed limit was the contributing factor of the accident.

4.2. Accident Prediction Models for Two-Lane and Multi-Lane Roads based on HSM-2010

Based on information outlined in the Highway Safety Manual (HSM-2010) for two-lane suburban roads and according research methodology (section of 3 this research tables (1 to 5) and equations (7 to 11)), the Crash modification factors are as follows:

- Effect of Roadway Width

$$\mathrm{CMF}_{1\mathrm{RD}} = (\mathrm{CMF}_{1\mathrm{rA}} - 1) \times P_{\mathrm{RU}} + 1 = (1 - 1) \times 0.574 + 1 = 1 \quad (7)$$

- Effect of right shoulder width

$$\mathrm{CMF}_{2\mathrm{nd}} = 1.30 \times 1 = 1.30 \quad (8)$$

- Effect of horizontal curve (length and radius), presence or absence of clothoids
- Effect of horizontal curve, super elevation

$$\mathrm{CMF}_{4r} = 1.06 + 3 \times (0.06 - 0.02) = 1.18 \quad (9)$$

- Effect of longitudinal slope

$$\mathrm{CMF}_{5\mathrm{nd}} = 1.1 \quad (10)$$

- Effect of traffic control cameras

If the camera is installed sufficiently along the road, the factor value for all accidents is considered to be 0.93.

- Effect of lighting

$$\mathrm{CMF}_{4\mathrm{RD}} = 1 - [(1 - 0.72 \times p_{\mathrm{inr}} - 0.83 p_{\mathrm{pnr}}) \times p_{\mathrm{nr}}] = 1 \quad (11)$$

Based on information outlined in the Highway Safety Manual (HSM-2010) for two-lane suburban roads, accident prediction models for two-lane two-way suburban roads can be predicted as follows:

$$N_{\mathrm{predictedrs}} = (N_{\mathrm{spfrs}} \times C_r \times (\mathrm{CMF}_{1x} \times \mathrm{CMF}_{1x} \times \ldots \times \mathrm{CMF}_{1x})) \quad (12)$$

$$N_{\mathrm{spfrs}} = \mathrm{AADT} \times L \times 365 \times 10^{-6} e^{-0.312} \quad (13)$$

Where:

L= route length

AADT=Annual average daily traffic

Based on route specifications, for the desired section:

$$N_{\text{spfrs}} = 3441 \times 33.95 \times 365 \times 10^{-6} e^{-0.312} \quad (14)$$

$$N_{\text{spfrs}} = 42.64 e^{-0.312} = 31.24 \quad (15)$$

number of predicted accidents

where finally based on the modification factors of the equation, including the width of each lane, the width and type of road shoulder, the length and radius of horizontal curves and the presence or absence of connection curves, the super elevation in horizontal curves, longitudinal slopes, the amount of traffic congestion, the presence or absence of lighting as well as automatic speed control measures along the route, the numerical value of equation (9) regarding the number of accidents is calculated and predicted as follows:

$$N_{\text{predictedrs}} = (31.24 \times 1 \times 1.30 \times 1.0004 \times 1.18 \times 1.1 \times 0.93 \times 1) = 49.04 \quad (16)$$

$$N_{\text{predictedrs}} = (31.24 \times 1 \times 1.00 \times 1.0004 \times 1.00 \times 1.0 \times 0.93 \times 1) = 29.06 \quad (17)$$

In the case of only modifying the side shoulder and increasing it to 2 feet, removing the horizontal curve with a radius of 300 m, leveling the route, and reducing its slope, the number of predictable accidents will decrease from 49 to 29 (therefor: 2949=41% reduction), and if the road converts into a four-lane suburban highway, for suburban highways:

$$N_{\text{Predicted}} = (N_{\text{spfx}} \times (\text{CMF}_{1x} \times \text{CMF}_{1x} \times \ldots \times \text{CMF}_{1x})) \times C_x \quad (18)$$

$$N_{\text{spfx}} = e^{(a+b+\ln(\text{AADT})+\ln(L))} \quad (19)$$

The weight coefficients of the equation (19) are given in Table 10. Based on it and based on modification factors for lane width, shoulder width, median width, lighting, and control cameras, the number of accidents predicted and calculated for the mentioned four-lane highway is 16 accidents in a year. The result is shown in Table 11 based on accident statistics of the traffic police and Road Maintenance and Transportation Organization.

Table 10. Weight coefficients in the equation of predicting the number of accidents

Severity Level	a	b	c
4-lane total	-9.025	1.049	1.549
4-lane fatal and injury	-8.837	0.958	1.687
4-lane fatal and injury[a]	-8.505	0.874	1.740

Table 11. The effect of converting (K-Q section) road (55 km) into a 4-lane highway in the long term on the number of accidents

Title	Number	% Reduction
The number of observed accidents in 2019	24	34
The number of accidents on the highway according to prediction models	16	

Therefore, the conversion, necessary measures, and geometrical modifications in the mentioned two-lane route will reduce the number of fatal accidents from 49 to 29 (41% reduction), and if the entire 55-km road is converted into a four-lane highway, as shown in Table12, the reduction will be 34%.

4.3. Analysis of Fatal Accidents for the Main Roads of the Province

In this section, based on the verified statistics and information of fatal and injury accidents, where the GPS[2] coordinates of the accident location and the general and geometrical shape of the location (three way - access - curve - straight path and straight with continuous line - residential area (city or village) and before reaching the curve and...) a general analysis and classification was conducted for 192 fatal accidents recorded for the three years 2018 to 2020 of the main roads of the province: Ardabil-Astara, Ardabil-Meshkinshahr, Ardabil-Sarab,

[2] Global Positioning System

the three -way section of Sahra-Garmi, Meshginshahr- Parsabad, Parsabad-Jafarabad, Parsabad- Aslan Duz, Meshginshahr-Ahar (source: accident statistics of the traffic police and Road Maintenance and Transportation Organization). Moreover, Data analysis and classification of the accident type, collision type, accident location, accident time, accident cause, weather and lighting conditions during the accident were accomplished in terms of their number and fatal and injury accidents. Furthermore, the geometric characteristics of the location of fatal accidents on the province's transportation roads have been implemented on the GIS[3] system (Figure 2). Tables 12, 13, and Figure 2 show the results of the classifications.

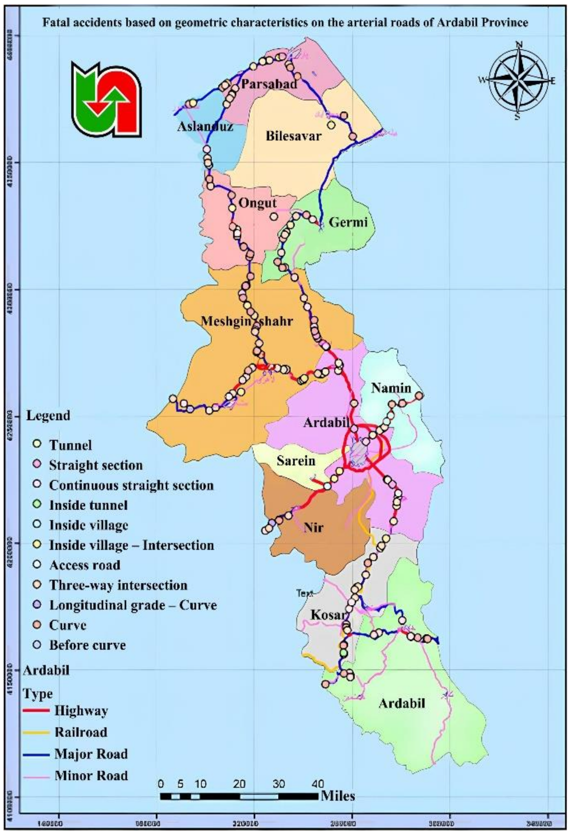

Figure 2. Geometric characteristics of accident location on the GIS system for the main roads of the province

[3] Geographic information system

Table 12. The frequency of accidents based on different parameters (192 cases for the main roads of Ardabil province - years 2018 to 2020)

parameter	detail	number
accident time	02:00 to 00:00	12
	04:00 to 02:00	8
	06:00 to 04:00	7
	08:00 to 06:00	9
	10:00 to 08:00	14
	12:00 to 10:00	11
	14:00 to 12:00	15
	16:00 to 14:00	28
	18:00 to 16:00	25
	20:00 to 18:00	26
	22:00 to 20:00	23
	24:00 to 22:00	14
Type of accident	fatal accidents	192
accident site	three way	81
	access	5
	curve	56
	straight path and straight with continuous	26
	residential area (city or village)	20
	Before the curve	2
	Other	2
how to deal	head-on	78
	rear-end	16
	Front-to-side accident	25
	Side by side accident	1
	overturning	45
	Other	27
Lighting	Day	115
	night	77
Vehicle collision	A vehicle accident	92
	Multi-vehicle accident	25
	Pedestrian collision	13
	Collision with an obstacle	2
	Motorcycle or bicycle	8
	Other	51
weather conditions	Clear	124
	foggy	2
	cloudy	47
	rainy	13
	snowy and blizzard	6
cause of accidents	Exceeding safe speed limit	35
	Turning and passing on the left	93
	Failure to pay attention to the front	28
	Fatigue and sleepiness	24
	Inability to control the vehicle	1
	Failure to yield the right of way	2
	Other	9

Table 13. The frequency of vehicles at-fault in accidents (192 cases for the main roads of Ardabil province - years 2018 to 2020)

Vehicle types / Occurred accidents	Car	Bus	Truck	trailer truck	RV	Motorcycles	Tractor	Unknown	Total
Main roads	141	1	10	4	31	2	2	1	192

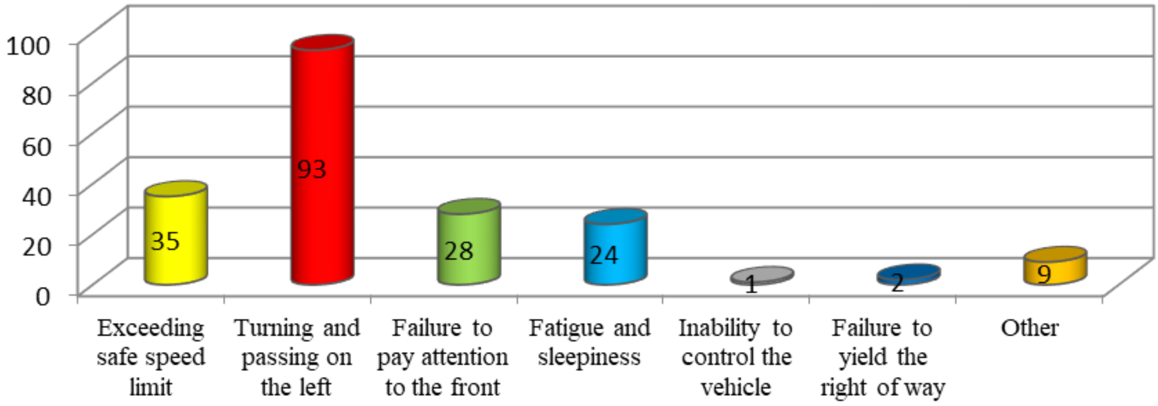

Figure 3. Frequency of the cause of accidents on all the main roads

As shown in Table 12 and Figure 3, the hours of the accident (14:00 to 22:00), the place and location of the accident (three-way, curve and continuous straight path), the manner of collision (head-on collision), weather conditions (clear weather), the leading cause of the accident (turning and overtaking on the left, exceeding the safe speed limit, failure to pay attention to the front, fatigue and sleepiness), the type of vehicle at-fault in the accident (car and its types) and the traffic volume (daily and hourly traffic statistics, accident rates based on million traffic per hundred kilometers of road) have played the most substantial role in the number of accidents leading to death. In the following, accidents on two important roads are analyzed.

4.4. Analysis of Accidents for the Main Roads of "Ardabil-Meshkinshahr" and "Kangarlu- Sarband Three-Way Section"

4.4.1. Analysis of Accidents for the Road of "Ardabil-Meshkinshahr"

The length of this road from Ardabil to the main entrance of Meshkinshahr is about 85 km, the first 25 km of which up to the three-way section of Sahra is separated as a four-lane highway, and before 2020, the road from the three-way section of Sahra to the three-way section of Meshkinshahr, about 40 km in length, was the main two-lane two-way with an average width of 11 to 12m. Last year, about 25 km of it were converted into a separated four-lanes. Before 2019, the road from three-way section of Meshkinshahr to the city entrance, about 20 km in length, was turned into a separated four-lane. Considering the statistics of fatal accidents before and after the highway construction in the area of Sahra three-way section to Arbab Kandi (Table 6), the effect of converting the mentioned section into four-lane highway on the statistics of fatal accidents (before and after construction) has been analyzed. Due to having 28 fatal accidents, it is one of the accident-prone roads of the province, and from the total of 28 fatal accidents over the last three years for the mentioned road, it can be written: accidents were scattered at different hours of the day and night, with the highest frequency between 18:00 and 20:00. Three-way intersection with 64% accounts for the largest share in the place of accidents, indicating the need to focus on the safety of intersections and related accesses, as well as control and application of the rules and regulations. Regarding manner of collisions, according to the information in table (12), heads-on collisions accounts for 35% of the accidents, which mostly occurred during the day and in clear weather, and overturning with 32% has the second frequency, which considering the 43% turning to the left, it can be said that the speeding and unauthorized overtaking are the main factors of the accidents on this roadway. If accident statistics and information on the four-lane sections of this road are available, a proper before-and-after study can be done in this regard. The approximate length of the road from Ardabil to Meshkinshahr is 85 km. The total vehicle traffic over the three years on this road was 33,293,371 vehicles (as a round trips, source: accident statistics of traffic police and Road Maintenance and Transportation Organization of the province).

Table 14. Statistics of fatal accidents before and after the highway construction in the area of the three-way section of Sahra to Arbab Kandi

Statistics of fatal accidents in the area of three-way section of Sahra- Arbab Kandi, before and after converting into the highway			
Manner of collisions	Number of fatalities	Number of fatal accidents	year
Two cases overturning + one case head-on	3	3	2020
Two cases overturning + two case head-on	4	4	2013
Four cases head-on + two cases rear-end + one case overturning	12	7	2012
One case head-on	4	1	2011

As shown in Table (14), according to the accident record, the total number of fatal accidents in terms of the accident record, before the highway construction in the area of three-way section of Sahra to Arbab Kandi, for the years 2011 to 2013 was 12 cases, an average of 4 cases per year. The recorded number was 3 cases for 2020 (after the highway construction). On the other hand, 20 people were killed in 12 accidents before the highway construction, an average of 7 people per year. However, after the construction of the highway, only 3 deaths were recorded in 3 cases of accidents, and it shows a reduction of more than 50% compared to before the highway construction. The analysis of manner of collisions in the last column of the table for before and after the highway construction also confirms that in 2011 to 2013, there were 7 cases of head-on collisions caused by turning to the left (for overtaking), this collision manner has been completely eliminated due to the highway construction, and only one case of front-side accident (probably at the three-way intersection) and two cases of overturning have been recorded. This issue indicates the importance of highway construction in reducing the number of accidents to less than 50% of the previous one, as well as reducing the severity of accidents and the number of deaths in each accident due to the elimination of head-on collisions.

4.4.2. Analysis of Accidents for the Road of "Kangarlu- Sarband Three-Way Section"

This road from the three-way section of Kangarlu to Sarband, about 130 km in length, is the most significant and longest road under study in the field of protection of the province. Considering that this road is mostly passing through the plain and plain of Mughan, high driving speed and narrow width of about 7.5m in the majority of the sections leading up to three-way section of Sarband make it the most accident-prone road in the province. This issue highlights the need to address the road and take into account the various human, traffic, and geometric factors contributing to accidents on this road.

Due to having 45 fatal accidents, it is the most accident-prone road in the province, and from the total of 45 fatal accidents over last three years, it can be written for the mentioned road:

Accidents occurred at different hours of the day and night. However, the maximum time period for accidents on this road is between 14:00 and 16:00 and then 18:00 to 22:00. 40% of the accidents occurred at curves and more than 30% of them occurred at intersections (three-way) (16 cases). Head-on accidents, with 47%, have the highest frequency in the manner of collision, caused by the turning to the unauthorized left, and are entirely consistent with the statistics of 21 cases related to the cause of accidents. A single-vehicle collision, with 73%, has the highest frequency on this road, and overturning accounts for 18% of the accidents. Moreover, most of accidents on this road occurred in clear weather (64%) and in daylight, which is normal considering the weather conditions of the region, and confirms the reasons for speeding and illegal overtaking. Therefore, widening the road up to the three-way section of Sarband, as well as imperceptible and perceptible control and mechanization of speed and violations, as well as revising the vertical and horizontal signs of the route and the use of transverse rumble strips to reduce speed before reaching curves and intersections, as well as the longitudinal type of these on the continuous line of the road axe can be effective short-term and medium-term solutions. The analysis resulting from the segmentation of this route indicates that the 50 km section located on (K-Q section) has a higher number of accidents, and highlights the need to focus on this section as the first priority. The approximate length of the road from the three-way section of Kangarlu to Sarband is 130 km. The total vehicle traffic over the three years on this route was 28,930,771 vehicles (as a round trip, source: accident statistics of traffic police and Road Maintenance and Transportation Organization of the province).

4.4.3. Analysis of Accidents Based on Prediction Models - (Case Study of K-Q Section)

In this section, the predication models of the number of accidents based on the Highway Safety Manual (HSM) are examined. The influencing parameters of traffic, geometric and lighting conditions, as well as the application of rules and control of driving violations are considered. Moreover, the effectiveness of each in reducing accidents is examined and evaluated.

Given that the Ardabil-Mughan road in the north of the province has been the most accident-prone over the last three years in terms of the number of fatal and injury accidents, and the 55-km section from Kangarlu to Qarah Aghaj (K-Q section) has been the most accident-prone, with over 20 fatal accidents in 2019, therefore, that section is investigated as a case study for predicting accidents. Figures 4 and 5 illustrates some sections of the route and aerial map.

Figure 4. some sections of (K-Q section) road at the intersection and straight line and its geometric conditions and road markings

Figure 5. (K-Q section) road on aerial map

Table 15. Ardabil-Mughan road accident statistics

Sections name	Section length (km)	Fatal accidents		Injury accidents	
		Number	Number of deaths	Number	Number of injured
Ardabil-Kangarlu	76	6	6	14	15

Sections name	Section length (km)	Fatal accidents		Injury accidents	
		Number	Number of deaths	Number	Number of injured
Kangarlu-Qarah Aghaj	55	9	20	15	25
Qarah Aghaj-Sarband	75	4	7	6	7
Sarband-Parsabad	23	3	3	5	5

Table 16. Annual and daily traffic volume of K-Q section and traffic prediction for 2024 (traffic growth: 4%)

	(K-Q section)			(Q-K section)		
	Total annual traffic (vehicle)	Car traffic	Average daily traffic (Vehicle)	Total annual traffic (Vehicle)	Car traffic	Average daily traffic (Vehicle)
2019	1185459	993763	3441	1232532	1034203	3547
2020 (5 months)	485393	405671	3203	508402	425929	3355
2024			4186			4315

4.4.4. Effect of Geometric Characteristics Modifications and Control Measures on Accident Frequency

Based on (4.4.1 to 4.4.3) sections of this study, figure 6 shows the relationship between the causes of accidents and their frequency for the years 2018, 2019, and 2020 on the main roads of the Ardabil province (Accident statistics of traffic police and road maintenance and transportation organization).

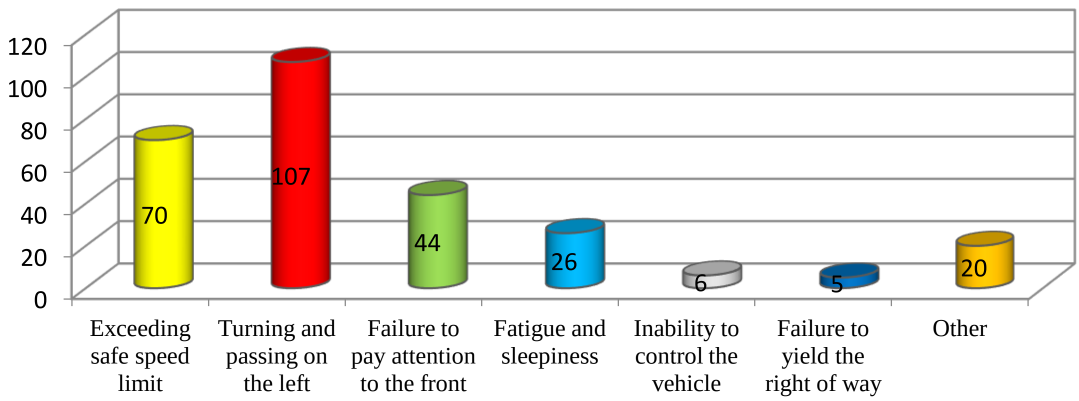

Figure 6. The frequency of fatal accidents for the years 2018 to 2020 in the studied roadways of Ardabil province

5. Discussion and Conclusion

In the present research, the collection of accident statistics and information from 2018 to 2020 and its verification with the location of the accidents and the accurate recording of the geographic coordinates of the location of accidents in UTM format, as well as the analysis of information, have been conducted based on different statistical methods for all the main roads of the province, in general, and separately. In addition, based on accident prediction models, with a special focus on geometric modifications in the width of the roadway and shoulders, reducing the amount of curvature of the curves and the slope of the routes, as well as speed control measures and lighting provision, it was observed that the number of accidents significantly decreases. In this research, several tests and statistical analyses were employed using R statistical software.

The obtained results indicate that the main causes of fatal accidents on the roads of Ardabil province are "turning and overtaking on the left," "failure to pay enough attention to the front," and "exceeding the safe speed limit." "Fatigue and sleepiness" are the next causes of fatal accidents.

Increasing the roadway width, eliminating curves with a radius less than 300 meters, reducing longitudinal slope, and applying banking and enforcing regulations including both visible and invisible speed control, they have a significant impact. The three-way roadways of Sahra-Garmi, Parsabad-Aslandooz, and Parsabad-Jafarabad have the highest accident severity index among the nine main roads of the province, respectively. Despite having the highest number of deaths in the last three years, the Meshkinshahr-Parsabad road has a lower index than other roads due to its longer length. However, the 55-km section of (K-Q section) has the highest number of accidents on this 130-km road. This highlights the need to focus on segmenting routes and further studying the geometric and traffic characteristics of the roads.

Furthermore, in the short and medium term, geometric modifications, including shoulder construction (creating a paved shoulder) and changing the width of the road from 7.30 m to 11 m (including asphalt shoulders), as well as providing lighting, and controlling the roadway with cameras, can reduce the number of accidents by 40% on a two-lane two-way road. In the long term, converting two-lane two-way roads into four-lane roads can reduce the number of accidents by 34% and completely eliminate head-on collisions.

Moreover, it should be noted that the mentioned analysis and the results are based solely on the available verified statistics and information and the parameters recorded in the columns of the accident registration form and focus more on human factors. Therefore, addressing the environment, the road (conditions governing the road and effective geometric factors and pavement conditions), and vehicle factors requires more detailed field and analytical studies, a precise survey of the current situation, and more detailed information about accidents. Due to limited access to data in terms of type and number of accident records, this research used regression methods and R statistical software. Obviously, with access to more precise base information with more detailed accident counts and severity, machine learning-based methods could be employed.

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