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# Evaluating the effects of external factors on pedestrian violations at signalized intersections (a case study of Mashhad, Iran)

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A B S T R A C T

One of the most critical reasons for accidents involving pedestrians in signalized urban intersections is their violations regarding running red lights. Therefore, studying the essential factors in this issue is of interest to researchers. This research aims to evaluate the external factors affecting the pedestrians' violation, specifically, factors regarding the geometrical design and traffic situation. Cameras recorded the behavior of 1590 pedestrians in 10 crosswalks of 6 intersections in Mashhad. Afterward, the effect of 12 distinct variables for each pedestrian was assessed. To analyze the data, SPSS was used in combination with binary logistic regression. Out of the nine variables participated in the model, "traffic volume", "the number of violators", "length of the crosswalk", "red light duration", and "physical movement problems" affect the pedestrians' decision to comply with or violate a red light. The analysis shows that with an increasing number of vehicles, the probability of violation would reduce by 9.5%. Moreover, if the number of other violating pedestrians grows, the probability of violation would increase significantly. The increase of one unit in "length of the crosswalk", would result in a violation reduction of 13.9%. Also, if the pedestrian suffers from physical disabilities, the probability of violation decreases by 78.6%. On the other hand, the growth of one unit in "red light duration" would increase the violations by pedestrians 2.2%.


## 1. Introduction

Safety concerns affect people's decisions in choosing the mode of transportation. Pedestrians are the most essential and vulnerable users of the transportation system, and the damages inflicted upon them in accidents are far higher than other users [1]. The ever-increasing growth of the urban population in developing countries highlights the safety-related issues of pedestrians. It was concluded that every 1000 increase in population would result in a 1.4% increase in pedestrian accidents [2]. The traffic accidents in Iran, like many other developing countries, is critical. For instance, according to The 12th Transport Statistics of Mashhad City was published by Mashhad Transportation and Traffic Organization, 56% of the accidents' fatalities and 31.3% of accidents' injuries were pedestrians in Mashhad in 2016. Comparatively, only 16% of total traffic fatalities were pedestrians in the U.S. in 2016 [3].

Among the most accident-prone spots in which there is a high degree of conflict between pedestrians and vehicles are the intersections, especially four-way intersections [4]. Accidents and safety issues of pedestrians in intersections have always attracted researchers' attention due to the frequent interferences, many turning movements, and high volume of traffic. Pedestrians running red lights are one of the most important causes of traffic accidents involving a pedestrian [5].

Some of the international studies correlate the majority of pedestrian accidents in signalized intersections with pedestrians crossing while the light is green [6]. However, accidents also happen when pedestrians try to run the red light. Thus investigating the crossings during red light must not be overlooked [7].

Moreover, the accidents' injuries for the pedestrians who run red lights are more severe [6]. Also the way in which violating pedestrians interfere with vehicles' path is different than those who abide the traffic signal. That is, individuals who cross the street during red light interfere with vehicles which are on a straight course with higher speed, whereas the non-violators mostly cross path with turning vehicles at lower speed.

Therefore, this research focuses on the safety of pedestrians in signalized urban intersections in order to investigate the circumstances in which the pedestrians' red-light violations are made and present solutions for alleviating this issue.

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This study analyzes the pedestrians' behavior concerning red lights in order to develop a model for predicting their behavior. Consequently, the model helps to provide solutions to reduce the frequency of violations.

## 2. Literature review

Numerous factors affect pedestrians' violations. According to previous studies, such factors can be categorized into four groups: factors regarding personal properties, psychological factors, environmental factors, and factors regarding traffic and geometry (Fig. 1). This study is concerned with the latter two groups. Therefore, personal factors— such as gender, age, level of education— and psychological factors— such as attitude, subjective norm, perceived risk, and conformity tendency — were not included.

In investigating the factors affecting pedestrians' delinquencies, there is a particular emphasis on the external factors which influence their behavior. Pedestrians have significant differences in their attitude and mental state. Naturally, these psychological backgrounds would have substantial effects on pedestrians' behavior. However, This research leaves the questions regarding psychology to psychological experts, and assesses the external factors affecting the pedestrians' behavior. Here, external factors are such as traffic properties, geometrical design of intersections, etc. Also, some studies showed that current situational factors are more effective in violation of pedestrians compared to the psychological background [8].

Pedestrians' physical abilities were the core subject of discussion for many of the previous studies. Regardless of age, individuals with physical disabilities, and those who carry heavy belongings show less illegal behaviors [2]. People with kids usually are more careful in crossing the street [9]. In China, 77% of the pedestrians would not run a red light if they are accompanied by children or elderlies [2]. These individuals would like to protect their fellow and demonstrate less risky behaviors.

Concerning geometry and traffic situations, one of the most critical factors affecting the pedestrians' behavior may be traffic volume [10]. It has been observed that pedestrians tend to run red lights in low traffic volumes. The higher is the traffic volume (irrespective of the gap), the lower are pedestrians violations [11,12]. Moreover, the effect of vehicle speed should be taken into account. A study in China has revealed that the higher is the speed of the vehicle and the gap between vehicles, the more likely it is that the pedestrians commit violations. The researchers expressed that this behavior is related to the failure of passing vehicles' speed detection. [13].

Not only could the vehicular volume impact pedestrians' behavior, but also their gap may matter. This variable is some seconds, which takes until the next vehicle passes the zebra crossing. Hamed [9] has displayed that pedestrians would use an increase in the gap to cross, and the risk rate would substantially grow as well. Duduta, Zhang, and Kroneberger [11] have considered the vehicles' gap as the most critical traffic factor affecting pedestrians' violations.

Most of the violating pedestrians are aware of the dangers of the running red lights [14], although studies have indicated that the convenience in crossing the intersection plays a role here. The longer the pedestrians wait for the green light, the less convenient they feel [15]. In their modeling, Duduta, Zhang, and Kroneberger [11] showed that there is less compliance with the law within intersections with long

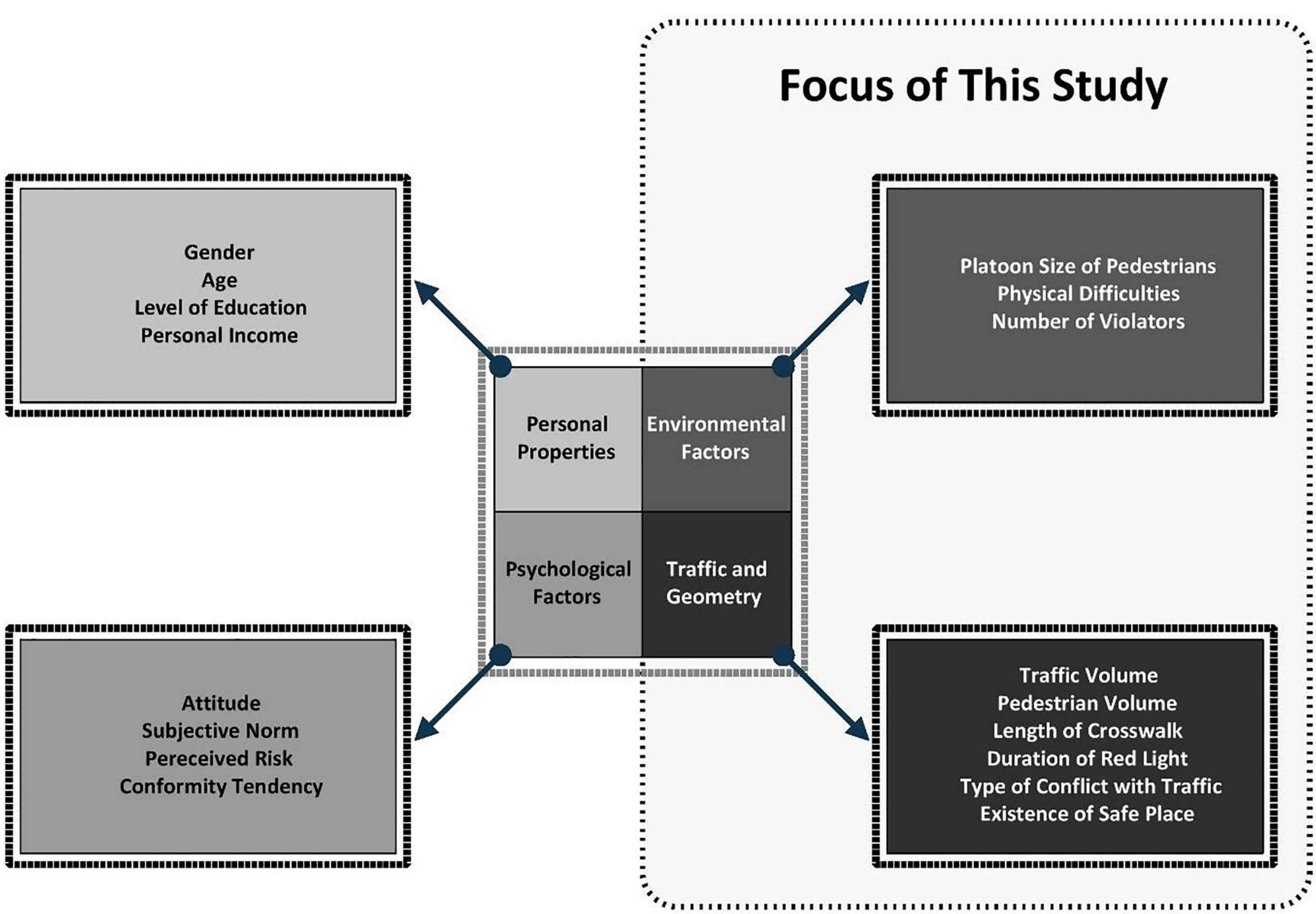


**Fig. 1.** The factors affected pedestrians' violation in a signalized intersection.

cycles and long crossing time. Similarly, other studies have confirmed that an increase in waiting time for the green light would mean more pedestrian violations [16,17]. Some findings pointed out that the duration of red light is the most significant external factor affecting the pedestrians' violation [13].

In Canada, Brosseau, Saunier, Le Mouel and Miranda-Moreno [16] indicated that if the clearance phase (lost time or the time during which all the vehicles are prohibited to cross) takes longer than the time needed for the pedestrians to cross, there will be significant growth in pedestrians' violations. Moreover, Zhuang, Wu, and Ma [18] found that most pedestrians (approximately 85%) cross the street when they arrive at the clearance phase. This issue becomes important when they realize that almost 8 out of 10 of the violators cannot reach the sidewalk before the beginning of red light.

This issue is also right concerning the length of the crosswalk. Longer crosswalks are expected to impede individuals from crossing. In other words, people are less interested in crossing intersections with long crosswalks [11,13]. Besides, research has asserted that with a one-meter increase in cross walk's length, there will be a 3% to 5% increase in pedestrian accidents [11]. As a result, a complex issue arises: shorter crosswalks would increase the probability of pedestrians' violations, and longer crosswalks would add to accidents. Also, pedestrians' decision is affected by the types of the road [19].

In certain intersections, the pedestrians' light remains red, mainly due to the possible collision between the pedestrians and the left-turning vehicles coming from other legs. A study has claimed that pedestrians are more likely to run red lights during this particular period [11].

As mentioned, some studies are investigating the factors affecting pedestrians' violations in signalized intersections. However, it would be of interest to also take into account the geometry and traffic situation within a local context. Moreover, this subject has not been explored much in the country of the study, Iran.

## 3. Method

This research's goal is to measure the effect of geometrical design and traffic factors on pedestrians' violations in signalized intersections. In this regard, six intersections in Mashhad were selected. Mashhad is the second-most populous city in Iran, with more than three million population. This city is the capital of Khorasan Razavi Province and located in the northeast of Iran.

The selections of the intersection were made with the intent to reflect different traffic volumes as well as different pedestrians' volumes. Therefore some of the selected intersections are near downtown, and some of them are far from crowded areas. Fig. 2 shows the location of selected intersections in the map of Mashhad city. The intersections consist of 1. *Imam* Khomeini-Modares, 2. Ebne Sina-Daneshgah 3. Ahmad Abad 4. Sanabad-Rahnamayi 5. Khayyam-Sajad, and 6. Moalem-Daneshjoo. (See Figs. 3 and 4.)

**Fig. 2.** The location of selected intersections on the map.

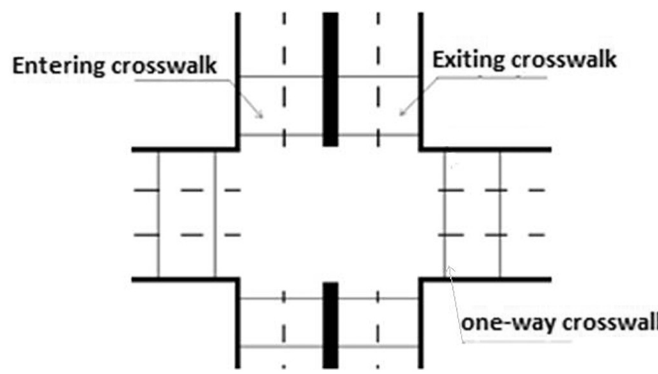


**Fig. 3.** A hypothetical intersection.

After field investigation, ten crosswalks from the intersections mentioned above were chosen for further analysis. The properties of the crosswalks included in this study are presented in Table 1. In this figure, a crosswalk that meets with incoming traffic to the intersection is defined as “Entering crosswalk” for a two-way street. Additionally, an “Exiting crosswalk” is defined as a crosswalk that meets with clearing traffic. For one-way streets, all crosswalks are labeled as “one-way crosswalk” (Figure).

In exiting crosswalks, the signal's cycle usually shows two red lights; once to prevent mixing pedestrians with vehicles through movement and once for avoiding mixing pedestrians with turning vehicles. That is why in Table 1 there are two red light durations for exiting crosswalks.

The next step was to gather data from the selected crosswalks. Since pedestrians' behavior towards red light was outstanding, there was no need to collect data about their reaction to green light. To obtain the data, the study used video records of the intersections taken on a business day in the middle of the week, which did not coincide with any special occasion. These records contained one hour of footage, from 18:00 to 19:00. Considering that pedestrians behave differently when faced with unusual weather conditions, the study had similar light conditions, temperature, and weather throughout the recording session in all of the crosswalks.

The cameras used to record the pedestrians had high-quality recording ability with a 720 by 1280-pixel resolution and an aspect ratio of 16:9. Consequently, the screen could be zoomed in without considerable loss of detail whenever necessary. The recording took place with 25 frames per second, which enabled the study to measure the exact moment of incidents and durations. As seen in Figure, these cameras were planted in such a way to cover parts of sidewalks and the traffic.

Table 2 summarizes all of the measured criteria in this research, along with a short description. All of the explanatory variables used to predict the dependent variable are indicated in a separate row. Due to the lack of software for extracting the data from the footage, it was collected manually.

Logistic regression was used to analyze the data and develop a prediction model for pedestrians' behavior. The aim of Logistic Regression is finding a model that best fits the relationship between a response variable and predictor(s) while having the least amount of predictors. In Linear Regression, the dependent variable must be quantitative and also of ratio or at least interval measurement level; however, the dependent variables in this research are qualitative and of nominal measurement level. A pedestrian's behavior towards the red light is


**Fig. 4.** An example of each camera's angle.

qualitative and binary, meaning the pedestrian either violate the red light or does not.

To identify the factors predicting the changes of a nominal variable, Logistic Regression can be used. This method, which first was presented in the 60s, is an alternative to Linear Regression and also Discriminant Analysis [20]. The dependent variable in this research can only have 0 or 1 values, as complying with the light and violating the light. As a result, linear models would not produce accurate results; Logistic models may have superior performance and are preferred in this study.

The general form of logistic models is represented in eq. (1). Logistic regression first transforms the dependent variable to a logit variable (2) — which is a natural logarithm of the odds that Y equals one of the categories — and then uses the maximum likelihood estimation to obtain the coefficients (1) [21]. In eq. (2), π is the likelihood a pedestrian violates red light, 1- π is the likelihood a pedestrian wait for the green light. $\beta_i$ is the estimated coefficient, and $X_i$ expresses the explanatory variables affecting the pedestrian's violation.

$$\pi = P(X) = \left(\frac{exp\,(\alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_x X_x)}{1 + exp\,(\alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_x X_x)}\right) \tag{1}$$

$$logit(Y) = ln\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_x X_x \tag{2}$$

## 4. Results and discussion

The outcome of statistical software is briefly presented here. The data collected from the aforementioned intersections took 1 h. Consequently, 10 h of footage was obtained, out of which the data relating to 1590 unique pedestrians became available.

Table 3 contains information regarding pedestrians at each intersection. As represented, about 34 to 636 persons reach the intersections when the pedestrian light is red. The least compliance with the light was among the pedestrians passing the existing crosswalk of *Imam* Khomeini-Modares intersection on the north; only 12.4% of the pedestrians waited during the red light. On the other hand, most compliance with the light was observed in the northern crosswalk of Khayyam-Sajad intersection, showing 91% waiting during the red light. Overall, more than 54.2% of the pedestrians were abiding the light's command. Also, Tables 4 and 5 present a summary of the collected data.

In order to conduct analytical statistics and modeling, the dependent and explanatory variables were entered into the software under logistic regression. Before starting the model, a correlation matrix for all explanatory variables was created. All coefficients are less than 0.8, so the regression model can be started without a multicollinearity problem.

**Table 1**
Properties of selected crosswalks.

| Intersection name | Crosswalk name | Length of the crosswalk (meters) | The width of the median (meters) | Duration of pedestrians' red light (seconds) |
|---|---|---|---|---|
| *Imam* Khomeini-Modares | North-entering | 8 | 0.1 | 77 |
| | North-exiting | 10.6 | 0.1 | 77 and 24 |
| | East (one-way) | 11.2 | 0 | 32 |
| Ebne Sina- Daneshgah | West (one-way) | 11.9 | 0 | 39 |
| Ahmad Abad | East (one-way) | 14.7 | 8.4 | 83 |
| Sanabad-Rahnamayi | West (one-way) | 15.7 | 0 | 45 |
| Khayyam-Sajad | North-entering | 15.4 | 2.5 | 26 |
| | North-exiting | 11.9 | 2.5 | 34 and 27 |
| Moalem-Daneshjoo | South-entering | 13.3 | 1.5 | 31 |
| | South-exiting | 9.1 | 1.5 | 39 and 27 |

**Table 2**
Variables description.

| Usage | Variables name | Variables description |
|---|---|---|
| Dependent Variable | P.Decision | Pedestrians' decision towards the red light (cross on red / wait for green). Violation = 1, or staying for green light = 0. |
| Explanatory Variables | Platoon | Platoon size of pedestrians (number of people). This variable is defined as the number of people who make a decision together. |
| | LackP.Ability | If pedestrians with lack of physical abilities or carrying a baby or heavy load. With difficulties = 1, or without difficulties = 0 |
| | T.Volume | The number of vehicles crossing the crosswalk during the red light phase (number of vehicles per lane per minute). This variable is defined as the average number of vehicles that passed through the crosswalk from each lane in one minute. |
| | P.Volume | The number of pedestrians arrives at the crosswalk during the red light phase (number of people). |
| | ViolatorNo | The percentage of violating pedestrian during the red light phase (under 25% = Low or 0, between 25% and 50% = Medium or 1, between 50% and 75% = High or 2, more than 75% = Very High or 3). |
| | CrossWalkLen | The length of the crosswalk (meter). |
| | RedLightDur | The duration of the red light phase (second). |
| | Conflict | The type of conflict with passing traffic (through traffic / other side traffic / left turn traffic). |
| | Safe.P | The existence of a safe place after violation. The pedestrian is able to reach a safe place (sidewalk or median with a length of 1.5 m or higher) = 0, or not = 1. |

**Table 3**
Number and behavior of pedestrians according to the intersection.

| Crosswalk name | Total vehicle volume (1 h) | Pedestrians' behavior | | Total pedestrian volume |
|---|---|---|---|---|
| | | Wait for green | Cross on red | |
| *Imam* Khomeini-Modares North-entering | 1068 | 38<br>20.8% | 145<br>79.2% | 183 |
| *Imam* Khomeini-Modares North-exiting | 1254 | 29<br>12.4% | 205<br>87.6% | 234 |
| *Imam* Khomeini-Modares East (one-way) | 1196 | 69<br>73.4% | 25<br>26.6% | 94 |
| Ebne Sina- Daneshgah West (one-way) | 1512 | 401<br>63.1% | 235<br>36.9% | 636 |
| Ahmad Abad East (one-way) | 2525 | 49<br>81.7% | 11<br>18.3% | 60 |
| Sanabad-Rahnamayi West (one-way) | 2172 | 141<br>72.7% | 53<br>27.3% | 194 |
| Khayyam-Sajad North-entering | 1612 | 31<br>91.2% | 3<br>8.8% | 34 |
| Khayyam-Sajad North-exiting | 1237 | 30<br>76.9% | 9<br>23.1% | 39 |
| Moalem-Daneshjoo South-entering | 1575 | 42<br>82.4% | 9<br>17.6% | 51 |
| Moalem-Daneshjoo South-exiting | 1327 | 32<br>49.2% | 33<br>50.8% | 65 |
| Total | 15,478 | 862<br>54.2% | 728<br>45.8% | 1590 |

The first output of the software analysis of the Logistic Regression Model is the case processing summary. The result presents the number of cases that are included in the model. Out of 1590 data points regarding pedestrians, all of them were analyzed, and there were not any excluded due to missed and unknown values.

The dependent variable (pedestrian behavior) is encoded, '0' for 'waiting for green light' and '1' for 'crossing on the red light'. Also, four categorical variables are encoded in the model. Considering type of conflict variable, 'through traffic' assumed as the reference category while it does not have parameter coding. 'Other side traffic' and 'left turn traffic' are labeled 'Conflict (1)' and 'Conflict (2)', respectively. In the encoding of the existence of safe place variable, '1' is referred to Yes (existence of a safe place after violation), and '0' is referred to No. Lack of physical ability is encoded too, '1' for pedestrians who are with physical movement problems and '0' for others. Finally, the number of violator variable is encoded into four categories. 'Low' assumed as the reference while 'Medium', 'High' and 'Very High' are labeled 'ViolatorNo(1)', 'ViolatorNo(2)', and 'ViolatorNo(3)', respectively.

**Table 4**
A summary of obtained data (quantitative variables).

| Pedestrian behavior | | Platoon | T. Volume | P. Volume | CrossWalkLen | RedLightDur |
|---|---|---|---|---|---|---|
| Wait for green | Mean | 0.930 | 11.598 | 8.894 | 12.499 | 42.809 |
| | S.D. | 2.079 | 3.451 | 7.301 | 2.012 | 14.517 |
| | Skewness | 5.791 | 1.735 | 0.933 | 0.109 | 1.826 |
| | Kurtosis | 36.325 | 4.049 | −0.096 | −0.252 | 2.457 |
| Cross on red | Mean | 0.598 | 10.697 | 7.556 | 10.957 | 52.181 |
| | S.D. | 0.750 | 2.921 | 6.005 | 2.059 | 20.905 |
| | Skewness | 2.380 | 0.961 | 1.046 | 0.450 | 0.234 |
| | Kurtosis | 10.492 | 2.529 | 0.310 | 0.238 | −1.660 |
| Total | Mean | 0.778 | 11.185 | 8.282 | 11.793 | 47.100 |
| | S.D. | 1.621 | 3.250 | 6.770 | 2.173 | 18.329 |
| | Skewness | 6.942 | 1.510 | 1.023 | 0.193 | 0.909 |
| | Kurtosis | 57.295 | 3.985 | 0.204 | −0.250 | −0.694 |

**Table 5**
A summary of obtained data (qualitative variables).

| Variable | | Observed percentage | Pedestrians' behavior (% of total) | |
|---|---|---|---|---|
| | | | Wait for green | Cross on red |
| Conflict | Through traffic | 78.7% | 48.5% | 30.3% |
| | Other side traffic | 13.1% | 3.7% | 9.4% |
| | Left turn traffic | 8.2% | 2.0% | 6.2% |
| Safe.P | No | 16.5% | 5.3% | 11.3% |
| | Yes | 83.5% | 48.9% | 34.5% |
| LackP.Ability | No | 95.3% | 50.4% | 45.0% |
| | Yes | 4.7% | 3.8% | 0.8% |
| ViolatorNo | Low | 43.4% | 41.0% | 2.4% |
| | Medium | 15.8% | 9.2% | 6.6% |
| | High | 7.9% | 3.0% | 5.0% |
| | Very High | 32.9% | 1.1% | 31.8% |

The Omnibus test results assess the performance of logit regression. According to the Omnibus test results, significant at the error level is less than 0.01 (error level = 4.1218E-264). Moreover, the chi-squared value is 1267.893, with 12 degrees of freedom.

The −2 Log-likelihood (−2LL) and pseudo-$R^2$ values are presented in The Model Summary Table. Comparing the -2LL value for the full model (925.009) to the -2LL for the null model in the 'omnibus test results', the model with explanatory variables is better than the baseline model significantly. The approximate variation in the outcome explained by the model can be found by the $R^2$ values. The Cox & Snell (0.550) and Nagelkerke $R^2$ (0.734) values tell that around 55% and 73% of the variation in the outcome are explained by the model, respectively.

The Hosmer-Lemeshow goodness-of-fit statistic (Chi-square = 8.074, df = 8, Sig. = 0.426) claims that the predictability's fitness of variations of the dependent variable is significant because the error level is more than 0.05. In other words, according to this test, the model is acceptable and has satisfactory fitness.

Based on Table 6's results, the pedestrians' classification validation has reached 87%, meaning, with 87% certainty, we can describe the changes in the dependent variable for violating the red light, which is a significant development compared to the null model with 54.2%. Also, only 69 and 137 people were mistakenly classified in abiding and violating pedestrian categories, respectively.

The main output of the software is a table named Variables in the equation, which describes the role of each variable in the equation. Table 7 is the most critical table in analyzing the results for significance and each variables' effect on the dependent variable.

Based on the regression analysis results in Table 7, Lack of physical ability, crosswalk length, Duration of red light, traffic volume and all dummy variables of the number of violator variable are capable of predicting the changes in a dependent variable– e.g. pedestrian's red light violation—and their prediction ability is significant at less than 0.05 error level. Type of conflict, pedestrian volume, platoon size, and the existence of safe place variables have more than 0.05 error levels and therefore, can be condoned in the prediction process.

With respect to the odds ratio for physical disability, holding all other variables constant, a pedestrian who has problems with physical movement is 78.6% less likely to violate the red light than a pedestrian without any movement problem.

Comparing to the situation when the number of violators is Low, the inverted odds ratio for the number of violators indicates that the probability of pedestrians' violation is 11.71, 24.22, and 387.45 times higher when the violators' number is Medium, High, and Very High, respectively.

Also, increasing the value of traffic volume reduces the violation of pedestrians by 9.5%. The odds ratio for the length of the crosswalk variable reveals that for a meter growth in crosswalk length, the probability of pedestrian violation declines by 13.9%. On the other hand, with a one-second increase in red light duration, pedestrians are 2.2% more likely to pass the red light.

In analyzing the external factors affecting the pedestrian's behavior regarding red light, nine explanatory variables were defined. The logistic regression identified 5 out of 9 variables to be more effective in predicting their behavior.

The previous studies have concluded that pedestrians' violations affect others' behavior [22–24]. In fact, due to the conformity tendency and descriptive norms, pedestrians are encouraged to commit violations when they observe others violating the rules. This research's results are also consistent with past studies. Meaning, data analysis showed the violation probability of pedestrians rises significantly when they observe other violating pedestrians; perhaps an inner feeling encourages pedestrians to follow similar behavior like others. Moreover, the probability of violation increases rapidly when the pedestrian is in a situation with more than half of the other pedestrians are running the red light. This issue is significantly different in developed countries compared with developing countries. In developing countries, although individuals are aware of the legitimacy of their actions, maybe fear of being different would encourage them to commit violations. It is also possible to discuss the positive effects of this issue as well. Meaning, people who intend to commit violations would be dissuaded when they see law-abiding citizens; therefore, with this issue in mind, promoting social education may have a significant effect on pedestrian violations.

**Table 6**
Classification for evaluation of the model's performance.

| Observed | | Predicted | | |
|---|---|---|---|---|
| | | P.Decision | | Percentage correct |
| | | Wait for green | Cross on red | |
| P.Decision | Wait for green | 793 | 69 | 92.0 |
| | Cross on red | 137 | 591 | 81.2 |
| Overall Percentage | | | | 87.0 |

The previous studies have indicated that pedestrians are less likely to commit violations in longer crosswalks [11,13]. The study at hand also confirmed the positive effect of crosswalk length on pedestrians' decision making. The analysis demonstrated that a one-meter increase in the length of a crosswalk would decrease the likelihood of pedestrian violation by 13.9%. Meaning, the pedestrians have lower risk acceptance in long crosswalks; therefore, narrower crosswalks should be more prioritized when it comes to pedestrian violation issues. However, it is worthy of noting that pedestrians' safety would be in danger in long crosswalks; for instance, pedestrians are more likely to change their speed in longer crosswalks [25], and this behavior puts them in a dangerous situation [26].

In accordance with other publications such as Duduta, Zhang, and Kroneberger [11] and Diependaele [12], traffic volume was one of the significant factors affecting pedestrian behavior. According to the model results, a one-unit increase in the number of vehicles reduces pedestrian violations by 9.5%. To elaborate, as traffic volume grows, the risk of collision with a car increases. Thus, a pedestrian is less likely to accept the increase in risk and run the red light.

Pedestrian volume was an insignificant variable in this study. Considering the fact that pedestrian volume has been an effective factor in the pedestrians' behavior in researches conducted in other parts of the world, the ineffectiveness of this factor could be attributed to local features. In other words, the violation of pedestrians from Mashhad is not dependent on the pedestrian volume, unlike pedestrians from other countries. On the other hand, having the ViolatorNo variable, the number of violating pedestrians, as a significant factor, shows that pedestrians put more emphasis on violators compared with total pedestrian volume.

Another significant factor was the duration of the red light. Past researches have considered the factor to influence pedestrians' behavior [16]. In this research, prolonging the red light proved to be increasing the probability of violations by 2.2%, which is following previous studies in this regard [11,17]. Hamed [9] concluded that if pedestrians are familiar with the crosswalk, they are more likely to commit violations; therefore, a portion of violations recorded in this research could be attributed to this phenomenon. Decreasing the red light duration can decrease pedestrian violations. The importance of this issue is more emphasized in short crosswalks, at which pedestrians would commit more violations. A solution could be reducing the signal's total cycle duration. Since the pedestrians take less time to pass short crosswalks, the pedestrians' green light duration can also be reduced to maintain a balance in the cycle.

Previous studies have demonstrated a significant difference between the behavior of one pedestrian and a group of pedestrians, consisting of two or more individuals at the crosswalks. However, this study shows that crossing in groups does not affect the behavior of pedestrians, i.e., there is no behavioral difference when the pedestrian is alone or with others. On the other hand, the drivers have displayed more yielding behavior facing a group of pedestrians by stopping, reducing the speed or redirecting [27], which explains why pedestrians are more inclined to commit violations in groups.

Furthermore, like the findings presented by Zhang, Wang, Wang, Feng and Du [2], lack of physical abilities increases the probability of pedestrian violation. The most frequent individuals who had limited physical abilities were people with children or strollers. The data analysis showed that this factor was of importance for the pedestrians. It may be attributed to the fact that this cohort has a less risk acceptance threshold. To elaborate, people with strollers need more space for jaywalking, which is rarely available. For another instance, disabled individuals cannot keep up with others who run the red light, which makes them more vulnerable to the incoming traffic.

The presence of a median (or sidewalk) was not significant in predicting the pedestrians' behavior. It seems other factors such as traffic volume, number of other violators, and red light duration are more critical in this regard.

**Table 7**
Variables in the Equation.

| | B | S.E. | Wald | df | Sig. | Exp(B) | 95% C.I. for EXP(B) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| Type of Conflict | | | 2.929 | 2 | 0.231 | | | |
| Type of Conflict (1) | −0.730 | 0.446 | 2.678 | 1 | 0.102 | 0.482 | 0.201 | 1.155 |
| Type of Conflict (2) | 0.076 | 0.577 | 0.017 | 1 | 0.895 | 1.079 | 0.348 | 3.341 |
| Pedestrian Volume | 0.008 | 0.015 | 0.276 | 1 | 0.599 | 1.008 | 0.978 | 1.039 |
| Lack of Physical Ability (1) | −1.539 | 0.493 | 9.753 | 1 | 0.002 | 0.214 | 0.082 | 0.564 |
| Length of Crosswalk | −0.149 | 0.068 | 4.864 | 1 | 0.027 | 0.861 | 0.754 | 0.984 |
| Red Light Duration | 0.022 | 0.009 | 5.589 | 1 | 0.018 | 1.022 | 1.004 | 1.040 |
| Safe Place Existence (1) | 0.335 | 0.422 | 0.631 | 1 | 0.427 | 1.398 | 0.612 | 3.195 |
| Number of Violator | | | 392.101 | 3 | 0.000 | | | |
| Number of Violator (1) | 2.461 | 0.222 | 123.006 | 1 | 0.000 | 11.712 | 7.582 | 18.092 |
| Number of Violator (2) | 3.187 | 0.260 | 150.331 | 1 | 0.000 | 24.217 | 14.550 | 40.307 |
| Number of Violator (3) | 5.960 | 0.321 | 345.736 | 1 | 0.000 | 387.449 | 206.725 | 726.163 |
| Traffic Volume | −0.100 | 0.046 | 4.623 | 1 | 0.032 | 0.905 | 0.826 | 0.991 |
| Platoon Size | −0.011 | 0.065 | 0.027 | 1 | 0.870 | 0.989 | 0.872 | 1.123 |
| Constant | −1.050 | 1.229 | 0.731 | 1 | 0.393 | 0.350 | | |

Concerning the studied intersections, there are two types a pedestrian would come in contact with vehicles based on their movement; either the vehicles are passing through in a straight line, i.e., through traffic or they are making a left turn. The study shows that pedestrians do (would) not behave differently for each type of contact.

## 5. Conclusion

Previous researches have shown that these factors belong to two separate groups; One is psychological and internal, and the other is external factors. Changing the factors in the first group demand considerable effort and precise long-term planning so that the social norms and culture are changed. However, external factors have short-term paybacks and can be quickly modified. This study aimed to identify the significant external factors in pedestrian violations concerning crossing intersections.

The data was obtained by video recording the pedestrians' behavior in several of Mashhad's busiest intersections. Subsequently, the logistic regression model was employed to analyze the data and develop a model for predicting whether a pedestrian runs a red light. Based on the model's result, there are direct relationships between the probability of pedestrians' violation with the number of violators and red light duration. On the other hand, increasing the length of crosswalk and traffic volume reduce the probability of violation. Also, pedestrians with physical disabilities are less likely to violate the red light.

This study focused primarily on crosswalks with moderate to dense traffic. Analyzing the effect of traffic volume on pedestrians' violations specifically could be a good starting point for more research.

Future studies in this field could cover the weakness of the current research and improve the model at hand. Adding intersections with low traffic, recording videos at different times of the day, and analyzing crosswalks with countdown timers and their effects on pedestrians' violations are among the potential topics for future work.

## Declaration of Competing Interest

None.

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