Effect of Pedestrians on the Saturation Flow Rate of Right Turn Movements at Signalized Intersection - Case Study from Rasht City

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Abstract. Saturation flow rate is one of the important items in the analysis of the capacity of signalized intersections that are affected by some factors. Pedestrian crossing on signalized intersection is one of the factors which influence the vehicles flow. In addition, the released researches determined that the greatest impact of pedestrian on the saturation flow occurred in the Conflict zone where the highest chance of the encounter of pedestrians and vehicles has in turning movements. The purpose of this paper is to estimate the saturation flow rate considering the effect of a pedestrian on right turn movements of the signalized intersections in Rasht city. For this goal, 6 signalized intersections with 90 cycles of reviews were selected for the estimation of saturation flow rate by the microscopic method and also 3 right turn lanes containing radius differences with 70 cycles of reviews were collected for the investigation of the pedestrians’ effects. Each phase of right turn lanes cycle was divided in the pieces of 10-second period which was totally 476 sample volumes of considered pedestrians and vehicles at that period. Only 101 samples of those were ranged as saturated conditions. Finally, using different regression models, the best relationship between pedestrian’s volume and right turning vehicles flow parameters was evaluated. The results indicate that there is a primarily linear relationship between pedestrian’s volume and right turning vehicles flow with $R^2=0.6261$. According to this regression model with the increase in pedestrians, saturation flow rate will be reduced. In addition, by comparing the adjustment factor obtained in the present study and other studies, it was found that the effect of pedestrians on the right-turn movements in Rasht city is less than the rest of the world.

1. Introduction
The main advantages of using traffic lights are their role to guide drivers and pedestrians, in which they have a key role in maintaining traffic order and safety through the separation and allocation of transit time to the movements. In functional analysis of signalized intersections, one of the key parameters in the estimation of capacity and delay is the saturation flow rate that is a fundamental element in the management of the intersections and its performance method. Calculating the saturation flow rate at the intersection is the most important assessment tool in the urban transport system and it is an effective parameter on the amount of capacity, delay and network timing. There are many parameters that can influence the determination of the saturation flow rate of the signalized intersection, that pedestrians with regard to their size and impact, especially at intersections located in city centres or other traffic areas, can be a more prominent role in determining the saturation flow rate and capacity of intersections. the other effective factors can be pointed to geometric conditions, traffic conditions, driver behaviour,
timing of traffic lights, gradient direction, number of lanes, lane width, volume and type of the turning movements and so on.

However, and given that each city and country has its own conditions and traffic behaviour, the proposed correction factors for credible sources like the book of the Highway Capacity Manual [1] will not be applied necessarily for all the regions. Therefore, the behaviour of pedestrians and its impact on the saturation flow rate and saturation headway are the target of present study. The presence of pedestrians at signalized intersections will reduce the efficiency of the saturation flow rate and have an influence on the saturation headway and thereby will cause delays in vehicles.

The book of the Highway Capacity Manual proposed the saturation flow rate and the saturation headway equal to 1800 vehicles per hour of green per lane (vphgl) and 2 seconds, respectively in 1985 [4]. In 1994, this amount increased to 1900 vphgl [5] and in 2000 the same amount was presented [6]. The last edition of this guide considers the same amount (1900 vphgl) in 2010 [1], in certain circumstances 1975 vehicles per hour of green per lane (veh/hg/l). However, all the above values show base saturation flow rate (ideal conditions) and taking into account other effective factors such as pedestrians, these values will decrease. In addition to these studies, more investigation is available in the field of base saturation flow rate that is collected by Turner and Harap [2, 3].

BargGol et al. in a study (2016) estimated the saturation flow rate with the macroscopic and microscopic methods in the far-side and near-side legs at signalized intersection in Rasht city and saturation flow rate values were compared in a different lane width. They concluded that the saturation flow rate values depend on the lane width of the intersection, so that increasing the width of the lane will result in an increased saturation flow rate. The greatest amount of correlation between the variables of lane width and the saturation flow rate is in relation to macroscopic far-side legs [7].

Rouphail and Eads (1997), in a study examined the impact of pedestrians on the saturation flow rate of the turning movements to help "CORSIM" simulator and in order to different samples from pedestrian volume found to three linear, logarithmic and polynomial diagrams that although narrowly, error coefficient of polynomial model was a bit smaller than other models, but the linear model due to the ease and compatibility with other existing models, as the final model was presented to the right-turn special lane and with the values obtained from field data of the United States and analytical three models in this country as well as Canada and Australia were compared and the results show little difference between the linear model and other models. [8]

Niittymäki and Pursula (1997) in Helsinki, Finland, in a study aimed at updating the base saturation flow rate in signalized intersections examined the external factors affecting it, such as weather, traffic, road and pedestrian conditions. Studies based on field data according to the proposed method (HCM85,94) in 30 different locations and microscopic simulation method through HUTSIM simulator were conducted in approximately 39,000 queues of vehicles that calibrated based on road conditions in Finland and [9].

Milazzo et al. (1998), in an extensive study investigated the Effect of Pedestrians on Capacity of Signalized Intersections. They pointed to HCM94, where all interactions between pedestrians and circulating vehicles were not considered in calculating the saturation flow rate. As a result, they decided to explain the interactions for left-turn and right-turn directions using the conflict zone occupancy coefficient. To simplify the interaction between pedestrian and vehicle, it was focused on the conflict zone and finally, turning movements saturation flow adjustment factors due to pedestrians and bicycles presented and then it will be considered by HCM. [10]

Huapu et al. (2006) performed a study on the traffic characteristics of signalized intersection in Beijing and Tokyo (China and Japan). The results showed that the saturation flow rate in the Beijing and the city of Tokyo was found between 989 to 1477 vphgl and between 1163 to 1899 vphgl, respectively. The saturation flow rate in the city of Tokyo is about 1.3 to 2 times in the city of Beijing that actually show much difference between the two cities. They stated that reason for this would be the existence of non-motorized vehicles and the congestion of the pedestrians, especially in Beijing that influences on vehicles and start-up lost time causes delay of discharge the intersection and non-optimal use of its capacity [11].

Chen et al. (2008) investigated the effects of pedestrians on the capacity of right-turn movements at Signalized Intersection in China. They are used simulation software of "VISSIM" in order to modeling of the interaction between pedestrians and vehicles. The results showed that pedestrians will have a
great impact on the capacity of right-turn movements that they could through the delay and reduced capacity affect the intersection performance due to having the potential of the threats on the road safety [12].

Ren et al. (2011) stated that one of the largest proportion of losses is related to pedestrians in China and the signalized intersections have the highest share in this field. Due to this, they studied on the behaviour of pedestrian crossing at signalized intersection. The results of this study showed that the main reason for violation of traffic rules is saving time and maintaining the convenience [13].

Chen et al. (2015) in another study in China studied the effects of pedestrian on the saturation flow rate of protected left-turn movement in urban intersections. A study in Beijing Metropolitan Area was performed, which includes massive amounts of urban intersections and is faced with certain problems, including high travel demand and high levels of illegality. Hence, the pedestrian impact on the capacity of intersection is studied from two perspectives: the disruption to the traffic flow by pedestrians and reducing speed and saturation flow rate due to the intervention of pedestrian [14].

After reviewing different global studies on the effect of pedestrian on the right-turn movement and estimation of the saturation flow rate, according to the lane width by BargGol et al. in Rasht. In the present study, the vehicle headway and the saturation flow rate in a through movement and the pedestrian impact on the flow of right turning vehicles, a total of six intersections are investigated and obtains the adjustment factor in accordance with traffic conditions and pedestrian behaviour in Rasht, because traffic parameters, specially the saturation flow rate is heavily depending on traffic conditions and the behaviour of each city and country. Finally, the right-turn saturation flow adjustment factor due to pedestrian of recommended model will be compared with various studies in the world.

2. Methodology

2.1 Study area

In order to study the saturation flow rate in the entry routes of signalized intersections for the through movement, six intersections in the city of Rasht were selected. The city is one of the metropolises in Iran and is the provincial capital. Rasht is situated in 49 degrees and 36 minutes' east longitude and 37 degrees 16 minutes' north latitude and its distance from the Iranian capital, Tehran, is 325 km. The population density of Rasht is 4340 people per square kilometre [15, 16].

The selected intersections were chosen according to criteria such as geographical distribution almost uniform, intersections in the city, intersections in arterial roads of the city, their presence in the city (outbound routes in southeast, west, north, the ring road and central business district of the city), geometric and control conditions relatively good at every intersection and forming a queue and the presence of the saturation flow at the intersection from among more than 30 signalized intersections. To study the saturation flow rate of the through movement, traffic specifications and information of 6 intersections in Table 1 are visible.

Table 1. Signalized intersections studied to calculate the saturation flow rate in nearside legs

| Intersection number | Area type | Cycle length | Number of phase | Number of lane | Lane width | Green time | Number of cycle |
|---------------------|-----------|--------------|----------------|---------------|------------|------------|----------------|
| 1                   | CBD       | 167          | 2              | 3             | 2.8        | 89         | 15             |
| 2                   | NON-CBD   | 86           | 2              | 4             | 2.6        | 47         | 15             |
| 3                   | NON-CBD   | 65           | 3              | 2             | 3.8        | 26         | 15             |
| 4                   | NON-CBD   | 131          | 2              | 4             | 3.8        | 75         | 15             |
| 5                   | NON-CBD   | 122          | 3              | 3             | 3.3        | 31         | 15             |
| 6                   | CBD       | 134          | 4              | 4             | 3.2        | 38         | 15             |

In order to calculate the right-turn saturation flow rate and pedestrian impact on it, forming a queue and saturation flow with a high volume of pedestrians is required, that among the above intersections, only two intersections have the necessary characteristics, no.1 and no.4. Intersection No.1 to the central business district located in the main artery of the city and the confluence of two important roads and the high presence of pedestrians in the area as well as Intersection No.4 due to the confluence of the main ring road of the city and highway leading up to the capital of the country and located in the vicinity
of the most important religious centre of the city, the university, passenger terminal and containing different right-turn radiiuses is of great importance that the large number of pedestrians and vehicles will bring. Therefore, according to the closeness of the right turn radius on all four sides of intersection no.1, a right turn lane and also because of the difference in the radius of intersection no.4, two lanes of it were selected. table 2 shows the information of three right turn lanes of those two intersections.

| Intersection number | Area type | Right-Turn Lane name | Turning radius (meter) | Right-Turn Lane width (meter) | Green time (second) | Number of cycle |
|---------------------|-----------|----------------------|------------------------|-------------------------------|--------------------|-----------------|
| 1                   | CBD       | Imam                 | 13.5                   | 2.8                           | 89                 | 20              |
| 4                   | NON-CBD   | Gil to Daryaei (1)   | 58                     | 3.8                           | 74                 | 25              |
|                     |           | Daryaei to Farhang (2)| 28                     | 3.8                           | 54                 | 25              |

2.2 Data Collecting

In this study, to collect the statistics and information and count the volume of vehicles and pedestrians was used the camera to record the video of intersections at peak hours and on high building located near the intersections was performed. The camera was located on the target building at least 15 minutes before the start of the study time period and for each intersection at least one and a half hours in peak hour traffic was filmed and saved.

After viewing the collected films, if sighting any behaviour contrary to the law, entering the vehicles from other phase to the intersection at the end of their yellow and intervention between vehicles at two consecutive phases, data were not used. Also, due to the low number of heavy vehicles at intersections studied was ignored the collection of that. due to the manoeuvre impact of the roadside park on near the curb lane data, headway information in other lanes was considered to calculate the saturation flow rate in through movement.

2.3 The procedure for estimating the saturation flow and the impact of pedestrians

In general, two main issues will be discussed in this study. First, determining the saturation flow rate in a through movement by the microscopic aspect (saturation headway method) in the nearside legs and then examine the effect of pedestrians on the saturation flow rate in the right-turn movements which focuses on the conflict zone.

2.3.1 Calculating the saturation flow rate in a through movement

In order to achieve the first goal, in other words, the estimation of the saturation flow rate, in total, data from 90 cycles in a saturated condition and first 12 vehicles of the queues information were collected contained 6-intersection, and based on the saturation headway method, the saturation flow rate was determined by measuring headway of the vehicle when crossing the intersection, using equation (1).

\[
S = \frac{3600}{h_s}
\]  

where, \(S\) is the saturation flow rate (veh / hg / l), and \(h_s\) is saturation headway in seconds [6]. The consecutive vehicle headway was the time between the passage of front bumper relative to each other, which was recorded by a chronometer. Baseline in data collection headway in the studied intersections in the nearside legs was considered with respect to the front bumper of vehicles because the vehicles were stopped ahead of the stop line.
2.3.2 Effect of Pedestrians on right-turn movements

To determine the pedestrian impact on the saturation flow rate of right-turn movements, three right turn lanes data with different turning radius and a total of 70 cycles were evaluated after registration. For this purpose, focusing on areas that have the most chance of facing vehicles with pedestrians, which, according to the book of Highway capacity manual [1] are known to conflict zones. A conflict zone is a portion of an intersection, typically in the crosswalk, in which pedestrians and vehicles compete for space [10].

In the present study, the conflict zone of the right turn vehicles and pedestrians crossing the intersection with respect to Figure 1 is considered. For this purpose, in each cycle of the study, the length of the phase was divided into small increments of 10 second periods, in which the number of crossing right turn vehicles and the number of pedestrians affecting vehicle flow in the conflict zone collide were recorded in the table of ordered pairs. 10-second period samples were chosen because the most of intersections have interrupted saturation flows during the phase, therefore, dividing the phase time to smaller intervals gives us the chance to exclude the unsaturated period. In the following, only those groups of samples of vehicle and pedestrian volumes will be investigated in 10-second periods, which were occurred in saturated mode. Furthermore, sample for the first and the last 10 seconds were excluded along with other samples because of the start-up lost time and clearance lost time.

Finally, the best relationship between the volume of pedestrian and vehicle flows equivalent of acceptable samples was presented to determine the adjustment factor for the effect of pedestrians on the right-turn saturation flow rate with the linear and nonlinear regression models and according to the statistical parameters including Spearman correlation coefficient (R²), F statistic and significance.

3. Results and discussion

To obtain the saturation flow rate in a through movement, an average headway must be achieved in every cycle. Table 3 shows the average headway for the first 12 vehicles in the queue of each intersection, which is the result of the evaluation of 15 cycles in each intersection. Also in Figure 2, the values of headway with respect to the location of vehicles in the queue for every 6 intersections are shown.

According to the values obtained from the graph of an average headway in the nearside legs, it can be said that the procedure will be uniform after the fourth or fifth vehicle, this means that the first 4 or 5 vehicles have a delay to start and the values of the next headway will promote to a fixed value, and will be effective in the range of effective green time.
Table 3. The amounts of headways in nearside legs of signalized intersections

| Intersection number | Average of headways of the vehicles in the queue (second) | Saturation Headway (second) |
|---------------------|--------------------------------------------------------|----------------------------|
|                     | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 |
| 1                   | 5.3 | 3.6 | 3.1 | 3.2 | 2.3 | 2.4 | 2.4 | 2.2 | 2.4 | 2.1 | 2.3 | 2.4 | 2.33 |
| 2                   | 3.5 | 2.6 | 2.3 | 2.2 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.2 | 2.03 |
| 3                   | 3.5 | 2.9 | 2.6 | 2.5 | 2.3 | 2.3 | 2.3 | 2.2 | 2.2 | 2.3 | 2.2 | -   | 2.29 |
| 4                   | 2.9 | 2.4 | 2.4 | 2.1 | 2.3 | 2.2 | 2.1 | 1.9 | 2.1 | 2.2 | 2.2 | 2.2 | 2.12 |
| 5                   | 3.6 | 2.8 | 2.4 | 2.2 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.2 | 2.2 | 2.12 |
| 6                   | 3.6 | 3.0 | 2.3 | 2.3 | 2.1 | 2.1 | 2.2 | 2.1 | 2.1 | 2.2 | 2.3 | 2.0 | 2.16 |

Figure 2. Average of headways of the vehicles in the queue

In the other words, the location of intersection in the central business district of the city has a large impact on the amount of saturated headway and the start-up lost time, so that increases the amount of them. As shown in Figure 2, intersection no.1 has the maximum of saturation headway values, because this intersection locating in the central business district, roadside parks of public vehicles, and reduced the effective width and disorders caused by pedestrians in the mentioned route.

In Table 4, the saturation flow rate was determined by Microscopic method and the reverse saturation headway in each nearside leg based on the existing lane width, and according to one meter of lane width in terms of vehicle per hour of green per lane at the studied intersections. Also Figure 2 shows the saturation flow rate per lane width unit in each direction of intersections with respect to the location of the vehicle in the queue. The average of saturation flow rate per lane width has been determined in the figure 3 for six intersections mentioned as dot line.

As shown Table 4, the saturation flow rate is variable in the range of lane width 2.6 to 3.8 m between 1545 to 1773 veh/hg/l. Also, given the saturation flow rate per lane width of direction in Figure 3, this range is variable between 414 to 682 vehicles per hour green per lane width unit (veh/hg/lw).

To determine the pedestrian’s effects on the right-turn movements, 476 10-second period samples obtained from field data were recorded, including the number of pedestrians and the transitional vehicle volume equivalent to pedestrians over 70 cycles. Meanwhile, 101 acceptable samples under saturated conditions were evaluated (Table 5).
Figure 3. Saturation flow rate per lane width of the vehicles in the queue

Table 4. Given Saturation flow rate by microscopic method from signalized intersections

| Intersection Number | Saturation headway (Second) | Saturation flow rate (veh/hg/l) | Lane width (Meter) | Saturation flow rate per lane width (veh/hg/lw) |
|---------------------|-----------------------------|--------------------------------|--------------------|-----------------------------------------------|
| 1                   | 2.33                        | 1545                           | 2.8                | 552                                           |
| 2                   | 2.03                        | 1773                           | 2.6                | 682                                           |
| 3                   | 2.29                        | 1572                           | 3.8                | 414                                           |
| 4                   | 2.12                        | 1698                           | 3.8                | 447                                           |
| 5                   | 2.12                        | 1698                           | 3.3                | 514                                           |
| 6                   | 2.16                        | 1667                           | 3.2                | 521                                           |

Figure 4. the relationship between pedestrian volume and the transitional vehicle volume in the 10-second period
According to the information collected, the greatest number of pedestrians passing through the right-turn lanes within 10-seconds was 10 pedestrians. In Table 5, each column shows the transitional vehicle volume equivalent to pedestrians in the 10 second period under saturated conditions, in which conflict zone occurred. The contribution of each intersection of these samples was characterized by a distinct colour, which blue, green and red colours are related to the samples of intersection no.1, those of lane 1 from intersection no.4 and those of lane 2 from intersection no.4, respectively.

**Table 5.** The transitional vehicle volume in the 10-second samples equivalent to the number of pedestrians

| Number of pedestrians | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|-----------------------|---|---|---|---|---|---|---|---|---|---|----|
| Vehicle vol. of the 10-sec. sample | 4 | 4 | 3 | 5 | 3 | 2 | N/A | 3 | 3 | 2 | 1  |
| Vehicle vol. of the 10-sec. sample | 5 | 5 | 4 | 4 | 3 | 2 | N/A | 2 | 3 | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 6 | 4 | 3 | 3 | 3 | 2 | N/A | 2 | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 5 | 5 | 4 | 3 | 2 | 2 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 5 | 5 | 4 | 3 | 2 | 2 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 6 | 5 | 4 | 4 | 3 | 3 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 5 | 5 | 4 | 3 | 3 | 3 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 5 | 4 | 3 | 4 | 3 | 3 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 4 | 5 | 4 | 5 | 3 | 1 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 4 | 5 | 5 | 3 | 2 | 3 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 7 | N/A | 4 | 4 | 3 | 3 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 5 | N/A | 4 | 4 | 3 | 3 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 5 | N/A | 3 | 3 | 3 | 3 | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | 6 | N/A | 5 | 4 | 3 | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 4 | 3 | 3 | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 5 | 3 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 5 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 4 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 4 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 5 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 4 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 4 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Vehicle vol. of the 10-sec. sample | N/A | N/A | 4 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
All 101 samples collected of two signalized intersections to determine the best model of intersections in Rasht were evaluated using different models to be determined the best relationship between pedestrian volume and transitional vehicles. In Table 6, the results of the evaluation and comparison of linear and nonlinear regression models, three best models compared to all conceived models, are presented.

Despite the proximity of values of $R^2$ of different models by reason of higher F-statistics as well as ease and compatibility with other studies, the linear model compared to other models was selected as the best model, in which $q'_{ped}$ is the flow of pedestrian when passing through the conflict zone during the clearance in terms of pedestrian per 10 second and $q'_{veh}$ is the flow of right-turn vehicles in terms of vehicle per 10 second. Table 6 and Figure 4 show best models and the best model selected and their graphs between pedestrian volume and the transitional vehicle volume in the 10 second period (samples).

Given the selection of the linear model between pedestrian volume and equivalent transitional vehicles, a comparison between three selected right-turn lanes and the general regression model of the samples was performed (Figure 5). As can be seen, all the equations show the negative effects of pedestrians on the vehicles flow.

### Table 6. A Comparison between the different regression models

| No. | Regression Type | Equation | $R^2$ value | F Statistic | P value | Significant source | Best relation |
|-----|----------------|----------|-------------|-------------|---------|--------------------|---------------|
| 1   | Exponential    | $q'_{veh} = 5.0839e^{-0.13q'_{ped}}$ | 0.6274      | 58.4        | 0.029   | *                  | -             |
| 2   | Linear         | $q'_{veh} = -0.4263q'_{ped} + 4.9113$ | 0.6261      | 326.4       | 0.049   | * **              |              |
| 3   | Polynomial     | $q'_{veh} = 0.0376q'_{ped}^2 - 0.7103q'_{ped} + 5.2541$ | 0.673       | 101.65      | 0.023   | *                  | -             |

![Figure 5](image-url). A Comparison of the relationship between pedestrian volume and equivalent transitional vehicles in three right-turn lanes
In addition, despite a big difference between right-turn radiiuses of both lanes of intersection no.4 to one another (almost double), a big difference between the models of the two right-turn lanes compared with each other was not observed. However, compared to the model of intersection no.1, in small volumes of pedestrians, the flow of transitional vehicles was lower than the other two lanes. The reason for this is intersection no.1 in the central business district, and having the lane width less than the two other lanes, leading to reduced manoeuvrability for drivers, faced with pedestrians in conflict zones, and thus reduced the flow of transitional vehicles. Therefore, it can be said that in examining the effects of pedestrians on saturation flow rate of signalized intersections in Rasht, different right-turn radiiuses compared to other factors such as transitional lane width and an area that the intersection is located in, had no significant effect on the results. And only in most cases, larger turning radius provides more manoeuvrability for drivers in the face to pedestrians.

Given that the saturated samples in the 10 sec. periods were examined, the number of pedestrians and equivalent transitional vehicles for the duration of an hour was calculated using the general linear model referred to in Figure 5, as shown in equation (2):

\[
\text{From figure (5): } \quad q_{\text{veh}} = -0.4263 q_{\text{ped}} + 4.9113
\]

\[
\times \frac{3600}{10} \rightarrow q_{\text{veh}} = -0.4263 q_{\text{ped}} + 1768.068 \quad \text{Eq. 2}
\]

Where, \( q_{\text{veh}} \) is average flow of right-turn vehicles in terms of \( (\text{Veh/hr}) \) and \( q_{\text{ped}} \) is average of pedestrian flow passing through crosswalk at the phase clearance in terms of \( (\text{Ped/hr}) \).

According to equation (2), the base saturation flow for right-turn movement (no pedestrian) at signalized intersection in Rasht city is about 1768 \( (\text{Veh/hr}) \), so right-turn saturation flow adjustment factors due to pedestrians in signalized intersections in Rasht city, based on the pedestrian flow rate according to equation (3) is presented in equation (4):

\[
F_{\text{Ped}} = \frac{q_{\text{veh}}}{1768.068} \quad \text{Eq. 3}
\]

\[
F_{\text{Ped}} = -0.0002411 q_{\text{ped}} + 1 \quad \text{Eq. 4}
\]

Where, \( F_{\text{Ped}} \) is right-turn saturation flow adjustment factor due to pedestrians at signalized intersections in Rasht city.

![Figure 6](image-url)  
**Figure 6.** Right-turn saturation flow adjustment factor due to pedestrians (Rasht City)
The results of this study and other studies in other parts of the world [10], in accordance with Figure 7 to determine the effects of pedestrians on the saturation flow rate of right-turn movement, imply less effect of pedestrians in Rasht on the flow rate of right turn movement than the rest of the world. This is due to illegal behaviours of the drivers of the city in the face of pedestrians as well as non-compliance with existing pedestrian crossing and finding passing space among pedestrians.

![Figure 7](image_url)

**Figure 7.** A comparison of various right-turn saturation flow adjustment factors due to pedestrians between present study and the rest of the world

4. Conclusion

By determining the headways of direct movements, the saturation flow rates per lane width unit of the routes were obtained. In addition, the effect of pedestrians on the right turn movements was analysed, the adjustment factor was calculated and the following results were obtained:

- Signalized intersections located in the central business district of the city, the roadside parking of public transport and reduced effective lane width had a large influence on the saturation headway and the start-up lost time, which increased the amount of them. Moreover, the saturation flow rates per lane width unit is variable between 414 and 682 vehicles per hour of green per lane width unit.

- By examining a variety of regression models between pedestrian’s flow and equivalent vehicles flow in right-turn movements, it was found that the linear model is the best model. In addition, the model is more consistent with other studies.

- The model indicates the negative effects of pedestrians on the vehicles flow in the right turn movement. However, by comparing the adjustment factor obtained in this study and other studies, it was found that the effect of pedestrians on the right-turn movement in Rasht is less than in the rest of the world. This is due to illegal behaviours of the drivers of the city in the face of pedestrians as well as a non-compliance with the existing pedestrian crossing and finding spaces among them.

- Intersections locating in the CBD area and reducing the effective lane width of the right-turn lanes can adversely affect the saturation flow rate of right-turn movements through the reduced manoeuvrability of drivers and increased friction of vehicles flow in the face of pedestrians. However, comparing the effect of different right-turn radiuses of an intersection with each other showed little difference. Therefore, it can be said the effect of right-turn radius is less than other factors such as the lane and type of the area.
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