Journal of Engineering and Sustainable Development
Vol. 29, No. 06, November 2025
https://jeasd.uomustansiriyah.edu.iq/index.php/jeasd
ISSN 2520-0917
Research Article
https://doi.org/10.31272/jeasd.2092

Effect of Relative Delay Rate on Predicted Accident at Karbala City Arterial Streets: A Simulation Study

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Article Info

Received	20/04/2024
Revised	19/04/2025
Accepted	15/05/2025

Abstract

Crash prediction is a suitable alternative to an unrealistic accident record for conducting traffic safety studies. The paper′s goal is to examine the impact of the relative delay rate (the ratio of the delay rate (minutes per mile) to the acceptable travel rate (minutes per mile)) on crash rates on arterial roads in the city of Karbala. The study area is Fatima Al-Zahraa Street, an urban arterial measuring 1.40 km. The traffic volume data were calculated manually from video camera recordings over five days (January 25th to 29th, 2023), averaging 16 hours per day. A simulation model was run in PTV VISSIM2023 (SP 09) to calculate average delay and service level. The accident was predicted using the Highway Safety Manual (HSM). According to the linear regression analysis, a linear relationship was established between the relative delay rate and the rate of crashes recorded during peak hours, consistent with previous literature.

Keywords: Arterial streets, Average delay, Highway Safety Manual, PTV VISSIM, Road safety.

1. Introduction

In many large cities, traffic congestion is a significant challenge, and the ratio of traffic accidents to vehicle numbers is rising rapidly as the number of different vehicles grows. Serious social and economic issues arise from traffic accidents [1]. For both drivers and society as a whole, traffic safety is becoming increasingly crucial. Excessive speeding, disregard for existing traffic laws and regulations, drunk driving, and environmental factors are the leading causes of accidents [2]. An arterial incident is a single, unanticipated event that significantly affects road capacity and travel speeds. It has a much longer-term effect at specific locations than a freeway incident, drastically lowering road capacity and travel speeds. Therefore, a situation that only slightly alters traffic flow on an arterial road is not considered an incident [3]. The lack of traffic signs and markings, the presence of traffic operation elements, and the maintenance of the roadway network are all cited as deficiencies in drivers' traffic culture [4], [5]. One of the most prevalent intersection types in Iraq's street network is an unsignalized intersection. Because there are so many unsignalized intersections on the highway system and because some of them often experience specific crash types, there is a need to improve safety. An intersection with effective and safe traffic flow can be achieved by combining good geometric design with effective traffic management. Effective traffic planning and justification of associated costs depend on a reliable model to predict the effects of delay mitigation for various event management methods [3].

Several researchers have investigated how operational conditions, such as congestion, queue length, and vehicle interactions, influence crash frequency and severity. According to Zengqiang et al. [1], traffic information can be effectively used for safety evaluation through intelligent modeling techniques such as ANFIS, demonstrating that higher congestion levels often lead to increased crash potential. The Highway Safety Manual (HSM 2010) [6] introduced predictive methods for estimating expected crash frequencies based on roadway, traffic, and environmental variables. This approach has been widely applied to signalized and unsignalized intersections, rural highways, and urban arterials. However, its direct application in Iraqi urban networks remains limited due to the absence of local calibration factors and reliable crash data. To overcome such limitations, simulation-based surrogate safety approaches have gained attention. For example, Wu et al. [7] validated the ability of PTV VISSIM and the Surrogate Safety Assessment Model (SSAM) to estimate conflicts between vehicles and pedestrians at signalized intersections, while Lakouari et al. [8] modeled emissions and safety indicators at roundabouts using microscopic simulation. Wood and Zhang [9] evaluated the relationships among perception–

reaction time, emergency deceleration behavior, and crash outcomes by analyzing crash data. Their findings supported the argument that unstable operations and sudden deceleration in congested urban corridors create a safety-critical environment even before an actual collision occurs. Ali et al. [10] applied an Extreme Value Theory framework to estimate crash risk during mandatory lane-changing in connected environments, confirming that acceleration noise and delay heterogeneity are key determinants of near-crash events. Hula et al. [11] evaluated how reaction times and accident statistics can predict the safety impact of automated vehicles on vulnerable road users. They showed that even small reductions in human reaction-time variance can substantially reduce collision risk in mixed traffic.

In the Iraqi context, Ewadh and Neham [4] and Ewadh [12] used the traffic conflict technique to predict the effectiveness of potential countermeasures at urban intersections. Their studies confirmed a linear relationship between average stopped delay and the number of conflicts, suggesting that delay can serve as a valuable operational predictor of safety. More recent works [5],[13],[14] applied system-based road safety assessments and geometric design improvements, but did not explicitly model the statistical relationship between delay rate and predicted crash frequency. Al-Nuaimi and Jameel [15] further investigated the influence of traffic characteristics on crash frequency, revealing that parameters such as traffic composition and flow rate significantly affect the occurrence of crashes in Iraqi cities

Despite these advances, no prior study has integrated VISSIM-based delay estimation with HSM crash prediction to evaluate arterial safety performance in Iraq. Existing research either focused on geometric design or conflict analysis without quantifying how the relative delay rate—the ratio of experienced delay to acceptable travel rate—affects the likelihood of crashes. Therefore, the current study contributes to bridging this gap by developing a combined simulation–prediction framework capable of quantifying the effect of relative delay on crash frequency for urban arterials such as Fatima Al-Zahraa Street in Karbala.

The objective of the present traffic study is to use the PTV VISSIM application to develop a simulation model to determine how the relative delay rate affects the frequency of collisions on arterial roadways in the city of Karbala.

2. Methodology

The research method starts with calculating the traffic volume during peak hours, from which the peak-hour factor is derived. Then, the PTV VISSIM program will be used to simulate the geometric and traffic conditions, evaluate and analyze the study area, and find the relative delay rate and service level. After that, the crash rate will be estimated using the Highway Safety Manual [6]. The effect of the relative delay coefficient on the number of accidents will be investigated to determine the relationship between the two.

2.1 The Study Area

Fatima Al-Zahraa Street is 1.40 km long and 45 m wide, with two lanes in each direction. As seen in Fig. 1, this street has three intersections along its length: Al-Safeena roundabout, Al-Dhareeba, and Sayed Jawda signalized intersections. These intersections carry a lot of traffic, including both motorized and non-motorized vehicles and pedestrians, and they frequently present conflicts at turning, crossing, and merging operations.

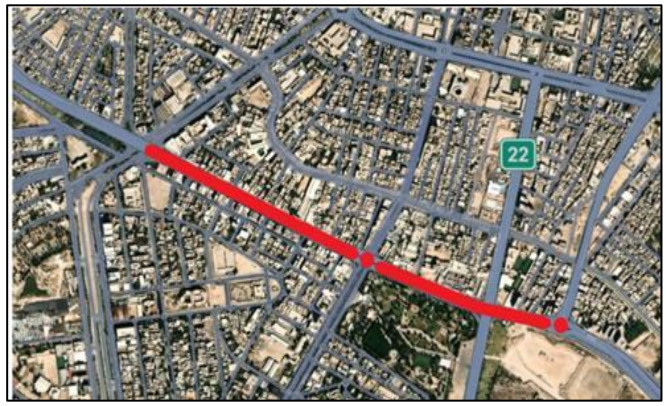

Figure 1. Fatima Al-Zahraa Road Location.

The volume of traffic easily exceeds the capacity of the current crossings during peak hours for several reasons, including economic expansion, increased car traffic, and population growth. Therefore, deteriorating traffic conditions increase safety concerns, emissions, accidents, and fuel consumption, thereby lowering the quality of life and worsening atmospheric conditions [16]. This street is severely congested, especially during peak hours, due to the presence of entertainment, commercial, and health centers. Fig. 2 depicts the six segments that make up this roadway.

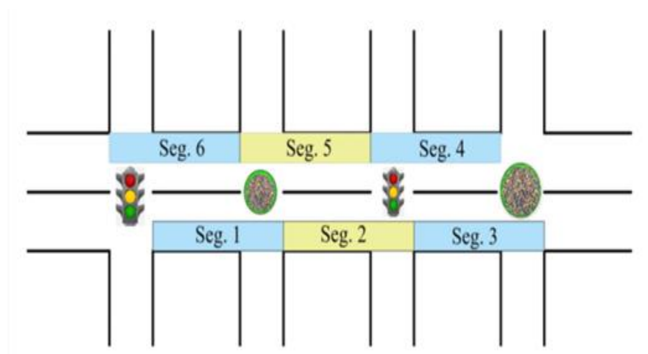

Figure 2. Segments of Fatima Al-Zahraa Street.

2.2 Traffic Volume Data and Peak Hour Factor

Traffic volumes were manually calculated from video recordings of the study area over 5 days, then measured every 15 minutes during peak hours to estimate the PHF [17], as shown in Table 1. While Figs. 3 to 6 show the traffic volume and PHF for the study area: Al-Sanater Street, Al-Dhareeba Intersection, AlSafeena Roundabout, and Sayad-Jawda Intersection.

Table 1. PHF values of Fatima Al-Zahraa Street.

Direction	PHF
Al-Dhareeba Intersection	
NB	0.9
SB	0.93
EB	0.88
WB	0.91
Al-Safeena Roundabout	
NB	0.92
SB	0.93
EB	0.93
WB	0.90
Al-Sanater Street	
NB	0.90
SB	0.86
Sayad Jawda intersection	
NB	0.90
SB	0.93
EB	0.88
WB	0.91

The HCM 2000 recommended setting the default value for arterial roads with congested circumstances to 0.92 and to 0.88 if the flow is generally regular. After that, the default values HCM (2010) suggests are 0.92 for urban regions and 0.88 for rural areas. As traffic volume rises, PHF's value increases. For Fatima Al-Zahraa Street (from the Sayed Jawda intersection to the Al-Dhareeba intersection), the PHF values range from 0.88 to 0.95, as it experiences high traffic density during peak hours, making it one of the most active and populated streets in the city. There are numerous commercial and marketing centers on Al-Sanater Street (which is a part of Fatima Al-Zahraa Street). People from the outskirts of Karbala, as well as Najaf, Baghdad, and Hilla, pass through this street, which connects to the city centre (the shrines of Imam Hussein and Imam Abbas), medical clinics, and other locations.

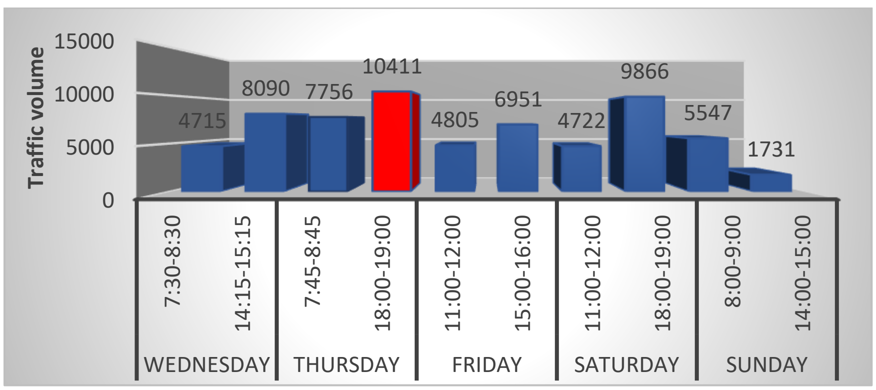

Figure 3. Traffic volume for Sayad Jawda intersection (Jan.25th-29th 2023).

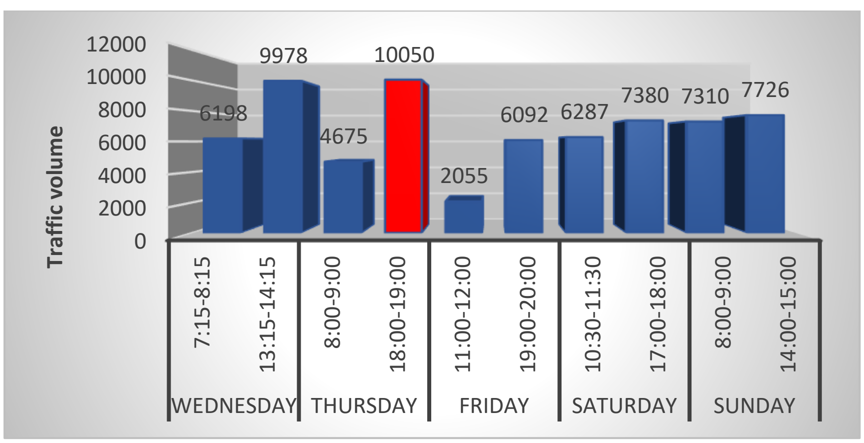

Figure 4. Traffic volume for AL-Safeena Roundabout (Jan.25th-29th 2023).

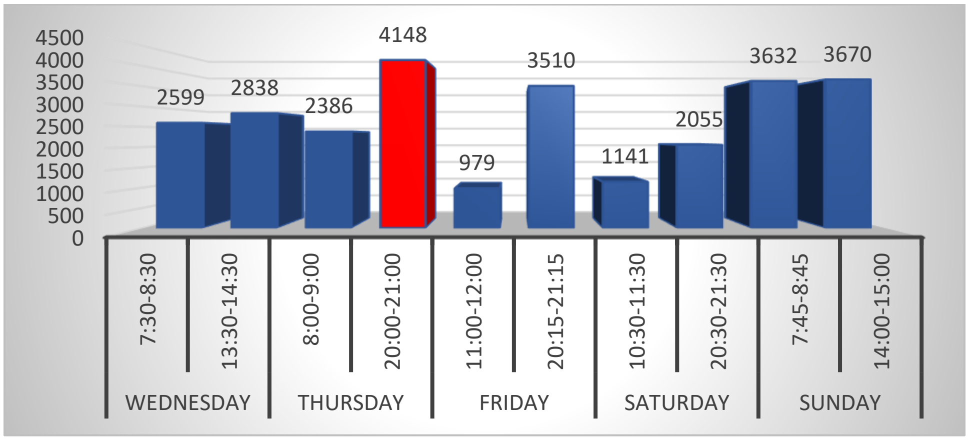

Figure 5. Traffic volume for Al-Sanater Street (Jan.25th-29th 2023).

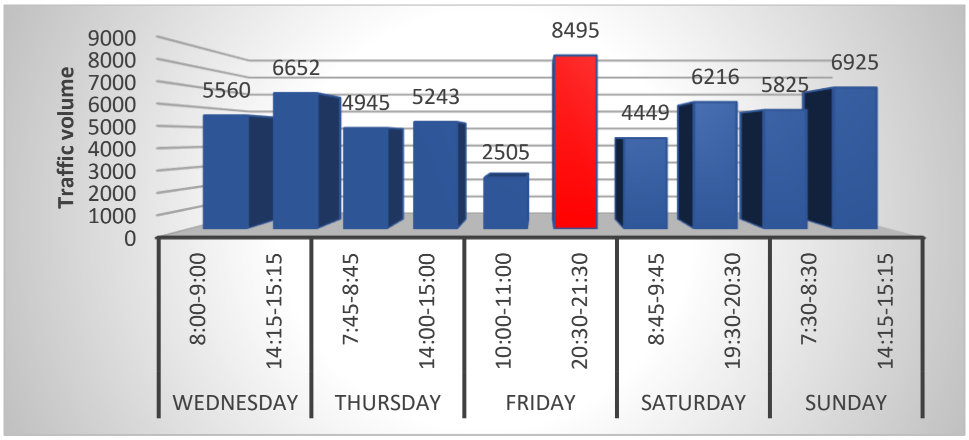

Figure 6. Traffic volume for Al-Dhareeba Intersection (Jan.25th-29th 2023).

2.3. Free Flow Speed

Free Flow Speed (FFS) is the average speed of the traffic stream when traffic volume is low enough that the presence of other cars does not influence drivers and when intersection traffic control is absent or far enough away not to have an impact on speed choice [17] Because this parameter is so crucial to the models used for planning, operational analysis, and performance evaluation of transportation systems, it must be carefully determined in the field. The requisite speed data can be calculated using various techniques. In this study, the free flow speed was estimated by measuring the running duration for each segment and then applying (1) (the moving car method)

$$FFS = \left(\frac{Distance}{Travel\ time}\right) * 3.6 \qquad (1)$$

Where:

FFS: the free-flow speed that takes intersection delay into account (Km/hr).

L: segment length (m).

TR: the length of time needed to transition from one segment to another (seconds).

It was necessary to determine the time period during which the traffic volume would be less than or equal to (200 veh/ln/hr) before collecting the free-flow speed data. After 12 A.M., it was discovered that the free-flow traffic condition (less than 200 vehicles per hour) was approaching. Standard cars were used to calculate FFS speeds over five days, and their average speeds were recorded at roundabouts. Table 2 provides clarification on some of the computed speeds on the arterial street.

2.4. PTV VISSIM

One of the best-known pieces of digitizing and simulation software, PTV VISSIM, is used globally to assess traffic-related issues such as safety, delay, pollution, and more. The PTV Group owns the VISSIM technology, which enables the simulation of large numbers of individuals and modes of transportation [18]. Traffic flow at roundabouts and intersections was simulated for this study using the VISSIM model. Here are some of VISSIM's primary advantages over other contemporary software [7],[8]:

Table 2. Sample of Average Free Flow Speed for Fatima Al-Zahraa Street.

No. Of vehicle	Speed(km/hr)
1	33
2	25
3	38
4	40
5	32
6	39
7	44
8	33
9	29
10	30
11	32
12	41
13	36
14	25
15	36
16	44
17	38
18	41
19	39
20	43

- Adaptability in handling interactions between vehicles travelling in the same lane, lateral movement of cars, and gap acceptance control [19].
- Allows calibration of numerous parameters, including driver behavior, to create realistic traffic scenarios.
- There are many alternatives for vehicle routing due to the wide range of results that VISSIM provides [20].
- Businesses and municipalities can save time and money, improve traffic safety, and minimize their environmental impacts by using VISSIM. As a result, VISSIM is a crucial and practical tool in transportation engineering [21], [22].

By running a simulation model as realistically as possible, simulation is a crucial tool for researching traffic and transportation issues. Analysis of problems such as traffic network performance, LOS, congestion, and delay is beneficial. To assess traffic in all of its complexity, traffic simulation tools are required [23]. Here are some quick instructions for building a model in VISSIM software and simulating.

- Locate the street being analyzed by the program by using the Google Maps link provided in the program interface [24].
- Inclusion of the study area with its roundabouts and intersections, as well as streets with the same number of lanes approaching the roundabout and intersection from all angles, to make the final geometric design as close to reality as feasible.
- Select inputs after linking the model's streets, vehicle types, and categories.
- The third stage sets the lanes that vehicles will travel on from the time they enter the street until they leave.
- Limiting the study area and scientifically calculating the simulation and output requirements for the program. Table 3 shows selected driving behavior parameters for the simulation model's calibration
- This method allows the program to run in both two- and three-dimensional modes [25].

Table 3. Selected Driving Behavior Parameters for the Simulation Model's Calibration.

Parameter	Definition according to VISSIM (sp 09)	Range	Default Value	Calibrated Value
Average standstill distance	The average desired distance between stopped cars	(1-3) m	2	1.52
Lock ahead distance	Max & Min forward distance that the vehicle driver can see within the same link.	(0 Min.- 250Max) m	75-150	35-110
Lock back distance	Max & Min back distance that the vehicle driver can see so that they can react to other vehicles behind within the same link	(0 Min.- 150Max) m	30-100	20-63
Vehicle's occupation of the wrong lane	Occupation of a lane not assigned for the movement of the vehicle by a driver, such as occupying the left-turn lane, whereas the destination is through	-	5%	12%
Driving behavior in the adjacent lane distance	The minimum distance between adjacent vehicles when vehicles are approaching the stop line	-	2	1.3
Car following model	Models of how vehicles behave within the network - No interaction - Wiedemann 74 - Wiedemann 99	NO W 99 W74	W 99	W 74
Reduced speed areas	To the right for open proper movement, left movement after the green light, changing lanes (speed decreases 10%)		No selected	selected

2.6. Predictive Method (HSM 2010)

For facilities with known characteristics, the predictive technique provides a systematic approach to estimate average crash frequency, crash severity, and collision types for urban or suburban arterial facilities.

Except for collisions involving bicycles and pedestrians, all crashes involving any vehicle are included. A predictive technique can be used to analyze alternative traffic volume predictions, new sites, and design alternatives for current sites or existing sites. It is possible to predict the frequency of crashes during a given period, either in the past (what happened or would have happened) or in the present (what is anticipated to happen). $N_{Predicted}$ was calculated for arterial roads and intersections based on (1) and (2) [6]. The results are shown in Table 3.

$$N_{predicted\ rs} = C_r \times \left(N_{br} + N_{pedr} + N_{biker}\right) \qquad (2)$$

Where:

$N_{Predicted}$: estimated average crash frequency for a specific section of road for the chosen year.

N_{br}: estimated average crash frequency for a specific section of road (excluding crashes involving vehicles, bicycles, and pedestrians).

N_{pedr}: anticipated typical crash frequency of vehicle-pedestrian crashes for a specific roadway stretch.

N_{biker}: anticipated average crash frequency of vehicle-bike collisions for an individual roadway part.

C_r: a calibration factor for a particular sort of road segment created for use in a specific location.

$$N_{predicted\ int} = C_i \times \left(N_{bi} + N_{pedi} + N_{bikei}\right) \qquad (3)$$

Where:

$N_{predicted\ int}$: anticipated average intersection crash frequency for the chosen year (SM2010).

N_{bi}: estimated average crash frequency for the intersection, excluding crashes involving bicycles and pedestrians.

N_{pedi}: estimated average crash frequency of vehicle-pedestrian collisions.

N_{bikei}: estimated average crash frequency of vehicle-bike collisions (HSM2010).

C_i: a calibration factor for a particular sort of road segment created for use in a specific location.

These are some of the engineering features of a portion of the study area used to compute the crash rate. For Al-Sanater street was a three-lane urban arterial roadway with a center two-way left-turn lane (TWLTL).:

- (730m) length.
- AADT=18300v/day.
- 13 driveways (8 minor commercial and 5 central residential).
- 26 roadside objects/km.
- 35km/hr. posted speed.
- Lighting present.

And for Al-Dhareeba intersection, a four-leg signalized intersection located on an urban arterial roadway, with the fact:

- 1 left-turn lane on each of two major road approaches
- 1 right-turn lane on each of two major road approaches
- Protected/permissive left-turn single phasing on a major road
- AADT of the major highway is 25401 veh/day
- AADT of the minor road is 22390 veh/day
- Lighting is present
- No approaches with prohibited right turn-on-red
- Four-lane divided major road
- Pedestrian volume is 100 peds/day
- The number of bus stops within 300m of the intersection is zero
- The presence of a school within 3 km of the intersection is zero
- The number of alcohol establishments within 300 m is zero

3. Analysis And Results

The LOS for Fatima Al-Zahra Street during peak hours is (F), as shown in Table 4, which also includes information on crash rates and relative delay rates for this arterial road.

Table 4. LOS & RDR & $N_{Predicted}$ for Fatima Al-Zahraa Street.

Direction	Relative Delay Rate (%)	LOS	$N_{Predicted}$(crash/year)
	AL-Dhareeba Intersection		
NB	88.9		6.763
	89	F	6.693
WB	90		7.39
EB	85.4		5.531
	AL-Sanater Street		
NB	81.7	F	4.528
SB	86		5.792
	AL-Safeena Roundabout		
NB	81		4.321
SB	75	F	2.059
WB	76.2		3.071
EB	77		3.365
	Fatima Al-Zahraa Street		
NB	79	F	3.932
SB	79.4		3.94
	Sayad Jawda Intersection		
NB	84		5.107
SB	88.7	F	6.612
WB	85.2		5.451
EB	83.7		5.016

It was feasible to establish a linear relationship between the relative delay rate and the rate of crashes during peak hours using linear regression analysis. The following statistical relationship explains the increasing variance (90%) of the relative delay rate for the rate of crashes, as seen in Fig. 7.

$$N_{predicted} = 0.305 * RDR - 20.35 \qquad (4)$$

Where:

$N_{Predicted}$: anticipated-average-collision frequency for a specific route segment for the chosen year (crash/year).

RDR: Relative Delay Rate (%).

The summary of the statistical model's parameters is shown in Table 5.

Table 5. Summary of the statistical model's parameters.

F Sig	Standard Error	P-value intercept	P-value	R^2
7.093 E-14	0.19852	1.458 E-12	7.093 E-14	0.9835

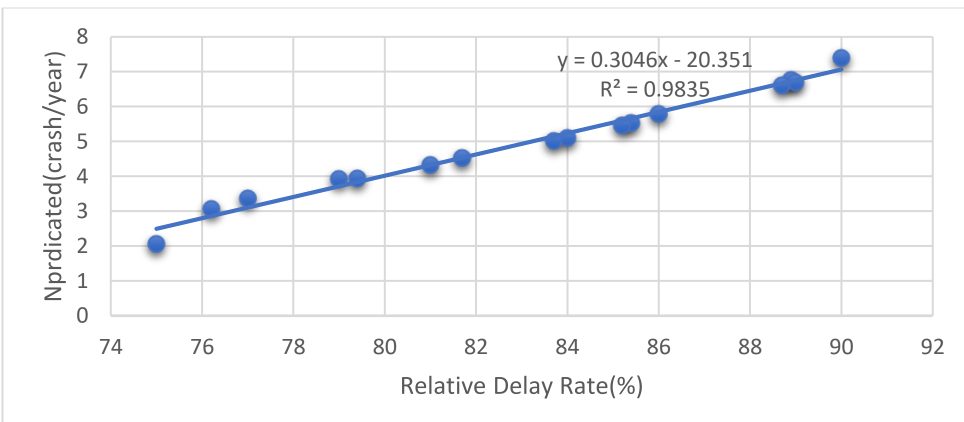

Figure 7. The linear relationship between $N_{predicted}$ & RDR for Fatima Al-Zahraa Street.

4. Discussion

The level of service on Fatima Al-Zahraa Street during peak periods is (F), as determined by a VISSIM-simulated model. However, the correlation between the relative delay rate and the number of accidents on this street was linear with a correlation coefficient of 0.9835, indicating that as the delay rate increases, accidents increase as well, particularly at intersections. The previous literature and studies are consistent with this result. Ewadh [12] found a linear relationship between traffic conflicts and average stopped delay at three-leg signalized intersections in Baghdad City. Ewadh and Neham [4] found that, for four-legged signalized intersections, a linear relationship adequately explains the relationship between traffic volume and the number of conflicts with traffic for all vehicle types, including passenger cars, large trucks, motorcycles, bicycles, and pedestrians. Because they are among the most prevalent roadway characteristics and each has significant potential for conflict, they rank among the biggest safety problems [26]. Table 3 shows that the Al-Dhareeba and Sayed Jawda intersections have the highest crash rates. Driver behavior is a leading cause of accidents. For example, although there are traffic signals at the junction of Al-Dhareeba and Sayed Jawda, the number of accidents there is significant. This is due to drivers' impaired driving, lack of awareness, and abrupt decision-making, as well as their disregard for speed limits at certain intersections and their speeding during traffic jams.

Because heavy vehicles, three-wheelers, and passenger cars are all on the road at the same time, accidents often involve a vehicle entering the path of a traffic light that is indicating a move. Other factors include the absence of bike and motorcycle lanes. It is essential to note that while street accidents involve both automobiles and pedestrians, they occur only at junctions. The lack of parking spots and a pedestrian bridge, along with the driver's bad behavior and the randomness of traffic on Al-Sanater Street, further congests the road and increases the risk of crashes.

5. Conclusions

The Fatima Al-Zahraa Street relative delay rate was found to be high, and the level of service was the worst (F) during peak hours, as inferred by the PTV VISSIM program. This street is crucial as it is the center of government, business, and health centers. It is connected to the city center. Additionally, statistical analysis revealed a linear relationship between the relative delay rate and the accident, with a regression coefficient of 0.9835. This relationship is consistent with previous literature and research, showing that accidents rise as the relative delay rate increases.

Conflict of interest

There is no conflict of interest in the current project.

Author Contribution Statement

Majida Salah Hadi: suggested the problem of the research, developed the theory, conducted the experimental work and calculations, verified the analytical methods, conducted the structure of the manuscript, and organized the outcomes of this study. Hussein A. Ewadh and Raid R. A. Almuhanna contributed to the final text and commented on the results.

Acknowledgements

The authors wish to express their appreciation to Assist. Prof. Dr. Abeer Khudhur Jameel for their assistance in carrying out the current work.

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