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Research Paper

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Traffic operations and safety condition analysis of signalized intersections

Mustafa Mohammad R. M. Saeed* and *Hussein A. Ewadh

Department of Civil Engineering , College of Engineering, University of Babylon, Babylon, Iraq.

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ABSTRACT

When reliable crash data is unavailable, Surrogate Safety Measures (SSMs) become valuable tools for traffic safety research. This study assesses traffic safety at signalized intersections, explicitly examining how traffic operations such as stopped delay time and Level of Service affect hourly traffic conflicts using surrogate measures. Three four-leg signalized junctions in Karbala City were selected. Data on traffic volume and conflicts were collected using video cameras managed by the Karbala Traffic Police. The VISSIM software was utilized for traffic operation analysis, which then served as input for the Surrogate Safety Assessment Model (SSAM) software. The results show that simulation-based hourly traffic conflicts increase as stopped delay time increases, with a correlation coefficient (R^2) ranging from $0.7533 - 0.9127$. Specifically, stopped delay values ranged from 117sec. at the Sayed Jawda intersection (considered high-risk) to 79sec. at the Al-Sofaraa intersection (considered low-risk). Rear-end conflicts accounted for the highest percentage of total conflicts, reaching 63%, 58%, and 66% at the respective intersections. This high percentage is attributed to rear-end conflicts predominantly occurring within the same approach in the traffic queue. This research provides valuable insights into evaluating safety at signalized intersections in urban areas and is an additional reference for future road safety studies. This study differs from previous research by emphasizing the correlation between stopped delay time and the frequency of hourly traffic conflicts using the SSAM software. This study provides a more nuanced understanding of the relationship between operational characteristics and safety at signalized intersections.

1. Introduction

Roads play a major role in Iraq's transportation system and are essential to the country's economic growth. Since Iraq's population has increased dramatically, the demand for products and services has increased in general [1]. Maintaining proper traffic operation and safety is crucial for developing the intersections. Consequently, there would be increased traffic congestion, crashes, fuel consumption, released pollutants, and noise if the level of service (LOS) drops. The World Health Organization claims that heavy traffic and jams worsen people's quality of life, waste energy, and fuel global warming [2]. delay of all movements through an intersection [3]. Vehicle delay evaluates the intangible variables, for example, missing travel time, drivers' discomfort, and annoyance. As measures of an intersection's potential capacity and performance, delay and level of service are significant contributing reasons for mediocre traffic jams [4]. Highway-related crashes are expected to rank as the fifth most significant cause of delay of all movements through an intersection [3]. Vehicle delay evaluates the intangible variables, for example, missing travel time, drivers' discomfort, and annoyance. As measures of an intersection's potential capacity and performance, delay and level of service are significant contributing reasons for mediocre traffic jams [4]. Highway-related crashes are expected to rank as the fifth most significant cause of mortality worldwide by 2030, with over 1.2 million fatalities and up to 50 million injuries occurring each year (World Health Organization, 2009, 2013). Highway-related collisions cause unimaginable anguish and suffering, billions of dollars' worth of medical costs, lost productivity, and death and injury figures. Due to the significant impact that highway safety has on human societies, enormous sums of money have been spent on safety-related countermeasures [5]. Traffic crashes regularly happen at intersections due to many conflicts caused by cars, buses, trucks, etc [6]. Traffic crash estimating models are precious methods in roadway safety, as they can determine the frequency of crashes and the underlying factors that transportation regulations may subsequently address. Car accident data can be used to simulate both the frequency of crashes and their intensity. Crash frequency is an estimate of how often accidents will occur on a specific roadway stretch or intersection during a given period [7]. Many Previous studies have suggested alternate methods as a simulation methodology for determining road safety. Collisions are frequently fatal situations, making it hard to continue with random conventional methods of studying traffic accidents. Microscopic simulation models are potential techniques for assessing the safety levels of present and new infrastructures [8]. Abd-alzahraa et al. [9] evaluated the performance of countermeasures at signalized intersections using the micro-simulation model (VISSM10) program and the Surrogate Safety Assessment Model (SSAM) to cope with traffic conflicts as surrogate measures instead of accident data. The investigation was conducted at four four-legged signalized junctions in Diwaniya, safety was assessed, and appropriate countermeasures were proposed. The results showed that various countermeasures are examined during simulation to determine their efficiency using two indices: the increase in time to collision and the proportion decrease in traffic conflicts. Astarita V. et al. [10] suggest a new surrogate safety indicator based on vehicle trajectories that can account for roadside items. The validity of the proposed indicator is evaluated by comparing the calculation of surrogate safety measures on micro-simulated trajectories to the real crash risk acquired from data on real crashes recorded at various urban intersection settings. The proposed experimental methodology also compares classical metrics such as TTC (time to collision) and PET (post-encroachment time).

*Corresponding Author.
E-mail address: eng.hussein.ewadh@uobabylon.edu.iq ; Tel: (+964) 780-1069 474 (Hussein Ewadh)

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Nomenclature

FHWA	Federal Highway Administration	*SSMs*	Surrogate Safety Measures
LOS	Level of Service	*TCT*	Traffic Conflict Technique
PET	Post encroachment time	*TTC*	Time to collision
SSAM	Surrogate Safety Assessment Model		

The research gap aims to compare traffic operations and safety conditions for signalized intersections by studying the relationship between traffic conflicts, stopped delays, and L.O.S. using micro simulation modeling. Ewadh, H. [11] analyzes traffic conflict "near-crash"data at specific locations in the traffic system. A case study of traffic conflict was conducted at three signalized junctions in Baghdad City. Regression analysis created a model that linked observed hourly traffic conflict with average halted delay. Based on HCM output, a countermeasure was evaluated based on a before and after study of average stopped delay and the involved disputes based on the developed statistical model, which revealed that more than 35% of potential conflicts could be reduced due to countermeasures, with the highest reduction (62.6%) due to increased lane width. This technique maximizes the value of conflict analysis as a long-term tool for predicting the effectiveness of any suggested countermeasure, hence improving safety in any traffic system. The research gap aims to compare traffic operations and safety conditions for signalized intersections by studying the relationship between traffic conflicts, stopped delays, and L.O.S. using micro-simulation modeling. Reviewing previous research on conflicts at intersections shows that studies vary significantly in their approaches to identifying and categorizing conflicts. While some research focuses on quantitative analysis, such as the frequency of specific conflict types (e.g., rear-end, side-swipe, or angle collisions), others adopt a qualitative approach, examining the underlying causes and contributing factors, such as driver behavior, traffic volume, and road design. A common finding across these studies is that rear-end collisions are the most frequent conflict type, particularly at signalized intersections where abrupt stopping can occur. However, angle collisions, though less frequent, are often highlighted as the most severe in terms of injury and fatality risk. The disparity in findings can be attributed to differences in data collection methods, definitions of conflict severity, and regional traffic conditions. To draw a comprehensive conclusion, it is essential to integrate both the frequency and severity of conflicts. This dual approach allows for a better understanding of the overall risk profile of each conflict type. For instance, while rear-end collisions are more common, angle collisions pose a higher risk due to the greater potential for severe injuries. Therefore, angle collisions should be prioritized when assessing the riskiest approach in terms of categorization severity and intersection risk due to their higher severity despite their lower frequency. This paragraph outlines the variations in research approaches, summarizes common findings, and concludes which type of conflict is considered riskiest based on frequency and severity. The study aims to identify traffic operation indicators, such as level of service (LOS) and stopped delay time at intersections, by using VISSIM software. It seeks to understand their impact on safety conditions at signalized intersections through a simulation-based approach using the Surrogate Safety Assessment Model (SSAM). This model simulates vehicle conflicts and evaluates them using two primary safety indicators: Time-to-Collision (TTC) and Post-Encroachment Time (PET). Additionally, the study focuses on determining the number and types of conflicts most common in each approach to the intersection and identifying the riskiest approach regarding conflict severity and risk severity.

1.1 Statistical indicators of crashes

1.1.1 Statistics in Iraq

The number of crashes recorded during the year was (11593), of which (3272) were fatal with a percentage of (96.7%) and (8444) non-fatal with a rate of (73%) in all governorates except Kurdistan Region compared to (12652) accidents in the year 2021 with an increasing of (8.1%). • The crashes for the year 2022 recorded the highest percentage (6423 accidents) with a percentage (56.3%) of the total number of accidents (11593 accidents), followed by run-over accidents (3794 accidents) with a percentage (32%). The number of overturning accidents was (1098) (9.5%), while the number of other accidents amounted to (208) with a percentage of (1.8%). • The number of accidents recorded (11593 accidents) If it is classified according to the type of the road, it is found that the most significant number of accidents that occurred on the main road (6219 accidents) with a percentage of (54%) of the total accidents for the year 2022, followed by the highway (2715 accidents (24.0%), then the minor road (1764 accidents (15.3%), and the lowest number of accidents on the rural highway (825 accidents (7.2%) as shown in Table 1, [12].

Table 1. Main indicators of traffic crash recorded for the years 2018-2022 [12].

Year	No. of Accidents	Deaths	Injuries
2018	9,852	2,767	10,439
2019	10,753	2,636	11,651
2020	8,186	2,152	8,383
2021	10,659	2,828	11,230
2022	11,523	3,021	12,677
Percentage rate for %(2022-2021)	—	6.8%	12.9%

1.1.2 Statistics in Karbala City

The total number of traffic crashes in Karbala reached 540, which were distributed to three regions, as shown in Table 2, [12].

Table 2. The number of traffic accidents recorded in the general traffic level for each governorate for the year 2022 [12].

No. of Accidents	Deaths	Injuries	Al Qada	Governorate
306	103	304	Kerbala Center	Kerbala
236	222	223	Aien - Tamour	
198	260	177	AL-Hindia	
540	165	504	⇐ Total	

2. Traffic conflicts concept

A traffic conflict is a situation in which two or more road users (vehicles, pedestrians, cyclists) narrowly avoid a collision due to the maneuvers of at least one party involved. A traffic conflict occurs when two or more vehicles are in a situation where their paths intersect and there is a potential for a collision. This can happen at intersections, merge points, lane changes, or any other situation where vehicles are moving near each other. The Traffic Conflict Technique (TCT) is a type of non-crash analysis that can be used to analyze and evaluate traffic safety situations. Evaluating traffic conflict as a Surrogate Safety Measure (SSM) is more proactive than crash-based analysis and, in some cases, more time-efficient, informative, and accurate [13].

3. Limitation of study

The study has several limitations. First, much-existing research is conducted in developed countries with relatively uniform traffic conditions, which may not accurately represent developing countries' diverse driving behaviors and traffic characteristics. Additionally, the study could benefit from using micro-simulation techniques and long-duration video sensor methods to enhance the analysis of traffic conflicts. Current conflict analysis methods are limited because they do not account for unavoidable crashes, such as single-car rollovers, tire bursts due to road conditions or vehicle overloading, and head-on collisions. Moreover, there is a need for highly skilled personnel with experience in collecting conflict data, as well as a focus on urban areas and driver behavior within these environments. Finally, surrogate safety assessment software like SSAM can analyze conflicts and assess severity using measures like TTC and PET. However, these findings are based on simulated vehicle trajectories, which may not fully capture real-world conditions. This challenge is further compounded when conflict studies are conducted at sites with unusual geometry or movements unfamiliar to analysts, such as non-intersection locations like weaving sections, diverging areas, and merging areas. These complex and less standardized environments introduce additional variables and uncertainties, making collecting and analyzing conflict data more difficult. Consequently, applying standard conflict analysis methods and simulation tools like SSAM might not adequately reflect the nuances of these unique traffic situations. Therefore, to improve the accuracy and applicability of traffic safety studies, there is a need for methods that can adapt to the diverse and complex conditions found in both developing countries and atypical traffic sites.

4. Micro-simulation technique

Micro-simulation tools are based on individual vehicles' and drivers' behavior and interactions. They can capture detailed and realistic traffic dynamics, such as lane changes, gap acceptance, car-following, and signal control. Micro-simulation tools can also model complex scenarios like incidents, congestion, and mixed traffic. However, micro-simulation tools also have some drawbacks. They require a lot of data and computational resources, making them time-consuming and expensive. They also depend on calibrating and validating various parameters and models, which can introduce uncertainty and variability in the result. All traffic simulation models involving VISSIM complete their work by the surrogate safety assessment model, SSAM.

4.1 Surrogate safety measures (SSMs) in safety assessment

When crash counts are unavailable, SSMs provide an alternative safety measure for evaluating traffic safety. An additional benefit of SSMs is that they save time, as there is no need to wait for a sufficient number of crashes to occur before identifying an issue and implementing a solution. Indirect safety techniques have also been applied to measure and monitor a location or several locations. Also known as surrogate safety techniques, indirect safety measures provide a surrogate method. Conflict research provides another indirect measure of safety. These researchers use firsthand observation of a place to investigate "near-crashes"to indirectly estimate probable crash concerns at a site [14].

4.2 PTV VISSIM

PTV VISSIM is a micro-simulation software that was used to replicate traffic flow, mimic driving behavior, and estimate measures of effectiveness. It is considered the foremost software for multimodal traffic simulation, and digitally replicates the traffic behaviors of all road users. This highly efficient traffic simulation software encompasses a range of functionalities, including simulation and analysis [15]. The VISSIM application can display and visualize complex traffic flows graphically. It can handle evaluations of diverse traffic and transit operations under various conditions and aid in assessing the traffic consequences of physical and operational alternatives in transportation planning. VISSIM can be regarded as a challenging program due to its complexity and minimal description in the manual [16].

4.3 Surrogate safety assessment model (SSAM)

SIEMENS' research team proposed a novel technique called the Surrogate Safety Assessment Model (SSAM), funded by the Federal Highway Administration (FHWA) of the United States. In 2003, Gettman and Head examined the idea of creating surrogate safety measures from widely available microscopic traffic simulation models, which finally led to the design of the SSAM. The SSAM technique uses several techniques to find conflicts in vehicle trajectory data generated by prominent microscopic simulation models such as VISSIM, PARAMICS, AIMSUN, and TEXAS. SSAM generates the number, kind, severity, and location of simulated conflicts for traffic facilities. SSAM uses five surrogate safety measures to determine the intensity of a simulated conflict: time to collision (TTC), post-encroachment time (PET), deceleration rate, maximum speed, and speed difference. The model includes three kinds of simulated conflicts: rear-end conflict, lane-change conflict, and crossing conflict. A conflict is recorded in SSAM when the minimum Time to collision and Post encroachment time values are above the predefined threshold values, and the conflict kind associated with every conflict is evaluated using lane and link information or the angle between the two converging vehicles [17]. For any pair of automobiles that are in conflict, SSAM may categorize them according to the conflict angle that it extracts from path files made with the VISSIM. The quantity and severity of confrontations are decided by SSAM. The three categories for the conflict are lane changes, rear ends, and crossings. [18] (Unclassified). When compared to other conventional safety analysis techniques that have a lengthy wait for data collection, using simulation software and SSAM saves time.

5. Methodology

5.1 Study area

The study focused on intersections within Karbala's urban areas, which serves as the central district of Karbala Governorate. Specifically, it examined three signalized intersections: Sayed Jawda, Police Central Al-Hussein, and Al-Sofaraa, as illustrated in Fig. 1. These intersections were selected due to increased traffic congestion resulting from the proliferation of schools, government buildings, and shopping centers in these areas. Significant characteristics of the chosen intersections are:

- The location of all selected four-legged intersections must be within an urban area of the city.
- The approaches to each intersection are at street level.
- Every intersection must maintain a fixed traffic signal for all phases throughout the day.

Figure 1. The Locations of Intersections Dropped onto Google Map Image.

5.2 Data collection

The necessary data which needed during this study includes the following:

5.2.1 Traffic Data

This data is useful for conducting simulations in the VISSIM software and for conducting a safety assessment through the SSAM software. The traffic flow data for intersections was collected using a video camera from the Karbala police. Table 3 shows the peak hour volume of intersections in the morning.

5.2.2 Traffic conflict data

Observing traffic conflicts in the field is a demanding activity that requires complete concentration during study time. Because of its versatility and dependability, video recording is always recommended to supplement field observations. In this study, traffic conflict data were collected in the field using cameras that captured traffic volumes. The cameras were mounted on roadside buildings to provide an adequate view of intersections. Table 4 shows the conflict data for selected intersections.

Table 3. Traffic peak hour volume of intersections at the study site.

Intersections name	Total traffic volume (veh/hr)	U-turn	Right	Left	Through	App.	Time
Sayed Jawda	1604	82	283	337	902	EB	7:30-8:30 am
	1458	65	193	228	972	WB	
	1283	39	241	340	663	NB	
	0981	58	315	379	509	SB	
AL-Hussein Policy Center	0735	00	206	145	384	EB	8:30 -9:30 am
	0856	43	183	394	236	WB	
	1168	48	418	305	697	NB	
	1341	54	193	306	788	SB	
AL-Soufaraa	1294	41	264	247	742	EB	7:45-8:45 am
	1126	27	194	221	684	WB	
	0523	15	107	91	310	NB	
	0646	18	113	231	284	SB	

Table 4. The conflict data for selected intersections.

Intersection	Time	Approach	Rear end conflict	Lane change conflict	Crossing conflict	Total conflict T_c/hr
Sayed Jawda	7:30-8:30 am	NB	31	17	4	225
		EB	40	22	9	
		SB	17	11	3	
		WB	39	25	7	
AL-Hussein Policy Center	8:30-9:30 am	NB	30	16	5	178
		EB	24	10	2	
		SB	34	17	4	
		WB	25	8	3	
AL-Soufaraa	7:45-9:45 am	NB	18	7	2	154
		EB	26	10	5	
		SB	22	11	2	
		WB	28	17	6	

Table 5. The geometric data for the study area.

Intersection Name	Approach Direction	No. of Lane	Lanes Width (m)	Splitter Island Width (m)	Entry Width (m)	Exclusive RT
Sayed Jawda	NB	3	3.5	0.75	11.0	Yes
	SB	3	3.5	0.75	11.0	Yes
	EB	3	3.6	3.70	11.5	Yes
	WB	3	3.6	5.80	11.5	No
AL-Hussein Policy Center	NB	3	3.5	1.50	13.0	Yes
	SB	3	3.5	0.75	10.0	No
	EB	3	3.3	0.75	10.0	Yes
	WB	3	3.3	0.75	07.5	Yes
AL-Soufaraa	NB	3	2.9	4.50	09.8	Yes
	SB	3	2.8	1.90	09.6	No
	EB	3	3.5	6.00	11.7	Yes
	WB	3	3.5	5.00	11.7	Yes

5.2.3 Geometric data

In spite of very little research in developing countries about the relationship between geometric characteristics of intersections and crash rates, the geometric characteristics remain an important cause of many traffic crashes. The most geometric characteristics data were measured at the intersections, including the number of lanes, lane widths, and turning radius, in addition to many important characteristics, including median width and the existence of the island to move to the right or not, as shown in Table 5. This data should be collected accurately in order to make the VISSIM simulation software similar to the field conditions.

5.2.4 Calibration data

A new group of data must be collected; this data was collected from the field over two days. Many parameters in the VISSIM software can be calibrated. These parameters include clearance distance and driving. A new group of data must be collected; this data was collected from the field over two days. Many parameters in the VISSIM software can be calibrated. These parameters include clearance distance, driving behavior on adjacent lanes distance, lane change distance, minimum headway, and standstill distance, as shown in Table 6.

6. PTV .VISSIM and SSAM

The methodology for assessing intersections using the SSAM and VISSIM software includes several steps. After collecting the data, it is entered into the VISSIM software to create a trajectory file using the SSAM software.

6.1 The use of VISSIM

Including the following steps, Fig. 2.

Step 1: An earth map appears after opening the VISSIM software interface. Write the name of the study site in the research box. Draw the intersection by adding links and connectors. The links show the main route, while connectors show the roads through the links. Enter the number of lanes into the list that appears; all lanes are displayed.

Step 2: After collecting the traffic volumes from the study site, these volumes are entered in the VISSIM software in the network objects vehicle input, and the vehicle according to their types (car, bus, tram, HGV, etc.) and the real percentages of each type so the total is equal to 100%. Then, distribute the vehicles according to their movement direction in the intersections (right, left, through, and U-turn) in the network objects vehicle routes, and model the traffic light signal in the VISSIM software and simulate the light signal at the study site. This signal must have the exact characteristics of the signal at the study site.

Step 3: Save the modeling of the intersection as a trajectory file. This file considers the outputs of the VISSIM and the inputs of the SSAM program.

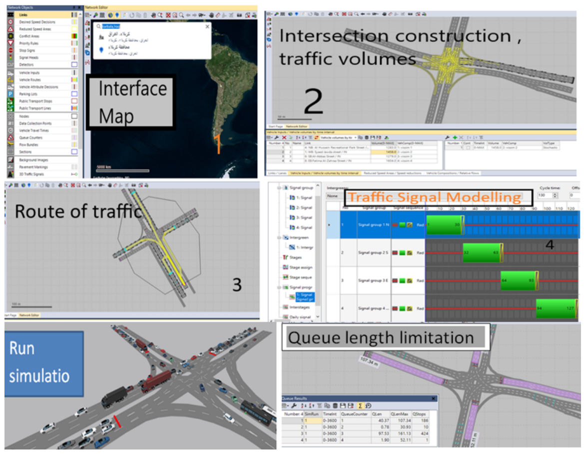

Figure 2. The Stages of Simulation Modeling Process at Sayed Jawda Intersection.

6.2 Traffic analysis operation by VISSIM

After completing the peak hour simulation and using the configuration command, we obtained the results of the traffic operation indicators (stopped delay and LOS) of intersections from the option result lists, which led to the Node result.

Table 6. Some driving behavior parameters for the calibration data used in VISSIM software.

Intersection	Approach	Driving behavior parameters			
		A	L	V	D
Sayed Jawda	NB	1.8	90	07	1.10
	SB	1.6	80	08	1.10
	EB	1.5	100	12	1.10
	SB	1.5	100	11	1.10
AL-Hussein Policy Center	NB	1.7	85	14	1.00
	SB	1.6	75	11	1.10
	EB	1.7	65	08	1.00
	SB	1.6	70	10	1.20
AL-Soufaraa	NB	1.5	100	00	1.30
	SB	1.4	110	13	1.11
	EB	1.6	80	06	1.00
	SB	1.6	75	09	1.10

Where:
A: Average standstill distance(m), rang value (1-3) m.
L: Lock ahead distance (m), rang value (0-250)m.
V: Vehicle occupation of the wrong lane volume %.
D: Driving behavior on adjacent lanes distance (m).

6.3 The steps for evaluating the intersection by SSAM software

Including the following steps, Fig. 3.
Step 1: After extracting the modeling using VISSIM software as a try, the File is exported into the SAAM software and appears as the threshold for significant safety indexes (time to collision and post-encroachment time). SSAM uses default values (TTC=1.5, PET= 5 seconds) based on previous research (Gettman and Head 2003) and can be changed by the user to find optimal values for the studied site [15].
Step 2: After determining the threshold of Time to collision and post-encroachment time indexes at 1.5 and 4.7, respectively, analyze the trajectory file by bringing the file to the SSAM software as a trajectory file. When clicking on the “Analyze”, the process of analyzing the file begins and finding the number of traffic conflicts for each approach and intersections and Optimal values for major safety indexes (TTC and PET) for determine the severity of the site.
Step 3: Convert the total conflicts to total crashes based on a yearly average of 24-hour ADT volumes due to the Eq. 1, [19]:

$$\frac{Crashes}{Year} = 0.119 \times \left[\frac{Conflicts}{Hour}\right]^{1.419} \quad (1)$$

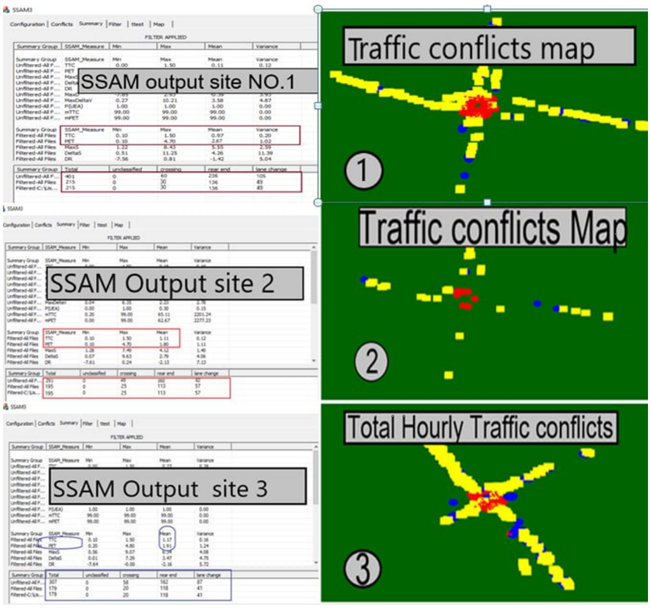

Figure 3. Summary of the SSAM software for study areas.

7. Results and discussions

The VISSIM software showed results on the stopped delay and Level of Service (L.O.S.) for the study areas. Additionally, the SSAM software presented results related to Time to Collision (TTC) and post-encroachment time. Furthermore, the SSAM software results obtained information on total hourly traffic conflicts, as indicated in Table 7 and Table 8. Based on results shown in Table 9, Intersections No.1 and No.2 have similar LOS (F), but Intersection No.1 experiences a higher stopped delay (110 seconds) than Intersection No.2 (85 seconds). Intersection No.3 has a slightly better LOS (E) and the lowest stopped delay (79 seconds). Several factors contribute to stopping delays at intersections, including traffic volume, signal timing, queue length, turning movements, etc. The results show that simulation-based hourly traffic conflicts increase as stopped delay time increases, with a correlation coefficient ranging from $R^2 = (0.7533 - 0.9127)$.

Table 7. Conflicts assessment at each approach of intersection sites.(Output SSAM Program).

Intersection	Approach	No. of Conflict/ hr.			T	Ri	Ti.
		R	L	C			
Sayed Jawda	EB	53	26	18	97	High-Risk	0.87
	WB	39	12	02	53	High-Risk	0.91
	NB	26	18	03	37	High-Risk	0.73
	SB	18	03	07	28	Mid-Risk	1.05
AL-Hussein Policy Center	EB	10	12	03	25	Low-Risk	1.70
	WB	20	08	00	28	Mid-Risk	1.15
	NB	48	21	15	84	High-Risk	0.89
	SB	35	16	07	58	Mid-Risk	1.23
AL-Soufaraa	EB	40	10	07	57	Mid-Risk	1.17
	WB	32	11	05	48	High-Risk	1.27
	NB	25	12	06	43	Mid-Risk	0.83
	SB	19	07	05	31	Mid-Risk	1.03

Where:
L: Lane change. **C:** Crossing.
R: Rear end. **T:** Total hourly traffic conflicts.
Ri: Risk of collision at approach. **Ti:** Time to collision at approach.

Table 8. List the results of the SSAM program.

Intersection	TTC	PET	T	V	T1	T2	Per.
Sayed Jawda	0.97	2.67	Rear End	136	215	243	63.25
			Lane change	49			22.79
			Crossing	30			13.96
AL-Hussein Policy Center	1.08	1.8	Rear End	113	195	210	57.95
			Lane change	57			29.23
			Crossing	25			12.82
AL-Soufaraa	1.17	1.23	Rear End	118	179	187	65.92
			Lane change	41			22.91
			Crossing	20			11.17

Where:
PET: Post encroachment time. **T:** Type of Conflicts.
V: Value of Conflicts. **T1:** Total Conflicts.
T2: Total Crash. **Per.:** Percentage of Conflicts %.
TTC: Time to collision .

According to the findings presented in Table 8, rear-end conflicts emerge as a prevalent issue across all three intersections. Specifically, rear-end conflicts constitute the highest percentage of total conflicts, reaching 66%, 58%, and 63% for the respective intersections. This is because most rear intersections occur during the same approach within the traffic queue. These results were extracted from simulation modeling within the study area, as depicted in Figs. 4, 5 and Fig. 6. Additionally, lane change conflicts exhibit notable variation between the intersections. Crossing intersections represent the most negligible value among the rest of the types because they are signalized intersections. As for the values of TTC and the stopped delay, the value of TTC at intersection number one reached (0.97), the lowest value. This indicates that this location is the most dangerous. The highest stopped delay also suggests that it experiences the highest traffic density.”

Table 9. Shows the results of the VISSIM program.

Intersection Name	Approach Direction	Delay Stopped (Sec.)	Delay%(Sec.)	Q Len Max(M)	Level of Service	Delay of Intersection(Sec.)	Level of service of Intersection
Sayed Jawda	NB	117	46.5	135.44	E	110	F
	SB	96	61.7	87.34	E		
	EB	129	84.30	153.84	F		
	WB	137	74.5	146.31	F		
AL-Hussein Policy Center	NB	94.7	91.70	139.37	F	85.0	F
	SB	83.5	95.30	132.78	F		
	EB	73.7	62.70	62.47	E		
	WB	45.30	57.40	69.89	D		
AL-Soufaraa	NB	35.67	21.40	53.63	C	79.3	E
	SB	46.37	38.90	78.74	D		
	EB	95.82	86.30	126.7	F		
	WB	62.34	64.70	97.16	E		

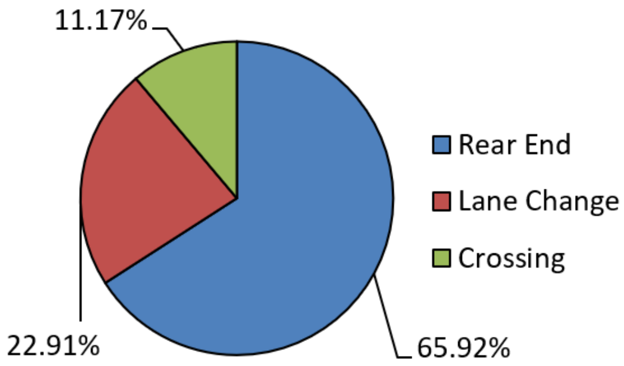

Figure 4. Percentage of conflict for Sayed Jawda intersection.

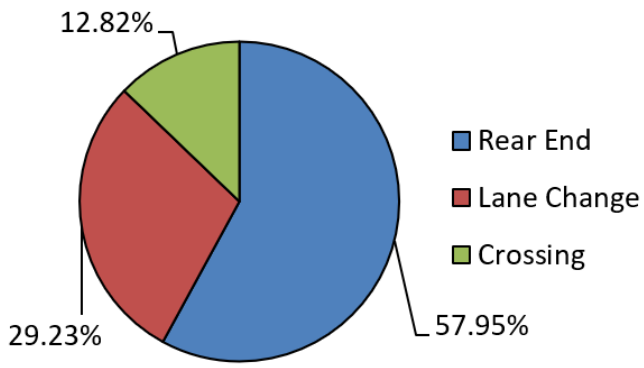

Figure 5. Percentage of conflict for Al Hussien Policy Center.

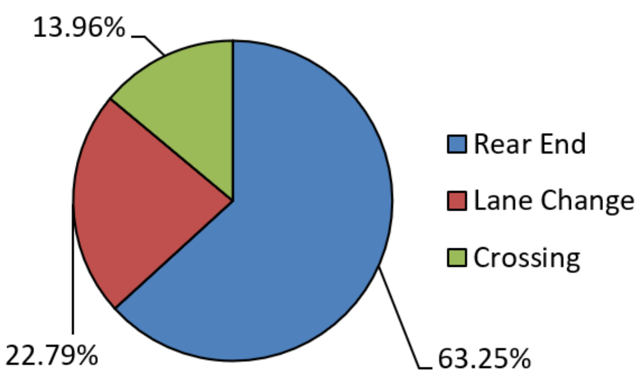

Figure 6. Percentage of conflict for Al Suofraa intersection.

Figures 7, 8, and 9 also illustrate the linear correlation between the stop delay time at each intersection, as derived from VISSIM traffic simulation outputs, and the total traffic conflicts for each peak hour, as determined by the SSAM program, with correlation coefficients for the three intersections being (91.3, 87.5, and 75.3%), respectively.

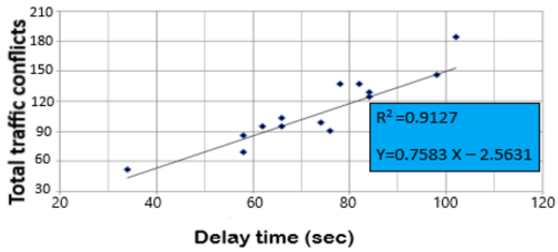

Figure 7. Relationship between Simulated Total Traffic Conflict and Stopped Delay Time of Sayed Jawda intersection.

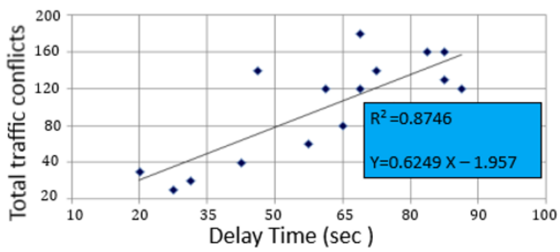

Figure 8. Relationship between Simulated Total Traffic Conflict and Stopped Delay Time of Al Hussien Policy Center intersection.

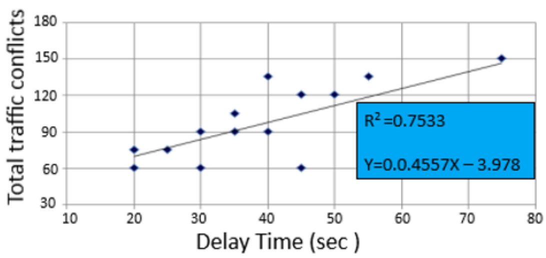

Figure 9. Relationship between Simulated Total Traffic Conflict and Stopped Delay Time of AL-Soufaraa intersection.

The data presented in Table 7 indicates varying levels of conflict and risk at each intersection and approach, which are influenced by the Time-to-Collision (TTC) values. TTC values range from zero to more than 1.5 seconds. A TTC of zero indicates that a collision has occurred. TTC values less than or equal to one second suggest high-intensity collisions, while values greater than one second represent moderate severity. When the TTC exceeds 1.5 seconds, the risk of a severe collision is low. These TTC-based conflict severity ratings align with those established by the Surrogate Safety Assessment Model (SSAM) and the classifications developed [19].

7.1 High-Risk Areas

Sayad Jawda EB, WB, and NB approaches, along with the Police Center NB approach, are considered high-risk due to their high conflict counts and low TTC values. This risk is attributed to heavy traffic and significant delays at these intersections, indicating a need for immediate safety improvements.

7.2 Moderate to low-risk areas

The Soufaraa intersection shows a moderate risk level across all approaches, except for the WB approach, which might require further investigation due to potential data irregularities. In contrast, the Police Center EB approach is identified as significantly safer. The study suggests that targeted interventions, such as adjusting traffic signals, modifying road designs, and enhancing signage, could help reduce risks in high-conflict areas. Moreover, monitoring driver behavior and traffic patterns can provide valuable insights for implementing additional safety measures.

8. Conclusions

- This research categorized traffic conflicts into three main types: diverging, merging, and crossing. Diverging disputes often stem from driver confusion and tend to be less severe, but can still pose a significant danger. For instance, a driver might mistakenly exit at the wrong point in a roundabout, causing a re-entry into circulating lanes. Merging conflicts are more common and frequently result in side-swipe collisions, typically due to driver misunderstandings, poor road design, or inadequate signage and lane markings.
- Simulation results reveal that the frequency of hourly traffic conflicts at the three studied intersections increases with higher stopped delay times. Intersection no. 1, which has the highest stopped delay time (Level of Service F), also experiences the highest frequency of hourly traffic conflicts. In contrast, intersection no. 3, with the lowest stopped delay time (Level of Service E), exhibits the fewest conflicts. This correlation between stopped delay time and conflict frequency highlights traffic management and infrastructure design's critical role in ensuring intersection safety.
- The study further identified varying levels of risk among the intersections. The Al-Sayed Jawda intersection was classified as high-risk, with a time-to-collision value of 0.97 seconds, indicating a high likelihood of severe conflicts. Meanwhile, the Al-Hussein Police Center and Al-Sofaraa intersections were categorized as moderate risk, with time-to-collision values of 1.08 and 1.17 seconds, respectively.
- The findings underscore the significant impact of traffic volume on safety, as increased traffic can raise the frequency of conflicts while potentially reducing their severity. This study emphasizes the importance of tailoring traffic programs to specific regional conditions. Implementation of traffic management strategies designed for already developed nations in Iraq or other developing countries may be ineffective or counterproductive without adjustments to account for local driver behavior and infrastructure conditions. Developing appropriate countermeasures based on these findings is essential for enhancing intersection safety and reducing traffic conflicts in the study area.
- Based on the results listed above, further recommendations to improve safety and efficiency include the following:
  - Re-timing signals, adding left turn phase or adding a left turn lane, and isolating left-turn vehicles to reduce collisions with vehicles heading forward
  - Geometric improvements such as widening lanes, adjusting lane configurations to accommodate turning movements, and reducing congestion, or evaluating sight distances for better visibility, especially at critical points (e.g., stop line).
  - Implementing innovative infrastructure upgrades like retrofitting existing intersections with smart technologies requires significant investment in sensors, communication networks, and control systems, and coordinating upgrades across multiple intersections can be logistically complex.
  - Real-time data collection (e.g., traffic flow and vehicle speeds) is crucial for adaptive signal control. However, privacy concerns may arise.
  - As for driver behavior, drivers must adapt to new signal patterns (e.g., flashing yellow arrows). Education and awareness campaigns are essential.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

[1] M. B. Mahdi, A. K. Alrawi, and L. V. Leong, "Compatibility between delay functions and highway capacity manual on iraqi highways," *Open Engineering*, vol. 12, no. 1, pp. 359–372, 2022. [Online]. Available: https://doi.org/10.1515/eng-2022-0028

[2] H. Joni and M. Hikmatt, "Assessment at al-ameer signalized intersection in samawa city," in *MATEC Web of Conferences*. EDP Sciences, 2018, p. 01039. [Online]. Available: https://www.matec-conferences.org/articles/matecconf/abs/2018/21/matecconf_bcee32018_01039/matecconf_bcee32018_01039.html

[3] Transportation Research Board, *Highway Capacity Manual (HCM 2010)*. Washington, DC: National Research Council, 2010. [Online]. Available: https://www.sciencedirect.com/topics/engineering/highway-capacity-manual

[4] T. G. Abate, "Evaluating the performance of signalized intersection and the associated economic impact of congestion: A case study on ras mekonnen street of addis ababa, ethiopia," Master's thesis, Addis Ababa University, 2014.

[5] F. L. Mannering and C. R. Bhat, "Analytic methods in accident research: Methodological frontier and future directions," *Analytic Methods in Accident Research*, vol. 1, pp. 1–22, 2014. [Online]. Available: https://doi.org/10.1016/j.amar.2013.09.001

[6] World Health Organization, *Global Status Report on Road Safety 2015*. World Health Organization, 2015.

[7] D. Lord and F. Mannering, "The statistical analysis of crash-frequency data: A review and assessment of methodological alternatives," *Transportation Research Part A: Policy and Practice*, vol. 44, no. 5, pp. 291–305, 2010. [Online]. Available: https://doi.org/10.1016/j.tra.2010.02.001

[8] C. Caliendo and M. Guida, "Microsimulation approach for predicting crashes at unsignalized intersections using traffic conflicts," *Journal of Transportation Engineering*, vol. 138, no. 12, pp. 1453–1467, 2012. [Online]. Available: https://doi.org/10.1061/(ASCE)TE.1943-5436.0000439

[9] S. Abd-alzahraa and H. Ewadh, "Simulated surrogate measures to assess the effectiveness of countermeasures at signalized intersections," *Heritage and Sustainable Development*, vol. 6, no. 1, pp. 21–32, 2024. [Online]. Available: https://doi.org/10.37532/hsd.2024.6(1).21-32

[10] V. Astarita, C. Caliendo, V. P. Giofrè, and I. Russo, "Surrogate safety measures from traffic simulation: Validation of safety indicators with intersection traffic crash data," *Sustainability*, vol. 12, no. 17, p. 6974, 2020. [Online]. Available: https://doi.org/10.3390/su12176974

[11] H. A. Ewadh, "A sustainable strategy to upgrade safety at traffic system," *Journal of Kerbala University*, vol. 13, no. 1, pp. 124–130, 2017.

[12] Central Statistical Organization Iraq, Ministry of Planning, Republic of Iraq, "Statistical report," Ministry of Planning, Republic of Iraq, Tech. Rep., 2022.

[13] C. Hydén, "The development of a method for traffic safety evaluation: The swedish traffic conflicts technique," Lund Institute of Technology, Department, Tech. Rep. 70, 1987. [Online]. Available: https://trid.trb.org/View/239059

[14] National Research Council (US), Transportation Research Board, Task Force on Development of the Highway Safety Manual, Transportation Officials, and Joint Task Force on the Highway Safety Manual, *Highway Safety Manual*. AASHTO, 2010.

[15] D. Gettman and L. Head, "Surrogate safety measures from traffic simulation models," *Transportation Research Record*, vol. 1840, no. 1, pp. 104–115, 2003. [Online]. Available: https://doi.org/10.3141/1840-12

[16] S. Y. Koh, Doina, and H. C. Chin, "Traffic simulation modeling vissim," National University of Singapore, Faculty of Engineering, Civil Engineering Department, Tech. Rep., 2009.

[17] D. Gettman, L. Pu, T. Sayed, and S. G. Shelby, "Surrogate safety assessment model and validation," Turner-Fairbank Highway Research Center, Tech. Rep., 2008. [Online]. Available: https://rosap.ntl.bts.gov/view/dot/35896

[18] D. Muley, M. Ghanim, and M. Kharbeche, "Prediction of traffic conflicts at signalized intersections using ssam," *Procedia Computer Science*, vol. 130, pp. 255–262, 2018. [Online]. Available: https://doi.org/10.1016/j.procs.2018.04.037

[19] T. Sayed and S. Zein, "Traffic conflict standards for intersections," *Transport Planning and Technology*, vol. 22, no. 4, pp. 309–323, 1999. [Online]. Available: https://doi.org/10.1080/03081069908717634

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